NATIONAL TECHNICAL UNIVERSITY OF ATHENS

SCHOOL OF RURAL, SURVEYING AND GEOINFORMATICS ENGINEERING

Integration of Performance Assessment Indicators for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs) into the Planning Practice: An Ontology-Oriented Approach

Doctoral Dissertation

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Rural, Surveying and Geoinformatics Engineer, MSc in Geoinformatics

Supervisor: Anastasia Stratigea, Professor NTUA

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ATHENS

JUNE 2023

Η έγκριση της Διδακτορικής Διατριβής από την Ανώτατη Σχολή Αγρονόμων και Τοπογράφων Μηχανικών – Μηχανικών Γεωπληροφορικής του Εθνικού Μετσόβιου Πολυτεχνείου δεν υποδηλώνει αποδοχή των γνωμών του συγγραφέα (Ν. 5343/1932, Άρθρο 202).

To little Marian and Alexandros

PREAMBLE

The present Doctoral Dissertation was conducted at the School of Rural, Surveying and Geoinformatics Engineering of National Technical University of Athens (NTUA), and more particularly at the department of Geography and Regional Planning, under the supervision of Professor Anastasia Stratigea. It has also been funded by the Special Account for Research Funding of NTUA for three consecutive years (2014-2016).

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I am deeply indebted to the rest of the members of my Examination Committee – Professor Marinos Kavouras, Professor Panos Fitsilis and Associate Professor Georgios Tsilimigkas – for their support and assistance.

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In conclusion, this Dissertation represents the culmination of years of hard work, dedication, and collaboration. All the people mentioned above have played a significant role in shaping my academic growth and helping me reach this important milestone. Their contributions, whether big or small, have left an indelible mark on my intellectual journey. I am truly honoured and humbled to have had the opportunity to work with such talented and supportive individuals.

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ABSTRACT

The last few decades have witnessed a rampant urbanization growth that has exerted massive pressures to cities, ranging from environmental degradation and resource scarcity to health, safety, and social inclusion alarming concerns. In this particular setting, the concept of smart city appears and is touted as a new urban development paradigm that leverages Information and Communication Technologies (ICTs) in an innovative and efficient manner to address urban challenges and support competitiveness and prosperity. Additionally, it aims at fostering informed and engaged citizens, who actively participate in decision-making processes.

Nonetheless, the above definition can be considered more or less arbitrary, given the fact that extended literature review brings to light a considerable conceptual gap regarding the semantics of the smart city term; an intricate state that has caused intense confusion among interested parties, and has also resulted in numerous inefficient smart strategies and initiatives.

Furthermore, aside from smartness, the incorporation of additional goals in the urban planning practice – with sustainability, resilience, and inclusiveness being the key protagonists – necessitates their immediate integration, but also their performance assessment in various domains.

Under those circumstances, it becomes crystal-clear that the effective treatment of modern complex issues requires that urban planners and policy makers have at their disposal broad in scope frameworks, which can capture cities' multifaceted nature. In this regard, the present Doctoral Dissertation places emphasis on the development of a new, holistic, multidimensional, and comprehensive smart city ontological representation scheme that is anticipated to operate as a Decision Support Tool for efficaciously dealing with contemporary urban issues and formulating appropriate policies for smart, sustainable, resilient, and inclusive urban development.

The outcomes of this research are expected to contribute to the field of spatial and developmental planning by providing a robust and standardized framework for assessing and steadily monitoring cities' performance in their effort to attain smart, sustainable, resilient, and inclusive goals. Moreover, the indicator-oriented ontology is envisaged to enhance understanding of the interconnections and trade-offs among different city

dimensions, thereby guiding decision makers in crafting evidence-based policies and strategies.

EXTENDED ABSTRACT (IN GREEK)

Τις τελευταίες δεκαετίες το φαινόμενο της αστικοποίησης εντείνεται με δραματικούς ρυθμούς παγκοσμίως, ενώ σύμφωνα με εκτιμήσεις των Ηνωμένων Εθνών αναμένεται περαιτέρω κλιμάκωσή του έως το 2050, με τον αστικό πληθυσμό να αγγίζει το 70%. Οι επιπτώσεις της ανεξέλεγκτης αστικοποίησης (υπέρμετρη κατανάλωση ενέργειας, έντονα προβλήματα στο πεδίο των μεταφορών και της κινητικότητας, αυξανόμενος όγκος αποβλήτων, φτώχεια, εγκληματικότητα, ρύπανση, αστικές παραγκουπόλεις, κ.ά.) βρίσκονται στο επίκεντρο του ενδιαφέροντος των χωρικών σχεδιαστών και των κέντρων λήψης αποφάσεων, με σκοπό την εξεύρεση και υλοποίηση ευρέως αποδεκτών, αποτελεσματικών, καινοτόμων, βιώσιμων και ανθεκτικών λύσεων για τον μετριασμό ή την αποσόβησή τους.

Επιπρόσθετα, το συνεχώς μεταλλασσόμενο παγκόσμιο περιβάλλον, ως προϊόν της έντονης δράσης κυρίαρχων μηχανισμών αλλαγής (π.χ., υπερπληθυσμός, οικονομική κρίση, κλιματική αλλαγή, μετανάστευση), καθιστά τη βιώσιμη αστική ανάπτυξη πρωταρχικό στόχο στην ατζέντα πολιτικής.

Παράλληλα, οι επαναστατικές εξελίξεις που συντελούνται στον τομέα των Τεχνολογιών Πληροφορίας και Επικοινωνίας (ΤΠΕ) είναι πλέον σε θέση να υποστηρίξουν μια πλειάδα αστικών λειτουργιών και υπηρεσιών, που απευθύνονται σε πολίτες, επιχειρήσεις και δημόσιους ή ιδιωτικούς οργανισμούς. Οι τεχνολογίες αυτές έχουν μεταβάλλει δραστικά μία πληθώρα επιστημονικών πεδίων, ανάμεσα στα οποία συγκαταλέγεται και ο χωρικός και αναπτυξιακός σχεδιασμός, προσφέροντας νέες προσεγγίσεις, τεχνολογίες και εργαλεία στη διαδικασία επιδίωξης στόχων βιωσιμότητας· και διευρύνοντας τις προοπτικές συμμετοχής πολιτών και φορέων σε μία τέτοια προσπάθεια. Η τελευταία παράμετρος – η συμμετοχή των πολιτών και εν γένει των ομάδων ενδιαφερόντων (stakeholders) – θεωρείται από πολλούς ερευνητές ιδιαίτερα κρίσιμη για την αποτελεσματική αντιμετώπιση των σύγχρονων αστικών προβλημάτων.

Η ευρεία αξιοποίηση των ΤΠΕ για τη διαχείριση της αστικής πραγματικότητας φέρνει στο προσκήνιο την ιδέα των έξυπνων πόλεων ως καινοτόμων αστικών οικοσυστημάτων, τα οποία μέσα από την υιοθέτηση / χρήση της τεχνολογίας επιδιώκουν στόχους βιωσιμότητας, ανθεκτικότητας και συμμετοχής των ομάδων ενδιαφερόντων στις διαδικασίες λήψης αποφάσεων. Διάφοροι ορισμοί της έξυπνης πόλης έχουν κατά καιρούς διατυπωθεί, οδηγώντας – μεταξύ άλλων – σε μία έντονη πολυφωνία και μία συνεπακόλουθη έλλειψη σημασιολογικής διαλειτουργικότητας του όρου. Από την επισκόπηση της διεθνούς βιβλιογραφίας διαφαίνεται ότι η έννοια της έξυπνης πόλης οριοθετείται αρχικά από αντιλήψεις προσανατολισμένες αποκλειστικά στην τεχνολογική διάσταση, με τις ΤΠΕ να θεωρούνται κυρίαρχοι και καθοριστικοί αναπτυξιακοί πυλώνες. Προϊόντος του χρόνου όμως, η επισκόπηση της διεθνούς βιβλιογραφίας αναδεικνύει ευρύτερες και πιο ολοκληρωμένες θεωρήσεις, που ενσωματώνουν στη σημασία του όρου – εκτός από την τεχνολογική διάσταση – πτυχές της κοινωνίας, της οικονομίας, της προστασίας του περιβάλλοντος, της διακυβέρνησης και της ενεργού συμμετοχής. Παρόλα αυτά, μέσα από τη μελέτη παραδειγμάτων έξυπνων πόλεων επισημαίνεται η επικράτηση της θεώρησης που συνδέεται στενά με την τεχνολογία, αλλά και η χαμηλή αποτελεσματικότητα τέτοιων προσεγγίσεων στους περισσότερους αστικούς τομείς.

Παρά τις όποιες διαφορές, κοινή συνισταμένη των διαφορετικών θεωρήσεων αποτελεί η αντίληψη ότι η έξυπνη πόλη αξιοποιεί με έναν καινοτόμο τρόπο τις ΤΠΕ για τη διαχείριση των προβλημάτων και των υποδομών της· τη στήριξη της ανταγωνιστικότητας και την τοπική ευημερία· καθώς και τη διαμόρφωση δημιουργικών, ενεργών, αφυπνισμένων και με βαθειά γνώση πολιτών ως φορέων αλλαγής του αστικού περιβάλλοντος.

Επιπλέον, τα ζητήματα / στόχοι που αναδύονται στο πεδίο του αστικού σχεδιασμού – βιωσιμότητα, ανθεκτικότητα και συμπερίληψη – απαιτούν την άμεση ολοκλήρωσή τους με την έννοια της έξυπνης πόλης, καθώς και την αξιολόγηση των επιδόσεων της πόλης μέσα από τη χρήση της τεχνολογίας σε διάφορους τομείς (ενέργεια, κινητικότητα, καινοτομία, οικονομία, κοινωνική συνοχή, περιβαλλοντική προστασία, κ.λπ.), με βάση τους προαναφερθέντες στόχους. Με αυτόν τον τρόπο, διαμορφώνεται μία νέα, ολοκληρωμένη και συμμετοχική προσέγγιση στον χωρικό και αναπτυξιακό σχεδιασμό, η οποία αντιμετωπίζει μέσα από μια ολιστική και ολοκληρωμένη θεώρηση τα θεμελιώδη, σύγχρονα, αστικά θέματα.

Μέσα σε αυτό το πλαίσιο, η παρούσα Διδακτορική Διατριβή επικεντρώνεται στην ανάπτυξη ενός νέου, ολοκληρωμένου, πολυδιάστατου και περιεκτικού εννοιολογικού πλαισίου (οντολογίας) για την έξυπνη πόλη, το οποίο αναμένεται να λειτουργήσει ως εργαλείο Στήριξης Αποφάσεων για την αποτελεσματική διαχείριση των σύγχρονων αστικών προβλημάτων και τον καθορισμό κατάλληλων πολιτικών για την επίτευξη της βιώσιμης, ανθεκτικής και συμπεριληπτικής αστικής ανάπτυξης. Πιο συγκεκριμένα,ο εν λόγω γενικός στόχος αναλύεται περαιτέρω στους ακόλουθους υποστόχους:

- Ανάπτυξη μιας νέας οντολογίας που αποτυπώνει τις ουσιώδεις έννοιες, σχέσεις και ιδιότητες που χαρακτηρίζουν το επιστημονικό πεδίο της έξυπνης πόλης. Η συγκεκριμένη οντολογία αναμένεται να λειτουργήσει ως βάση για την οργάνωση και δόμηση των δεδομένων και της γνώσης πάνω στον τομέα ενδιαφέροντος.
- Εντοπισμός, εξέταση και ανάπτυξη ενός συστήματος δεικτών, οι οποίοι μετρούν και αξιολογούν αποτελεσματικά τις πτυχές της βιωσιμότητας, της ευφυίας, της συμπερίληψης και της ανθεκτικότητας στο πλαίσιο της έξυπνης πόλης, μέσω εκτεταμένης μελέτης και κριτικής επισκόπησης των σχετικών διεθνών συστημάτων δεικτών.
- Συγκέντρωση / επεξεργασία των δεικτών που απορρέουν από τα προαναφερθέντα διεθνή συστήματα και ολοκλήρωσή τους σε ένα ενοποιημένο, πολυδιάστατο, πλουσιότερο και συνεκτικό πλαίσιο.
- Ενσωμάτωση του πολυδιάστατου αυτού πλαισίου δεικτών σε ένα νέο οντολογικό σχήμα, θεμελιώνοντας σχέσεις και εξαρτήσεις μεταξύ των δεικτών και των διαφόρων συνιστωσών της οντολογίας, έτσι ώστε αυτή να είναι σε θέση να αποτυπώσει και να αναπαραστήσει αποτελεσματικά την περίπλοκη και πολυσχιδή φύση της έξυπνης πόλης.
- Παροχή συστάσεων και κατευθυντήριων γραμμών για την πρακτική εφαρμογή της οντολογίας στον αστικό σχεδιασμό. Οι εν λόγω συστάσεις προβλέπουν την υιοθέτηση της προτεινόμενης οντολογίας από υπάρχοντα πλαίσια αστικού σχεδιασμού, καθώς επίσης και τις όποιες απαραίτητες προσαρμογές και βελτιώσεις του οντολογικού μοντέλου.

Τα καινοτόμα χαρακτηριστικά της Διδακτορικής Διατριβής συνοψίζονται στα εξής κομβικά σημεία, που ταυτόχρονα αποτελούν και επιθυμητά αποτελέσματά της:

- Δημιουργία ενός ολοκληρωμένου, πολυδιάστατου, συνεκτικού και συνεπούς εννοιολογικού πλαισίου, το οποίο θα προετοιμάσει το έδαφος για: την καλύτερη αντίληψη των έξυπνων πόλεων και των αλληλεπιδράσεων μεταξύ των διαφόρων πτυχών τους· και την κατανόηση του ρόλου που καλείται να διαδραματίσει ο αστικός σχεδιασμός στο πλαίσιο της έξυπνης πόλης.
- Αξιοποίηση εμπειρικής γνώσης σχετικής με την αποδοτικότητα, την αποτελεσματικότητα, τις προκλήσεις, τις ευκαιρίες, τις αδυναμίες ή/και τις

επιπτώσεις των έξυπνων πρωτοβουλιών που έχουν εφαρμοστεί σε συγκεκριμένα αστικά περιβάλλοντα.

- Ενδυνάμωση της ίδιας της διαδικασίας του αστικού σχεδιασμού, μέσα από την ενσωμάτωση σε αυτή δεικτών που αφορούν στην αξιολόγηση της αστικής ευφυίας, της βιωσιμότητας, της ανθεκτικότητας και της συμπερίληψης σε μία νέα οντολογία για τις έξυπνες πόλεις. Το οντολογικό αυτό σχήμα δύναται να λειτουργήσει ως βάση γνώσης και εργαλείο στήριξης αποφάσεων για τους χωρικούς σχεδιαστές, επιτρέποντάς τους να αξιολογούν και να προτεραιοποιούν διάφορες πτυχές της αστικής ανάπτυξης, να αναγνωρίζουν πιθανές συνέργειες μεταξύ των δεικτών και να διαμορφώνουν πιο αποτελεσματικές, ορθολογικές και βιώσιμες λύσεις.
- Υποστήριξη της αξιολόγησης πολιτικών και της σύγκρισης (benchmarking) των έξυπνων πόλεων μέσω της καθιέρωσης ενός κοινού συνόλου δεικτών, οι οποίοι θα διευκολύνουν συγκριτικές αναλύσεις μεταξύ πόλεων, εντοπίζοντας έτσι επιτυχημένες στρατηγικές και τομείς για περαιτέρω βελτίωση.
- Προώθηση της εννοιολογικής συνέπειας και της τυποποίησης της γνώσης, καθώς η προτεινόμενη οντολογία προσφέρει ένα κοινό λεξιλόγιο και ένα τυποποιημένο πλαίσιο για την περιγραφή και μέτρηση των διαφορετικών διαστάσεων των έξυπνων πόλεων.
- Πρόταση καινοτόμων λύσεων, αρχών σχεδιασμού και τεχνολογικών παρεμβάσεων για την ενίσχυση των διαδικασιών του αστικού σχεδιασμού και την προώθηση της βιώσιμης αστικής ανάπτυξης συνολικά.
- Επισήμανση της επείγουσας ανάγκης που προκύπτει για την προώθηση της συμμετοχής και την ενσωμάτωσή της σε κάθε στάδιο της διαδικασίας του σχεδιασμού (από τον καθορισμό των στόχων έως την αξιολόγηση και την εφαρμογή του επιλεγμένου σχεδίου), προκειμένου να αναπτυχθούν ευρέως αποδεκτές πρωτοβουλίες.

Η σύνθεση όλων των προαναφερθέντων αναμενόμενων αποτελεσμάτων της Διδακτορικής Διατριβής οδηγεί στον πυρήνα της συμβολής της, ο οποίος στρέφεται γύρω από τη διαμόρφωση και υιοθέτηση ενός πιο ευέλικτου / ευπροσάρμοστου και διαχρονικού μοντέλου χωρικού και αναπτυξιακού σχεδιασμού. Το θεωρητικό υπόβαθρο μαζί με την ανάπτυξη ενός ενιαίου πλαισίου δεικτών, ενσωματωμένου σε μια νέα οντολογία έξυπνης πόλης, επιτρέπουν στους σχεδιαστές και στα κέντρα λήψης αποφάσεων να προβλέψουν και να ανταποκριθούν δυναμικά στις αναδυόμενες αστικές προκλήσεις και ευκαιρίες (π.χ., τεχνολογικές εξελίξεις, δημογραφικές μεταβολές, κοινωνικοοικονομικές και περιβαλλοντικές αλλαγές). Επιπλέον, καθώς η αστική πραγματικότητα εξελίσσεται δυναμικά, η προτεινόμενη οντολογία δύναται να επικαιροποιείται, να εμπλουτίζεται και να επεκτείνεται συνεχώς, διασφαλίζοντας με αυτόν τον τρόπο ότι παραμένει σχετική και έτοιμη να προσαρμοστεί ανά πάσα στιγμή σε πιθανές αλλαγές. Αυτή η προληπτική προσέγγιση εγγυάται την προσαρμογή στις εξελίξεις του ευρύτερου περιβάλλοντος, διασφαλίζοντας έτσι ότι οι πόλεις παραμένουν βιώσιμες και ανθεκτικές υπό το φως των συνεχών εξελίξεων.

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Acronyms and Initialisms

5G	Fifth-Generation Cellular Network
ACE	Accelerated Conservation and Efficiency
AdI	Advanced Indicator
AGI	Artificial General Intelligence
AI	Additional Indicator
AI	Artificial Intelligence
ANI	Artificial Narrow Intelligence
API	Application Programming Interface
AP-NORC	Associated Press-NORC
AQI	Air Quality Index
AR	Augmented Reality
ASI	Artificial Super Intelligence
BCG	Bacillus Calmette-Guerin
BEV	Battery Electric Vehicle
BFO	Basic Formal Ontology
BLI	Better Life Index
BMI	Body Mass Index
BPL	Broadband over Powerline
BREEAM	Building Research Establishment Environmental Assessment Method
BRT	Bus Rapid Transit
BSI	British Standards Institution
CAD	Computed-Aided Design
CETRAN	Center of Excellence for Testing and Research of Autonomous Vehicles
CI	Core Indicator
CityGML	City Geography Markup Language
COP	Child Online Protection
CPI	City Prosperity Index
CPS	Cyber-Physical Systems
CRF	City Resilience Framework
CRI	City Resilience Index

CRS4	Center for Advanced Research and Development Studies of Sardinia
CTTC	Catalan Telecommunications Technology Centre
CUTLER	Coastal Urban developmenT through the LEnses of Resiliency
CV	Connected Vehicle
DC Ontology	Dublin Core Ontology
DCCG-CitiesNet	Digital Cities of Central Greece
DIPO	Data Innovation Program Office
DIS	Draft International Standard
DL	Description Logic
DO	Doctor of Osteopathic Medicine
DOLCE	Descriptive Ontology for Linguistic and Cognitive Engineering
DPSIR	Driver – Pressure – State – Impact – Response
DPT	Diphtheria – Pertussis – Tetanus
DRR	Disaster Risk Reduction
DSI	Digital Social Innovation
DSL	Digital Subscriber Line
EEA	European Environmental Agency
EER	Enhanced Entity-Relationship Model
EERA	European Energy Research Alliance
EL-V	Electric Light Vehicle
EMF	Electromagnetic Field
ENISA	European Network and Information Security Agency
ENoLL	European Network of Living Labs
EPA	Environmental Protection Agency
E-R Model	Entity-Relationship Model
ESRI	Environmental Systems Research Institute
EU	European Union
Eurostat	Statistical Office of the European Communities
EV	Electric Vehicles
FBI	Federal Bureau of Investigation
FCEV	Fuel Cell Electric Vehicle
FDI	Foreign Direct Investment
FG-SSC	Focus Group on Smart Sustainable Cities

FI	Future Internet
FOAF Ontology	Friend of a Friend Ontology
GDP	Gross Domestic Product
GeoDF	GIS enabled Discussion Forum
GFO	General Formal Ontology
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GIScience	Geographic Information Science
GPS	Global Positioning System
GRP	Gross Regional Product
GTALCC	Green Technology Application for the Development of Low Carbon Cities
GUI	Graphical User Interface
HDI	Human Development Index
HLY	Healthy Life Years
HQ	Headquarters
IaaS	Infrastructure as Service
IAEA	International Atomic Energy Agency
ICF	Intelligent Community Forum
ICT	Information and Communication Technologies
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ILO	International Labor Organization
IMDA	Infocomm Media Development Authority
IoT	Internet of Things
IP	Internet Protocol
IPCC	Intergovernmental Panel on Climate Change
ISCED	International Standard Classification of Education
ISO	International Organization for Standardization
IT	Information Technology
ITS	Intelligent Transportation Systems
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union’s Telecommunication

	Standardization Sector
JIC	Joint Innovation Center
JPSC	Joint Programme on Smart Cities
JRC	Joint Research Centre of the European Commission
JTC	Jurong Town Corporation
KIC	Knowledge and Innovation Communities
KPI	Key Performance Indicator
LEED	Leadership in Energy and Environmental Design
LF	Labor Force
LoD	Level of Detail
LoRaWAN	Long Range Wide Area Network
LSOA	Lower Super Output Area
LTA	Land Transport Authority
M2M	Machine-to-Machine
MAN	Metropolitan Area Network
MCA	Multi-Criteria Analysis
MD	Doctor of Medicine
ML	Machine Learning
MOPAC	Mayor’s Office for Policing And Crime
MTPAS	Mobile Telecommunication Privileged Access Scheme
MWRA	Massachusetts Water Resources Authority
NCD	Noncommunicable disease
NCGIA	National Center for Geographic Information and Analysis
NEET	Not in Education, Employment, or Training
NGO	Non-Governmental Organization
NIST	National Institute of Standards and Technology
NOW	Neighbourhoods of Winnipeg
NPL	Natural Language Processing
NRF	National Research Foundation
NTU	Nanyang Technological University
NYC	New York City
ODC	Open Data Cities
OECD	Organization for Economic Co-operation and Development

OFGEM	Office of Gas and Electricity Markets
OGC	Open Geospatial Consortium
OWL	Web Ontology Language
PaaS	Platform as a Service
PC	Personal Computer
PEPESEC	Partnership Energy Planning as a tool for realizing European Sustainable Energy Communities
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
PPGIS	Public Participation Geographic Information System
PPP	Purchasing Power Parity
PPPP	Public-Private-People Partnership
PPS	Prospective Payment System
PROTON	PROTo Ontology
PSR	Pressure – State – Response
PwCPL	PricewaterhouseCoopers Private Limited
QC	Quantified Community
R&D	Research and Development
RDF	Resource Description Framework
RDF-S	Resource Description Framework Schema
REEV	Range Extended Electric Vehicle
REX	Range Extender
RFID	Radio Frequency Identification
RIS3	Research and Innovation Strategy for Smart Specialization
RTDI	Research, Technology Development and Innovation
S2RIC	Smart, Sustainable, Resilient, and Inclusive City
S2RICO	Smart, Sustainable, Resilient, and Inclusive City Ontology
SaaS	Software as a Service
SCO	Smart City Ontology
SDG	Sustainable Development Goal
SDI	Spatial Data Infrastructure
SDSS	Spatial Decision Support System
SGFinDex	Singapore Financial Data Exchange

SGTraDex	Singapore Trade Data Exchange
SME	Small and Medium-Sized Enterprise
SOFIA	Smart Objects For Intelligent Applications
SSC	Smart and Sustainable City
STAMP	Sustainability Assessment and Measuring Principles
STEM	Science, Technology, Engineering and Mathematics
SUMO	Suggested Upper Merged Ontology
SUMP	Sustainable Urban Mobility Plan
SWRL	Sematic Web Rule Language
TSP	Transit Signal Priority
U4SSC	United for Smart Sustainable Cities
UAB	Autonomous University of Barcelona
UK	United Kingdom
UML	Unified Modeling Language
UN	United Nations
UNCSD	United Nations Commission on Sustainable Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDRR	United Nations Office for Disaster Risk Reduction
UNECE	United Nations Economic Commission for Europe
UNGA	United Nations General Assembly
UN-Habitat	United Nations Human Settlements Programme
UNISDR	United Nations International Strategy for Disaster Risk Reduction
UNODC	United Nations Office on Drugs and Crime
UNSDN	United Nations Social Development Network
URA	Urban Redevelopment Authority
VGI	Volunteered Geographic Information
VR	Virtual Reality
W3C	World Wide Web Consortium
WCCD	World Council on City Data
WebSDSS	Web-based Spatial Decision Support System
WEF	World Economic Forum
WHO	World Health Organization
WiMAX	Worldwide Interoperability for Microwave Access

WPS	Wi-Fi Positioning System
WWW	World Wide Web
XML	Extensible Markup Language

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Part 1 — **Contextual Background**

Part 2 — Bibliographic Review on Smart Cities

Part 3 — Construction of an Integrated Indicator Framework for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 4 — Bibliographic Review on Semantics & Ontologies

Part 5 — Development of an Ontology for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 6 — Conclusions & Future Research

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CHAPTER 1: CITIES OF TODAY AND EMERGING URBAN CONCERNS – DELINEATING THE CONTEXTUAL BACKGROUND OF THE DOCTORAL DISSERTATION – RESEARCH TOPIC, GOAL AND OBJECTIVES, METHODOLOGICAL APPROACH

Synopsis*: The introductory chapter endeavors to set the context in which the whole research effort is taking place. In this respect, its initial part is dedicated to the delineation of the major driving forces behind the rise and phenomenal expansion of the smart city concept. Indeed, these forces, ranging from rapid urbanization pace to resource scarcity, environmental degradation and insufficient public service provision, have propelled the emergence of smart cities as an innovative transformative response. By harnessing cutting-edge technologies and data-driven approaches, smart cities appear to be a promising solution to address the intricacies of urbanization, underpin economic growth, boost environmental sustainability, and enhance quality of life. The smart city rationale, imbued with dimensions of sustainability, resilience, and inclusiveness, constitutes the main axis of the Dissertation. The chapter proceeds with analysing the research topics of the Doctoral Thesis and shedding light on its goal and objectives. Moreover, its added value and the scientific gaps that are anticipated to be bridged are also discussed. Finally, the methodological approach crafted and followed throughout the Thesis is described. By elucidating the research methodology, the credibility and validity of the Dissertation's chapters are solidified.*

1.1. Current Urban Reality – Contemporary Challenges and Threats

Today's cities and large urban systems in general have been transformed into the meeting points of human societies and the magnets for population and talents (Sassen, 2001). The unprecedented urbanization intensity and the rampant growth of urban systems of the last two decades offer new developmental opportunities, while posing, at the same time, a multitude of very critical concerns; thereby reflecting the two sides of the same coin. Therefore, even though contemporary cities represent incubators of technology, innovation, investments, knowledge, entrepreneurship, creativity, culture, etc., they are also perceived as areas highly prone to acute problems and threats. A great share of scientific research and policy documents make extensive reference to these problems and classify them under six main dimensions (economy, environment, governance, mobility, people, and living) (Monzon, 2015).

Financial crises and *fiscal imbalances*, that many cities around the world are suffering from, are often identified as the most significant urban challenges and are placed at the core of almost all current policies. This is justified by the dominant structure of the economic system, which treats cities as hubs of economic growth. The concentration of human resources and capital has transformed urban environments into economic poles of crucial importance, where 80% of the global Gross Domestic Product (GDP) is produced (Clos, 2016). However, cities' magnitude in the economic status-quo is not new at all, since "from their very inception, cities have arisen through the geographical and social concentration of a surplus product" (Harvey, 2012, p. 5).

Urban unemployment also constitutes a vexing issue, which directly affects both the lives and functions of residents; and drastically contributes to the emergence of social fragmentation phenomena. Of course, unemployment is not exclusively confined to urban systems. Nevertheless, the accumulation of population in urban environments and the intensity of the spatial concentration of this trend, culminate in the manifestation of unemployment with a more pronounced character; provoking thus severe social tensions. In other cases, cities that heavily rely either on specific sectors or on the exploitation of particular resources, are confronted with problems arising from market instability, especially when there are fluctuations in the price or demand of the items or services they produce.

Additionally, urbanization exerts significant pressures on various urban systems and infrastructure, as well as on energy, water and waste management, critical areas whose effective monitoring and control constitute a concern of great significance for most cities worldwide.

Urban mobility and transport represent a major challenge as well, with traffic congestion being a dreadful reality for millions of urban dwellers. The cost of traffic congestion was estimated at one trillion dollars for 2013 (The Economist, 2014); while the average American driver spends 42 hours in traffic congestion every year (Cramton et al., 2019).

These issues appear to be interdependent; they fuel each other by actually setting a perpetual vicious circle in motion. Financial problems afflict the social fabric, environmental crises impose economic and social pressures, social disruption causes extreme economic upheavals, and so forth. This occurs as the arising urban threats are linked to four key factors – *urbanization, economic crisis, climate change, technological advancements* – which instigate, are directly associated with, or act as catalysts for the manifestation of the aforementioned issues. Proper identification and analysis of these factors are considered absolutely necessary in the endeavor to effectively deal with contemporary urban challenges.

1.1.1. Urbanization

Today, an estimated 56% of the world's population – 4.4 billion people – resides in cities. This trend is expected to escalate in the future, with cities' inhabitants doubling their current size by 2050, when nearly 7 out of 10 people will be urban dwellers (The World Bank, 2023). Intensified urbanization occurs mainly due to the further tertiarization of developed economies and the industrialization of Southeast Asian economies and societies. Countries such as India and China – with their populations exceeding 2.5 billion, the majority of which live in non-urban areas – are experiencing strong urbanization forces. Delhi, the capital of India, is projected to have more than 35 million inhabitants by 2050 and is predicted to be the most crowded city in the world by 2028, surpassing Tokyo (see Figure 1-1).

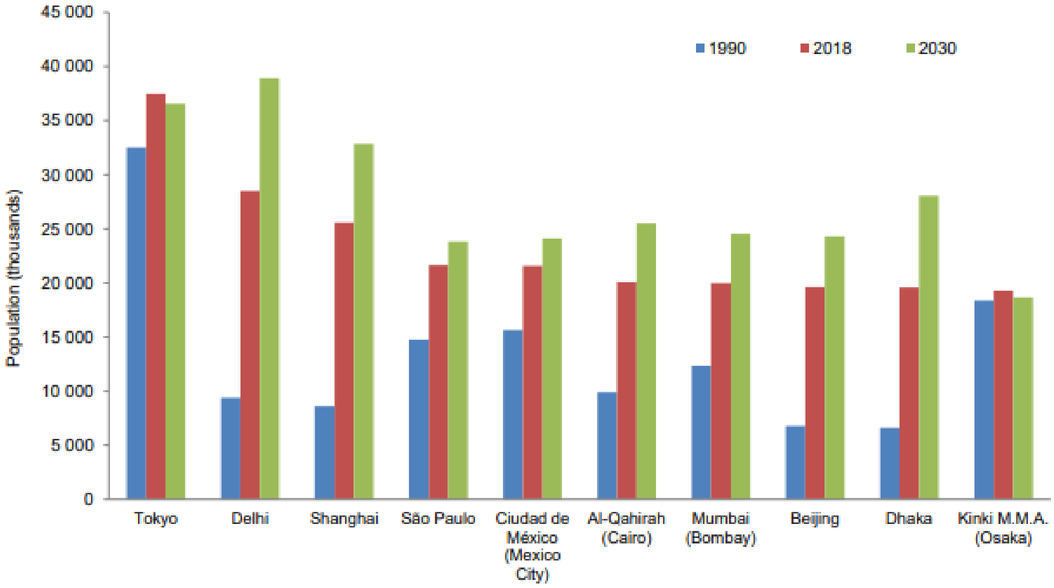

Figure 1-1: Population of the World's 10 Largest Urban Agglomerations in 2018, with Estimates and Projections for 1990 and 2030 (Source: UN, 2019a)

Megacities are well-known for their massive size and the dense concentration of economic activities, while they host 529 million people. Currently, it is estimated that there are 33 megacities around the world with a population of more than 10 million (Figure 1-2); and by 2030, 10 additional cities are expected to join this mega category with two of them located in Africa, seven in Asia and only one in Europe (United Nations [UN], 2019a).

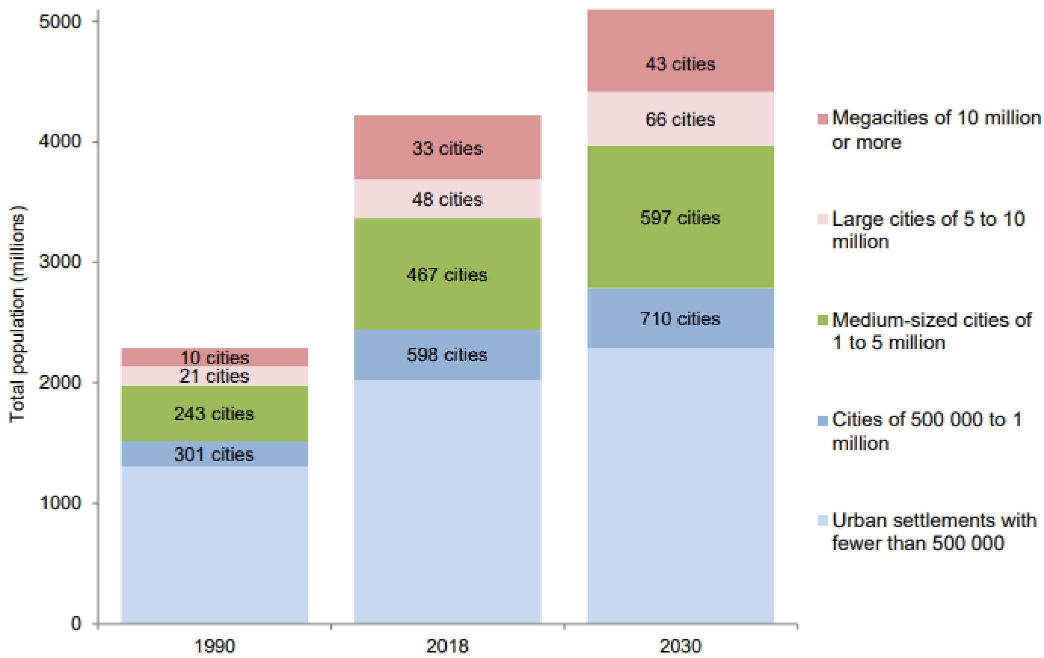

Figure 1-2: Population and Number of Cities Worldwide, by Class of Urban Settlement for 1970, 1990, 2018 and 2030 (Source: UN, 2019a)

The ongoing concentration of urban population has a catalytic effect on everyday life, economy, and social relationships. Systems and services, being shaped for decades, need to be restructured in order to meet the demands of the new reality. However, based on their current architecture and mode of operation, urban systems, infrastructure, and services are not easily adaptable to constantly evolving environments. Additionally, urbanization is the source of several other critical urban issues that need to be taken into account as well, such as overcrowding, housing crisis, development of slums, sanitation and water shortage problems, health hazards, urban crime, increased rates of poverty, malnutrition, obesity, etc.

Moreover, the continuous population growth within and around cities has led to their categorization into three classes: the *city proper*, the *urban agglomeration*, and the *metropolitan area*. Population increase in these areas occurs at varying rates (UN, 2019a). This new urban scenery can be expressed as the difference between the de jure city (the part of the urban system considered administratively unified) and the de facto city (the portion of the urban system considered a unified entity due to the interaction of its individual systems). It is worth mentioning that the problems arising in urban transportation are a direct outcome of this issue. For instance, a transportation system designed on the basis of the de jure boundaries of a city during a period of time when urbanization is less pressing, cannot adequately meet the needs of today's residents.

Urbanization affects each city differently and, therefore, this phenomenon should not be translated just into peoples' tendency to accumulate in a specific place. There are many cities worldwide that experience population shifting to other urban systems, or see their overall population remaining stable but moving from the city centre to the suburbs; thereby further expanding their boundaries.

The promotion of relevant processes and technological advancements that target cities' smartness is founded on the need for constant and reliable monitoring of their key aspects and the nature of changes taking place in them. This enables cities to promptly adjust their systems' operation and tailor their services to satisfy community expectations.

Today, urbanization is deemed to be both an opportunity for the development of human societies and a source of numerous major problems. Bearing in mind that it represents a trend which, as all predictions indicate, will continue for at least the next few decades, cities' effort to become smart is not an attempt to reverse this trend, but rather an adaptation to the new challenges it brings.

1.1.2. Financial Crisis

The financial crisis of 2008, instigated by the collapse of the United States' real estate market, spread extremely rapidly all over the world due to the multinational and diversified nature of contemporary business conglomerates. The globalized landscape of the international market and economy conduced to the worst economic meltdown since the Great Crash of 1929 (Temin, 2010). Evidently, the extend of the economic decline varied across different productive sectors, as did the outcomes in each state and region. During the period of the financial crisis, cities exhibited different characteristics and patterns related to both resilience and vulnerability to abrupt economic fluctuations.

In the European Union, the majority of metropolitan areas (cities with population of 250,000 inhabitants or more) performed quite better in terms of unemployment rates compared to non-metropolitan areas; apart from Finland, Greece, Hungary, and Latvia, where the reversed phenomenon was observed. In addition, both metropolitan and non-metropolitan areas in the United Kingdom and Spain followed equally intensive negative developmental trajectories. At the same time, poverty and the risk of social exclusion considerably increased within European cities, in comparison to the population residing in non-urban areas (Redalyc Project, 2013).

The reason behind cities' desire to become smart appears to be twofold in this respect. Besides the anticipated economic benefits to be reaped, this direction is also deemed to be a fruitful process whereby cities will achieve high levels of social cohesion; reducing thus their vulnerability to sudden economic, social, and political changes.

Furthermore, during the economic crisis of 2008-2009, cities realized that not only were they competing with their neighbouring cities, but also with cities all around the world, due to the development and wide spread of the Internet and the consequent evolution of globalization. Therefore, their interest in becoming smart is reflected in their desire to promote and advertise themselves in order to attract investments and high-level human capital, with the ultimate goal of creating a new labour-productive class (Florida, 2003).

In order to reach this ideal state, the question that scientists, especially those involved in the creation / planning of new cities, are now called upon to answer focuses on how to make cities more liveable and attractive. In this regard, they have decided to embed in this sought-after competitive city, infrastructure such as public Wi-Fi networks, electric vehicle charging stations, bike lanes, and other modern technologies and practices. Therefore, smart cities shape an alluring environment for their people by providing universal access to wireless networks, contributing to the creation of networks as tools of interaction among stakeholders, citizens, business, scientific communities, etc., and eliminating long-standing bureaucratic obstacles. At the same time, smart cities' primary goal is to support sustainable urban development by focusing on all urban sectors / functions, in total harmony with their natural and cultural reserves.

1.1.3. Climate Change

The concept of climate change continues to be a flashpoint for human societies, despite the detailed reports from international bodies and organizations, and the overwhelming consensus within the scientific community. Global warming and the responsibility of human activities for the manifestation of this phenomenon is oppugned by a range of enterprises that predominantly operate in the energy sector, as well as by national governments. United States of America has already withdrawn from the Paris Agreement on climate change, while ExxonMobil faces a series of legal disputes regarding the concealment of information on climate change. In the research conducted by Supran and Oreskes (2017), which studies the company's stance both internally and in its public statements, it was concluded that despite being aware of the anthropogenic nature of the issue, the company kept focusing on data uncertainty to disorient the public opinion.

In 2018, the Intergovernmental Panel on Climate Change (IPCC) – an intergovernmental organization under the auspices of the United Nations, whose goal is the scientific study of climate change and its effects – released a report on the changes that are predicted to occur if the average global temperature rises by 1.5 °C compared to the pre-industrial levels (Intergovernmental Panel on Climate Change [IPCC], 2018). Pursuant to this report, which takes into account international conventions and is structured in alignment with the goals set by the UN 2030 Agenda, the impacts that would be caused if temperature increase reaches 2 °C are now expected to occur at 1.5 °C (IPCC, 2018; Fountain, 2019). Based on the prevailing production and consumption models and the current emission levels, the increase of 1.5 °C in global temperature will most probably be reached by 2040. The report outlines the ramifications that will deluge human societies, as well as their spatial variation, since their intensity highly depends on the region in which every community is located.

Despite the divergent perspectives formed and opposed to scientifically substantiated positions, the majority of stakeholders involved in urban planning recognize climate change as one of the key factors that will aggravate the vulnerability of human existence both directly and indirectly. It is estimated that it will directly affect the productive capacity of human societies and expose them to a wide spectrum of environmental hazards. Phenomena such as drought, water scarcity, flooding, and mudslides are expected to escalate within urban systems, jeopardizing their smooth functioning and causing humanitarian and social crises as well as more severe economic devastation. The displacement of populations from affected areas is also expected to further exacerbate the pressures exerted on urban ecosystems.

The rationale behind the development of smart cities is based on their need to reduce the human footprint on the natural environment; thereby limiting the increase in average global temperature and mitigating its consequences, while simultaneously enhancing systems' capacity to adapt to the new environmental conditions. Nowadays, cities represent the primary energy consumers and waste producers, hence their pivotal role in managing and addressing environmental issues.

1.1.4. Technological Boom

The radical technological advancements have indubitably played a pivotal role in fostering the emergence of smart cities, which represent a modern paradigm of urban development (Caragliu et al., 2011). These technologically integrated urban environments are characterized by the seamless incorporation of cutting-edge Information and Communication Technologies (ICTs) to optimize various aspects of city life, including infrastructure, governance, environmental sustainability, well-being and quality of life. Through its multifaceted contributions, technology has immensely affected the transformation of traditional urban landscapes into intelligent, efficient, and interconnected urban ecosystems.

Primarily, technology has promoted the creation of robust digital infrastructure, that form smart cities' backbone. The widespread deployment of high-speed broadband networks and the expansion of wireless connectivity have significantly upgraded interconnection possibilities by enabling the rapid exchange of data and fostering real-time communication among various stakeholders (Neirotti et al., 2014). This interconnectedness has pushed forward the collection, processing, and analysis of voluminous amounts of data from diverse urban systems, giving rise to the concept of big data. Harnessing the potential of big data has opened up cities' opportunities to gain valuable insights into urban patterns, behaviour, and trends (Batty, 2013); and has allowed city authorities to make informed decisions and craft evidence-based policies that result in more efficient resource allocation, enhanced service delivery, and improved urban planning.

Moreover, technology has completely reformed urban mobility and transportation systems by effectively addressing the challenges imposed by severe traffic congestion, pollution, and inadequate infrastructure. Advanced technologies such as Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML) have been instrumental in the development of intelligent transportation systems (ITS).

The integration of technology has propelled the concept of energy-efficient and sustainable cities, which aim at optimizing resource consumption and minimizing environmental impact (Neirotti et al., 2014). Smart grids and energy management systems use data analytics and IoT devices to monitor, control, and optimize energy consumption across urban infrastructure. These systems enable efficient distribution, reduce energy waste, and promote renewable energy sources. Additionally, the deployment of smart meters and real-time energy monitoring tools empowers citizens to have control over their energy usage, leading in this way to increased awareness and behavioural changes towards more responsible and sustainable practices.

Technology has also strengthened citizens' engagement and participatory governance by empowering residents to involve in decision-making processes. Digital platforms and mobile applications have been deployed to enable citizens to report local issues, provide feedback, and communicate with local authorities (Anthopoulos, 2015). This two-way interaction has established a more inclusive and transparent governance model, where citizens can actively participate in shaping urban policies and initiatives. Moreover, technology-driven platforms have facilitated the delivery of e-government services; thereby simplifying administrative processes, enhancing efficiency, and improving access to essential services.

In conclusion, technology has undeniably been a driving force behind the advent of smart cities. Its transformative potential has revolutionized urban development by promoting efficacy, sustainability, public participation, and quality of life. As technology continues to evolve, the trajectory of smart cities is poised to advance further, therefore offering immense opportunities for urban innovation, prosperity, and progress.

1.2. Goal and Objectives of the Doctoral Dissertation

The global urban challenges and threats, as previously delineated, have given birth to the concept of smart cities, as modern, highly innovative urban environments that leverage ICTs in an efficient manner to address urban issues and support their overall competitiveness. However, extended literature review uncovers a significant *conceptual gap* regarding the semantics of the smart city term, which has induced, inter alia, great confusion among planners, policy makers and other urban stakeholders; and has also led to a great share of failed or partially successful smart strategies and initiatives. Moreover, the rise of new (or updated) concerns in the urban planning realm – *sustainability, resilience, and inclusiveness* – calls for their immediate integration with the notion of smartness as well as for their performance measurement in various city domains; thereby shaping a new, holistic and participatory planning approach that embraces the fundamental, contemporary urban desiderata.

In this respect, the present Doctoral Dissertation focuses on developing a new, integrated, multifaceted, and comprehensive smart city conceptual framework that is expected to act as a Decision Support Tool for managing contemporary urban issues and formulating appropriate policies for sustainable, resilient and inclusive urban development. More specifically, this goal is further analysed into the following objectives:

- Development of a robust ontology that captures the essential concepts, relationships, and attributes of the smart city field. The ontology is expected to serve as a foundation for organizing and structuring data and knowledge in the domain of interest.
- Identification and selection of indicators that effectively measure and assess the aspects of sustainability, smartness, inclusiveness, and resilience in the smart city context, through a rigorous and critical review of relevant, international indicator systems.

- Consolidation of the selected indicator systems into a unified, multidimensional, more enriched, and coherent framework.
- Integration of the constructed indicator framework into the new ontology by establishing the relationships and dependencies between the indicators and the various components of the ontology. The incorporation of the indicator framework into the ontological representation ensures that the latter can effectively capture and represent the multidimensional and intricate nature of a smart city.
- Provision of recommendations and guidelines for the practical implementation of the ontology in urban planning. These recommendations consider the introduction of the proposed ontology to existing urban planning frameworks, as well as any necessary adjustments and enhancements.

By attaining the above goal and objectives, the Thesis is anticipated to deliver a well-established and valuable instrument to urban planners, decision and policy makers, researchers, and other interested urban stakeholders, which will allow them to leverage innovative approaches in order to refine the outcomes of the planning process.

1.3. Research Questions of the Doctoral Dissertation

Taking into consideration the intended goal and objectives, the present Doctoral Dissertation endeavors to provide well-established and convincing answers to two central groups of research questions:

<u>Core Research Questions – Group 1</u>

What is actually a smart city?
What are the underlying semantics of the term and their interrelations?
How does smartness manifest when it comes to urban environments and spatial planning?

Core Research Questions – Group 2

How can cities effectively gauge their progress towards becoming smarter, more sustainable, more resilient, and more inclusive?
What are the key indicators to be used in this respect?
How can cities select the most appropriate set of standards, requirements, and metrics to secure the success of their projects?

More specifically, initially, the Thesis attempts to thoroughly explore the very nature of smart cities; uncover the underlying semantics of this fuzzy concept; describe its main constituents as well as their interconnections through the construction of a new ontological scheme; and, finally, make some safe inferences on whether this is a true and promising urban planning paradigm or a transient urban trend, mostly imposed by colossal tech industries. To do so, the first set of research questions is further analysed into several research sub-questions:

- What is the role of technology in the smart urban context? Is it an end in itself or the medium for reaching urban prosperity? Research community appears to be divided on that matter. Some equate smartness with radical technological advancements and with the full automation of all urban functions; others adopt a much more socially-oriented approach in which people are the protagonists and technology the tool to achieve urban sustainability objectives; while the rest are somewhere in-between these two streams.
- What are the lessons learnt from successful smart city case studies around the world, and how can those insights be adapted and applied to inform urban planning processes in different geographic, socio-economic, and cultural contexts?
- What are the essential concepts, relationships, and properties of an ontology, specifically designed for smart cities; and how can these be sufficiently described to provide a comprehensive and structured representation of urban domains that will support decision-making processes in urban planning?
- What are the main challenges and barriers in developing ontologies for smart cities, and how can they be addressed?

- How can the development of a smart city ontology contribute to the effective implementation of smart initiatives and enhance urban planning processes?

Seeking to cover the second group of the posed research questions, the Thesis proceeds with the construction of a unified, global indicator framework and its incorporation into the new ontology, thereby offering answers to a series of research sub-questions that emerge:

- How can ontologies be designed and integrated with indicator frameworks in order for: a comprehensive and standardized measurement system for assessing smart cities' performance to be offered; and the identification and selection of relevant indicators that capture the multidimensional aspects of smart cities' progress in areas such as transportation, energy, governance, and social inclusion to be attained?
- How can the incorporation of indicators into the ontology-based evaluation framework guide data-enabled decision-making processes and support evidence-based policy formulation for smart city planning and development, enhancing thus the efficacy and effectiveness of urban planning in terms of resource allocation, infrastructure development, and service delivery in smart cities?

The Thesis is addressed to a wide range of target audiences that are related to (participatory) planning, sustainable urban development and/or policy making, such as academic communities, governmental or private agencies and organizations, practitioners and professionals, industry and technology stakeholders. It may also have a broader outreach by assisting in raising awareness and educating the general public about the opportunities and challenges associated with smart cities.

1.4. Added Value and Contribution of the Doctoral Dissertation

Considering the lack of substantial linkages between the knowledge reserves on the smart city field and its use as a promising concept to spatial (and developmental) urban planning, the present Dissertation focuses on providing helpful, coherent, and meaningful insights both on the theoretical and the applied level of related domains. In this regard, it attempts to bridge the abovementioned gap by establishing a bottom-up approach, guided by current city objectives and pertinent assessment frameworks and coupled with ontological theoretic ground for knowledge structuring and visualization.

The Dissertation wishes to disentangle the smart city concept and to shed light on its planning-related facets that remain in the shadows or have not been adequately covered so far. Its results are expected to facilitate and enrich the spatial planning and developmental processes by contributing to the crafting of successful, integrated, comprehensive, place-based, and citizen-oriented smart city strategies and initiatives. More specifically, it intends to:

- Carve out a holistic, multidimensional, comprehensive, and coherent conceptual framework that sets the ground for: better understanding smart cities and the interactions among their various aspects; and grasping the role that urban planning should possess in a smart city context. This integrative approach will allow urban planners and policy makers to consider multiple factors / parameters simultaneously and make informed decisions.
- Capitalize on empirical findings regarding the efficacy, effectiveness, challenges, opportunities, weaknesses, and/or impacts of smart city initiatives in specific urban contexts.
- Enhance the urban planning process per se by embedding indicators pertinent to smartness, sustainability, resilience, and inclusiveness into the proposed smart city ontological scheme. In this respect, the ontology can serve as a knowledge base and decision support tool for urban planners that will enable them to assess and prioritize different aspects of city development, identify potential trade-offs or synergies between indicators, and shape more effective and sustainable urban solutions.
- Foster policy assessment and benchmarking of smart cities through the establishment of a common set of indicators that will facilitate comparative analyses across cities, thereby identifying successful strategies and areas for improvement.
- Support conceptual consistency and standardization since it offers a common vocabulary and a standardized framework for describing and measuring the different dimensions of smart cities.

- Provide potential for actionable recommendations, guidelines, or best practices to urban planners, policy and decision makers, and other interested parties involved in smart city planning and policy implementation.
- Propose innovative solutions, design principles, and technological interventions to enhance urban planning processes and foster sustainable urban development in general.
- Unveil the urgent necessity to promote public participation and incorporate it in every stage of the planning process (from the articulation of goal and objectives to the assessment and implementation of the selected plan), in order to develop widely accepted and supported, community-driven initiatives.

The synthesis of all the abovementioned expected outcomes – and added value features at the same time – of the Doctoral Dissertation actually leads to the very core of its contribution that revolves around shaping and adopting a more *adaptive and future-proof form of urban planning*. The established theoretical ground together with the development of a unified indicator framework, embedded into a new smart city ontology, enable planners to anticipate and respond to emerging challenges and opportunities, such as technological advancements, changing demographics, socio-economic and environmental shifts. Moreover, as urban reality evolves, the ontology can be continuously updated and expanded, thereby ensuring that the framework remains relevant and adaptable to possible alterations. This proactive approach guarantees that cities remain sustainable and resilient in the face of evolving urban contexts.

1.5. Methodological Approach and Structure of the Doctoral Dissertation

In order to meet the goal and objectives, and address the research questions posed in the present Doctoral Dissertation, a series of methodological steps – being, at the same time, the chapters of the Thesis – are implemented (see also Figure 1-3).

Chapter 1 serves as the foundation for the entire research by setting the contextual ground that sheds light on its significance and relevance. In this respect, it endeavors to establish a succinct framework for delineating the major challenges and threats that contemporary urban environments are confronted with, and are the actual instigators of the colossal smart cities' wave. Moreover, the research topic as well as the goal and objectives are clearly articulated, thereby assisting the reader in fully grasping the Thesis's purpose. Finally, the methodological approach employed throughout the whole research effort is detailed.

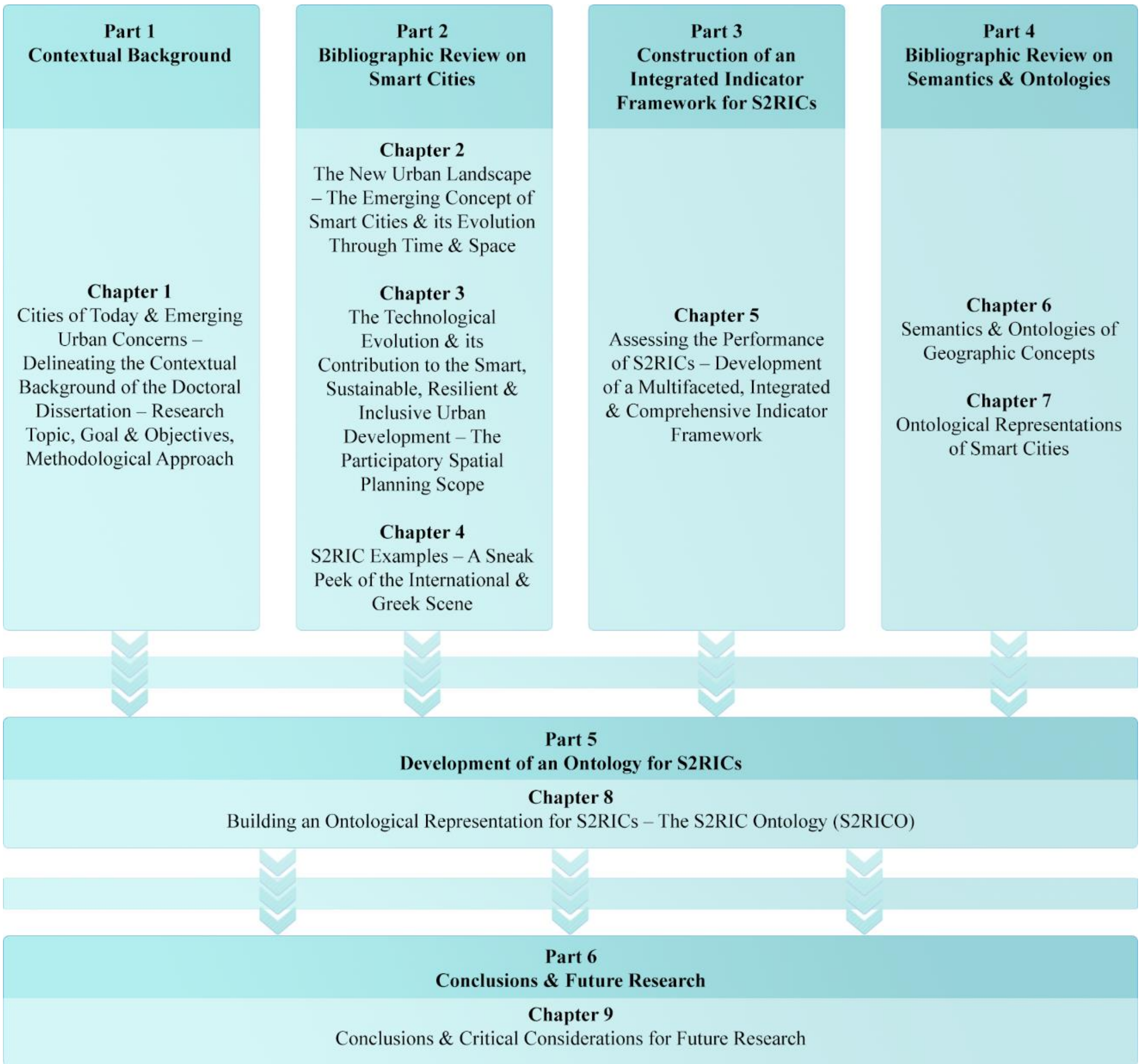

Figure 1-3: Methodological Approach of the Doctoral Dissertation (Source: Own Elaboration)

Chapter 2 delves into the emerging concept of smart cities and explores how the term has evolved over time. By tracing the historical development and spatial expansion of the concept, a comprehensive understanding of its significance and transformative potential is achieved. The chapter critically examines the key elements and characteristics that define smart cities, such as advanced technologies, data-driven decision-making, and sustainable urban practices. The sustainable, inclusive and resilient dimensions of the smart city – primary and desired planning outcomes – that are at the core of modern urban development and management, are particularly stressed. The thorough analysis of the evolution of smart cities provides useful insights into the challenges and opportunities associated with their implementation and the broader implications for urban development.

Chapter 3 focuses on the profound impact of technological advancements on smart, sustainable, resilient, and inclusive urban development. It explores how technological innovations have revolutionized urban planning and management practices, enabling thus the realization of more efficient, equitable, and environmentally friendly cities. Particular emphasis is placed on participatory planning as a crucial approach for engaging stakeholders in urban decision-making processes. By incorporating diverse perspectives and ensuring inclusiveness, participatory planning facilitates the development of sustainable and resilient cities that meet the needs and aspirations of their inhabitants. Additionally, the most prevalent state-of-the-art technologies and tools for efficaciously implementing (participatory) spatial planning exercises in the smart city context are briefly described.

Chapter 4 offers a captivating glimpse into real-world examples of smart, sustainable, resilient, and inclusive cities (S2RICs). Drawing from the international and the Greek reality, the chapter explores noteworthy case studies that embody the principles and goals of S2RICs. The investigation of successful examples uncovers valuable insights into the practical implementation of smart city initiatives and the integration of sustainability, resilience, and inclusiveness goals. Moreover, through detailed analyses of diverse urban settings, this chapter highlights the multifaceted approaches employed to address various urban challenges and achieve positive outcomes.

Chapter 5 describes the process of structuring and deploying a multifaceted, integrated, and comprehensive indicator framework for assessing the performance of smart, sustainable, resilient, and inclusive cities (S2RICs). More specifically, it explores the complexities involved in evaluating the effectiveness and impact of urban development initiatives within the S2RIC paradigm; and discusses the formulation of a comprehensive set of indicators that capture various dimensions of urban performance, including social equity, environmental sustainability, economic vitality, and technological innovation. The proposed indicator framework constitutes a valuable tool for policymakers, urban planners, and researchers, to assess and monitor the progress of S2RIC initiatives; thereby facilitating evidence-based decision-making and fostering continuous improvement.

Chapter 6 provides a general overview of the scientific field of semantics and ontologies, while placing particular emphasis on the semantics of geospatial concepts and geographic ontologies. It explores the factors that influence their perception and understanding, as well as several fundamental semantic and ontological issues. The chapter proceeds with analysing ontologies' usability and the various fields of their application, the different types of ontologies, the basic stages of ontological design, as well as the process of ontology alignment, merging and integration.

Chapter 7 dives into various smart city ontological representations, building upon the theoretical groundwork established in the previous chapter. This chapter explores how ontologies can be utilized to capture the complex interdependencies and relationships within smart city systems, facilitating in this way comprehensive knowledge representation. By leveraging ontologies, the chapter provides a framework for organizing and structuring information, enabling the development of intelligent systems and decision support tools that can effectively address urban challenges.

Chapter 8 constitutes the applied part of the Dissertation and thoroughly describes the development of the S2RIC Ontology (S2RICO), an ontological representation designed specifically for integrating the assessment of smart, sustainable, resilient, and inclusive cities' performance into the planning practice. The chapter presents the conceptual framework and methodology used to construct the S2RICO and outlines the processes and considerations involved in creating a comprehensive knowledge model. The S2RICO ontology serves as a powerful tool for researchers, policymakers, and urban planners to understand and finally overcome the complexities of S2RIC environments and facilitate data-driven, holistic approaches to urban development.

Finally, *chapter 9* presents the conclusions drawn from the whole research and provides a comprehensive summary of its key findings. This chapter reflects the research objectives, the proposed methodology, and insights obtained throughout the Dissertation by offering a critical analysis of the contributions made to the field of smart, sustainable, resilient, and inclusive urban development. Moreover, it discusses the implications of the research findings and suggests avenues for future research and practical applications. By synthesizing the knowledge presented in the previous chapters, this concluding section consolidates the overall contribution of the Doctoral Dissertation, highlighting its significance and potential impact on the field of urban studies and planning.

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Part 1 Contextual Background

Part 2 **Bibliographic Review on Smart Cities**

Part 3 Construction of an Integrated Indicator Framework for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 4 Bibliographic Review on Semantics & Ontologies

Part 5 Development of an Ontology for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 6 Conclusions & Future Research

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CHAPTER 2: THE NEW URBAN LANDSCAPE – THE EMERGING CONCEPT OF SMART CITIES AND ITS EVOLUTION THROUGH TIME AND SPACE

***Synopsis**: Sustainable, resilient, and inclusive development constitutes a contemporary, overarching planning goal for a profusion of urban environments that strive to cope with intense challenges and threats, mainly pertinent to the frenetic urbanization pace and climate crisis. In such a context, the concept of smart cities comes to the surface as a promising policy option for effectively dealing with sustainability objectives by leveraging state-of-the-art technologies, which immensely contribute to the optimal management of urban resources. But what exactly does the smart city signify? Although, the term has been broadly used for over the last decade, a great part of this 'urban labelling' phenomenon (Hollands, 2008) remains in the shadows. The dearth of knowledge and deep understanding of the meaning of smart city, combined with its uncharted conceptual depth, render its study and analysis even more cumbersome. In this respect, the present chapter focuses on clarifying the smart city concept by delving into the wide spectrum of diverse (slightly or not) definitions introduced from time to time. Moreover, particular emphasis is placed on the sustainable, inclusive and resilient dimensions of the smart city – primary and desired planning outcomes – that are at the core of modern urban development and management. This is followed by a critical view among the different definitional streams, based on extended bibliographic survey. The issue of the semantic discrepancies observed between the smart city and several 'similar' to smart city terms, that are interchangeably and, in many cases, recklessly used, is also addressed. The chapter proceeds with the dissection of the smart city 'establishment' by elaborating on its fundamental constituents (dimensions, characteristics and domains). Finally, the last section refers to some prominent success factors for the best possible selection and implementation of smart initiatives.*

2.1. Shedding Light on the Concept of Smart City

Over the past few years, the definition of "Smart Cities" has evolved to mean many things to many people. Yet, one thing remains constant: part of being "smart" is utilizing information and communications technology (ICT) and the Internet to address urban challenges (Mitchell et al., 2013, p. 1).

As already analysed in chapter 1, *urbanization* has dramatically intensified over the last years and according to United Nations' estimations it is expected to considerably escalate in the near future. Indeed, relevant projections reveal that nearly 64% of inhabitants in developing countries and 86% of people living in developed ones will be residing in urban environments by 2050; while the phenomenon is anticipated to exhibit particular tension in Asia and Africa (United Nations [UN], 2014). The radical and ominous impacts of the extremely rapid urbanization pace (imprudent energy consumption, increased waste generation, poverty, slums, resource scarcity, pollution, lack of social cohesion, etc.) constitute the focal point of policy makers and urban planners' work all around the globe, who desire to deliver widely acceptable, efficacious, sustainable and innovative solutions in order to mitigate or prevent those impacts (Madlener & Sunak, 2011; Uttara et al., 2012; Patra et al., 2018; Smith et al., 2018; Wang et al., 2018).

At the same time, the revolutionary advancements of *Information and Communications Technologies* (ICTs), that underpin myriads of urban functions and offer improved and high-quality services to citizens, businesses as well as to public and private actors, have induced drastic alterations to the scientific fields of spatial planning and sustainable urban development; while they can decisively contribute to the effective management of contemporary urban problems (Talvitie, 2003; Caperna, 2010; Fernández -Maldonando, 2012; etc.). ICTs have significantly affected the interaction potential among various actors by providing access to distributed knowledge and intelligence, but also to a wide spectrum of tools and applications. The latter allow networking and cooperation at a *glocal* (global-local) level by eliminating space and time barriers and transferring many urban functions from the space of 'places' to the space of 'flows' (Castells, 1992), i.e., a digital environment, where value is created and flows in webs (Kelly, 1998). This new scenery brings to the forefront the concept of *smart cities* as urban environments which, through the wide adoption and use of technology, promote innovation, pursue sustainable urban development objectives and encourage participation of citizens, businesses and other stakeholders in decision-making processes (Caragliu et al., 2011; Deakin & Al Waer, 2011; Nam & Pardo, 2011; Stratigea, 2012; Herrschel, 2013; Albino et al., 2015; Ishkineeva et al., 2015; Meijer & Bolívar, 2015; Meijer et al., 2015; Monfaredzadeh & Berardi, 2015; Grimaldi & Fernández, 2017; Stratigea et al., 2017; Panagiotopoulou et al., 2020; etc.).

But, what does 'smart city' actually mean? According to the literature review, it becomes obvious that although the use of the term has tremendously increased, especially during the last few years, there is still no clear and broadly accepted comprehension of this concept. Therefore, a common ground of mutual understanding, which would serve as a *semantic bridge* among different scientific disciplines, has not yet been established, with smart cities still *"striving to clarify their identity"* (Zait, 2017, p. 377). This has provoked some sort of cacophony in the international literature and academia (Boulton et al., 2011), since numerous definitions have been introduced from time to time. As Chourabi et al. (2012) point out, defining the semantics of a smart city is a complex subject of conceptual research that is still in progress. Indeed, the bibliographic research reveals a plethora of definitions (International Telecommunication Union [ITU], 2014a; Stratigea & Panagiotopoulou, 2015; Stratigea et al., 2015, 2017; Kummitha & Crutzen, 2017; Panagiotopoulou, 2018; Panagiotopoulou et al, 2019, 2020; etc.) that emanate from various theoretical backgrounds; represent different conceptual approaches; and underline intense *semantic ambiguity* and unsolved *polysemy* issues (Panagiotopoulou, 2018; Panagiotopoulou et al., 2019). Some of them focus exclusively on ICT as the prevalent developmental lever of urban environments; while others adopt a broader approach, embracing aspects of society, economy, governance and public participation (Manville et al., 2014; Stratigea et al., 2015).

2.1.1. Introduced Smart City Conceptualizations

The definitions presented below are among the most popular ones, as they have been extensively used in both practice and academia[1]. Furthermore, they are incorporated in several seminal works on the field, such as "Smart Cities – Ranking of European

1 Annex I provides an extended list of proposed smart city definitions, as these are gathered and elaborated by International Telecommunication Union (International Telecommunication Union [ITU], 2014a).

Medium-Sized Cities" by Giffinger et al. (2007); "Conceptualizing Smart City with Dimensions of Technology, People, and Institutions" by Nam and Pardo (2011); "Smart Sustainable Cities: An Analysis of Definitions" by International Telecommunication Union (International Telecommunication Union [ITU], 2014a); and "Smart Cities: Definitions, Dimensions, Performance, and Initiatives" by Albino et al. (2015).

Hall et al. (2000), perceive the smart city as

> a city that monitors and integrates conditions of all of its critical infrastructure, including roads, bridges, tunnels, rail / subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens. (p. 1)

The authors believe that every smart city should put in place a *self-monitoring* and *self-response* system (Nam & Pardo, 2011). Therefore, *technology* and its capacity to constantly monitor the state of urban key infrastructure and functions in order for better and safer services to be delivered, appears to be the core of the above definition. The significance of a city's ability to keep track of its critical infrastructure and its current conditions – the prerequisites for effectively responding to natural and manmade emergencies, but also an integral part of a smart city's vision – is particularly emphasized (Hall et al., 2000).

Komninos (2006) suggests that smart cities are "territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management" (p. 13). In this respect, *urban innovation*, *knowledge creation*, *learning*, *problem solving* and cities' *'digital skin'* (technological dimension) are deemed to be the cornerstones and key drivers of smart cities.

Pursuant to Giffinger et al. (2007), a smart city is "a city well performing in a forward-looking way in smart economy, smart people, smart governance, smart mobility, smart environment and smart living, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens" (p. 11). Giffinger et al. (2007) perceive the smart city as an urban environment that is built upon six fundamental dimensions (these are concisely described in the following sub-section), while they also provide an indicator framework to assess the performance of different medium-sized European cities towards their 'going smart' transition.

Eger (2009) claims that

> a "smart community" – a community which makes a conscious decision to aggressively deploy technology as a catalyst to solving its social and business needs – will undoubtedly focus on building its highspeed broadband infrastructure, the real opportunity is in rebuilding and renewing a sense of place, and in the process a sense of civic pride. (pp. 47–48)

It is pretty evident that Eger places great emphasis on the technological aspect of a smart city, yet, he combines that notion with the possibilities offered by the development of new technological infrastructure and their applications for effectively coping with the social and economic problems of an urban system.

Kanter and Litow (2009) hold the opinion that:

> A smarter city infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems and fix them quickly, recover rapidly from disasters, collect data to make better decisions and deploy resources effectively, and share data to enable collaboration across entities and domains. Its operations are instrumented and guided by performance metrics, with interconnections across sectors and silos. But infusing intelligence into each subsystem of a city, one by one – transport, energy, education, health care, buildings, physical infrastructure, food, water, public safety, etc. – is not enough to become a smarter city. A smarter city should be viewed as an *organic whole* – as a *network*, as a *linked system*. In a smarter city, attention is paid to the connections and not just to the parts. Civic improvement stems from improved interfaces and integration. And that means a smarter city understands that the most important connectors across multiple subsystems are the *people* who give to the city by turning it from a mechanistic bundle of infrastructure elements into a set of vibrant human communities. (p. 2)

In this context, a very interesting and to the point metaphor is used to express the meaning of smart cities, since these are viewed as an extended, organic system of systems (Nam & Pardo, 2011). Particular focus is placed on how these systems interact and communicate with each other, while the pivotal role of the human capital – the begetter and instigator of all urban functions – is greatly accentuated.

According to Harrison et al. (2010), a smart city "is connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city" (p. 2). In this case, the smart city concept is strongly associated with the interconnection and communication among the different forms of urban infrastructure in order to boost operational efficiency and improve quality of life. This remark is in total alignment with IBM's belief that communication and interaction among its key systems and infrastructure are the key components of the smart city (Dirks & Keeling, 2009).

Toppeta (2010) grasps the smart city as an urban environment that "is combining ICT and Web 2.0 technology with other organizational, design and planning efforts to de-materialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability" (p. 4). Toppeta's view of smart cities transcends the rigid idea of the 'imposed' technological dominance and reaches other critical urban aspects by treating novel technological advancements as an indispensable *tool* / *medium* – and not an end in itself – whereby overall urban sustainability can be attained.

Washburn et al. (2010) state that:

> What makes a "smart city" smart is the combined use of software systems, server infrastructure, network infrastructure, and client devices – which Forrester calls Smart Computing technologies – to better connect seven critical city infrastructure components and services: city administration, education, healthcare, public safety, real estate, transportation, and utilities. (p. 1)

Once again, technology – smart computing systems in particular – is highlighted as the most significant 'ingredient' of smart cities, which may conduce to the overall improvement and increased efficacy of their existing urban infrastructure and services. The reason why this definition deals specifically with smart computing technologies is twofold. On one hand, it has an *economic perspective*, since this is a field with a rapidly growing rate of investment; and on the other hand, smart computing, unlike former tech cycles that are mainly horizontal or exclusively IT-oriented, significantly increases the potential for "a highly vertical industry focus – such as city administration, education, healthcare, transportation, and utilities – and cities are the microcosm where all of the industries intersect" (Washburn et al., 2010, p. 2).

Caragliu et al. (2011) describe the smart city as "a city where investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (p. 70). This definition places equal emphasis on three critical smart city aspects – *technological*, *social* and *institutional* – and tries to explore how these are interconnected / correlated. As mentioned by the authors, since the late 1990s, the smart city concept has been basically coupled with the Internet and ICTs; whereas their definition is conceptually broader by capitalizing on the six characteristics of a smart city, as these are introduced by Giffinger et al. (2007) (Caragliu et al., 2011).

Barrionuevo et al. (2012), claim that "being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centers that are at once integrated, habitable and sustainable" (p. 50). In this respect, the use of technology and available resources emerges as a key element in shaping liveable urban systems.

Kourtit and Nijkamp (2012), suggest that smart cities

> are the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities. Such smart cities are based on a promising mix of human capital (e.g., skilled labor force), infrastructural capital (e.g., high-tech communication facilities), social capital (e.g., intense and open network linkages) and entrepreneurial capital (e.g., creative and risk-taking business activities). (p. 93)

This definition adopts a more *holistic approach* by linking the institutional (strategies), the technological (high-tech infrastructure) and the social / human capital, as the necessary prerequisites for a city's economic development and prosperity. The term 'capital' is intentionally used, as Kourtit and Nijkamp perceive the increase of *local productivity* – as a result of cities' efforts to become smart – a quite critical factor, since it is an absolutely necessary condition for achieving economic growth (Kourtit & Nijkamp, 2012). The inextricable connection between high productivity and smart cities is also stressed by Kourtit et al. (2012), who claim that "smart cities have a high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output-oriented planning systems, creative activities and sustainability-oriented initiatives" (Kourtit et al., 2012, p. 232).

Finally, Manville et al. (2014) conceive the smart city as "a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally-based partnership" (p. 9). In this respect, *governance* and *technology* are deemed to be smart cities' fundamental building blocks. Therefore, smart cities are treated as urban environments that deal with everyday issues by supporting participatory-oriented, city- and citizen-specific solutions and encouraging multi-stakeholder alliances and coalitions through technologies and tools that improve provided services and foster communication, participation, mutual understanding and collective responsibility.

The inspection of the wide spectrum of articulated definitions leads to the conclusion that the primary goal behind the smart city paradigm is the delivery of high-quality and innovative services to citizens, businesses, institutions, and visitors; combined with the provision of a safe, pleasant, prosperous, and highly inclusive urban environment (Stratigea, 2012; Stratigea & Panagiotopoulou, 2015; Stratigea et al., 2015).

Apart from technology's pivotal role in shaping innovative, competitive and sustainable futures for all, the available literature uncovers several other critical smart city aspects, such as (Stratigea, 2012):

- *Sustainability* – strives to keep the balance among environmental, social and economic objectives.
- *Innovation* – aims at empowering both people and places.
- *Governance* – focuses on the way that rules are set and implemented by governing bodies in order to adopt more effective resource management patterns.
- *Investments* in specific ICT infrastructure and applications that are harmonized with the peculiarities, needs, requirements and aspirations of every single urban context.

Moreover, the *collaborative perspective* – alluding to the interaction and communication among various urban actors (policy and decision makers, planners, stakeholders, citizens, experts, scientists, etc.) – also comes to the surface as a distinctive smart city characteristic (Stratigea & Panagiotopoulou, 2015; Stratigea et al., 2015; Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018). In this regard, a smart city can underpin – among others – *community development processes*, which may lead to a more *equitable* and *fairer share* of information and knowledge among societal groups, thereby fueling a shift of *power structure* and reformulating decision-making norms by rendering them more participative (Stratigea & Panagiotopoulou, 2015; Panagiotopoulou & Stratigea, 2017). This remark reflects smart cities' *user-driven* and *user-focused* nature, unlike the pure technology-based orientation concepts like digital or ubiquitous cities (see also section 2.3 "Conceptual Relatives of the Smart City Paradigm"). Moreover, it is in total alignment with the argument that smart city solutions and initiatives must begin with the *'city'* not with the *'smart'*, a fact that entails a certain shift from a technology-pushed to a *human-centric*, *place-based* and *application-pulled* planning approach, thereby matching different types of 'smartness' (technologies, applications and tools) with different types of urban functions and contexts (Stratigea & Panagiotopoulou, 2015; Stratigea et al., 2015; Panagiotopoulou & Stratigea, 2017, 2021; Panagiotopoulou et al., 2018).

Despite all the contradictory views on what the smart city actually is, the challenge is to identify the commonalities, analyse the nodal points, bridge the conceptual gaps, and try to redefine the term as an environment of innovation, empowerment and engagement of citizens, businesses and stakeholders in participatory processes for shaping their future, through the choices they have at their disposal and the decisions they make (Schaffers et al., 2012). In such a context, the concept of *public participation* as "the involvement in knowledge production and/or decision-making of those involved in, affected by, knowledgeable of, or having relevant expertise or experience on the issue at stake" (Van Asselt Marjolein & Rijkens-Klomp, 2002, p. 168), appears to gain critical importance. More specifically, it acts as a tool for identifying areas / fields / aspects of stakeholders' *mutual understanding* and *consensus* that can drive policy choices on specific ICTs infrastructure, applications, etc., serving thus – to the best possible extend – the vision of the local community (Stratigea et al., 2015; Stratigea & Panagiotopoulou, 2015; Panagiotopoulou & Stratigea, 2017, 2021).

Ultimately, it is worth mentioning that smart cities' successful development is primarily based on five critical factors, used also as evaluation criteria for assessing their going smart progress. These are (Figure 2-1) (Bell et al., 2008; Passerini & Wu, 2008; Komninos, 2009):

- *Broadband infrastructure* refers to the upgrading of local capacity for digital communication through broadband connectivity.
- *Knowledge-based workforce* implies the proper education and training of the human capital to improve its ICTs skills for performing knowledge-intensive activities, participating in knowledge creation processes, etc.;
- *Digital democracy* promotes the concept of *e-governance* and bridges the *digital divide* among different societal groups.
- *Innovation* fosters the creation of an innovation-friendly and disruptive environment that allures highly creative people and businesses.
- *Marketing* of smart cities as appealing places to live, work and run a business, in order to attract talented employment and investments.

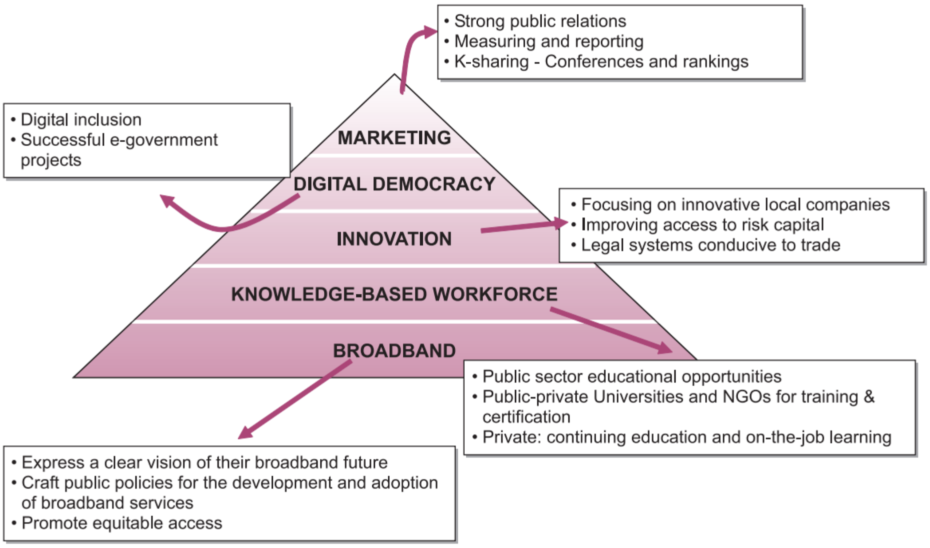

Figure 2-1: Critical 'Going Smart' Factors (Source: Passerini & Wu, 2008)

2.1.2. Shifting from the 'Smart' Notion to the 'Smart and Sustainable' Perspective

All the different interpretations of the smart city phenomenon allude – inter alia – to a diversified emphasis on various urban aspects, placed by different city contexts that claim to be smart. Such interpretations highlight distinct smart aspects (e.g., the technical aspect – ICT infrastructure, the green aspect – green infrastructure, the e-government aspect – e-services to citizens). This conceptual labyrinth is nicely and aptly depicted in Hollands's ground-breaking work "Will the Real Smart City Please Stand Up?" (2008). Different approaches uncover the still unanswered question of whether the smart city concept is an *instrumental* or a *normative* one, i.e., a set of ICT-enabled systems, services, and products, mostly pushed by technological advances and the market; or a desired, tech supported outcome, which properly integrates cities' attributes / functions and increases their efficacy in their effort to pursue smart and sustainable development end states.

Additionally – but strongly tied to the instrumental and normative view – the prominence given to the goal of sustainability comes to the surface. The majority of proposed definitions does not always explicitly refer to this goal (Stratigea et al., 2017; Angelidou et al., 2018; Panagiotopoulou et al., 2020), while smart cities' contribution to sustainable development remains fairly vague (Bifulco et al., 2016). Furthermore, the smart city concept has been blatantly criticized for favouring technological solutions, for often being extremely techno-centric, and for serving the agendas of technological industries to the detriment of social inclusion and urban innovation; while underestimating and sidelining cities' needs and environmental sustainability (Hollands, 2015; Glasmeier & Nebiolo, 2016; Komninos et al., 2015; Paskaleva et al., 2017; Huovila et al., 2019; Yigitcanlar et al., 2019). Actually, a rather utopian notion of the 'smart' concept is touted by colossal tech industries, turning thus smart cities into an omnipresent, omniscient show, monopolized by such companies (Valverde & Flynn, 2018); thereby conceding immense social power to them.

As various researchers claim, although a smart city may as well be potentially sustainable, there can be smart cities proved to be unsustainable (Hollands, 2008; Hilty et al., 2014; Komninos et al., 2015), i.e., their contribution to urban sustainability is questionable (Colding & Barthel, 2017; Hollands, 2015; Mora et al., 2017; Yigitcanlar & Kamruzzaman, 2018); implying that the relation between smartness and sustainability is not necessarily bidirectional. As a matter of fact, a smart city can – but is not obliged to – be a city which is developed in a sustainable way (Lövehagen & Bondesson, 2013). This largely depends on the environmental footprint of implemented ICT applications, compared to the actual reduction of the environmental impact they achieve by improving other processes (Hilty et al., 2014). However, the concept of sustainability has been harshly blamed for remaining partly outdated as regards the needs and potential of the rapidly evolving digitalized society (Huovila et al., 2019).

According to the vast literature of the last two decades, the pros and cons of smartness and sustainability highlight that the significance of pursuing sustainability in the smart city context stems from a planning process which treats technology as a medium for steering interventions for the benefit of the environment, society, and economy. This perspective has given birth to the *smart sustainable city* (SSC) term (ITU, 2014a; Höjer & Wangel, 2015; Bifulco et al., 2016; Stratigea et al., 2017; Bibri & Krogstie, 2017; Yigitcanlar & Kamruzzaman, 2018; Akande et al., 2019; Panagiotopoulou et al., 2020). Conceptualized by the ITU's *Focus Group on Smart Sustainable Cities* (FG-SSC), the smart sustainable city is conceived as

> an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects. (ITU, 2014a, p. 13)

In reality, SSC is deemed to be a variant of the smart city notion that has the goal of sustainability at its core (Figure 2-2). At the same time, it fully embraces smart technologies and integrates urban sustainability and smartness into a broader conceptual framework (Stratigea et al., 2017; Panagiotopoulou et al., 2020). It, also, constitutes a *pivotal force* for effectively managing several urban functions in the highly connected, knowledge- and information-intensive 3rd millennium era. Additionally, SSCs seem to best serve UN's Sustainable Development Goals (SDGs), transcending thus smart cities' narrow-minded focus on smartness; and rendering the broader SSC concept an emerging sustainable urban development and planning paradigm in many cities around the globe, more suitable and preferable for policy formulation (Huovila et al., 2019).

Figure 2-2: Smart Sustainable Cities (SSC) – The Intersection of Two Distinct Planning Paradigms (Source: PricewaterhouseCoopers Private Limited [PwCPL], 2015)

The rising SSC concept appears to be more aligned with planners and decision makers' point of view. It perceives smartness as a pillar for crafting ICT-enabled policies, strategies and interventions with the ultimate goal of attaining sustainability objectives. Multidimensional targeting of sustainability alludes to the need for an integrated approach, adopted at both the planning and implementation stages of smart and sustainable strategies (PwCPL, 2015). Bearing, also, the diversified city contexts in mind, this approach should prioritize different dimensions of every city, in order to better adjust to city-specific requirements and challenges (Stratigea et al., 2017; Panagiotopoulou et al., 2020).

2.1.3. Inclusiveness as a Prerequisite for Smart City Development

During the almost twenty years of smart cities' appearance in the international scene and the recent advent of SSCs, a remarkable shift of the smart city meaning – from a plethora of complex information systems that boost the integration of urban infrastructure and services, to almost any form of technology-based innovation in support of cities' planning, development, and operation – is observed (Harrison & Donnelly, 2011). Particular attention is paid to public engagement and interaction among all actors of urban ecosystems (citizens, businesses, public administration, research institutions, NGOs, etc.) for setting up inclusive, efficacious and effective urban management and governance schemes. Nowadays, public participation has become inseparable part of the smart and sustainable city debate about searching and implementing city- and citizen-specific, ICT-enabled solutions to urban problems. This definitely redefines technology's role in urban management, i.e., treats technology as a tool for attaining specific societal targets, rather than an end in itself. Engagement emphasizes ICT-enabled citizens and stakeholders' participation for specifying and prioritizing urban targets and efficient resource management in problem-solving. Collaborative approaches for coping with urban issues and challenges appear to be a no longer optional, but an imperative choice (Nalbandian et al., 2013), largely supported by current technological developments that permeate all smart city domains (Coe et al., 2001; Lombardi et al., 2012; Stratigea et al., 2015; Lara et al., 2016; Bell, 2017; Panagiotopoulou & Stratigea, 2017).

The current understanding of city- and people-centered approaches that target smart and sustainable urban development and the necessity to engage all urban actors in searching for liveable future pathways, do not seem to go hand-in-hand with empirical evidence on public empowerment and engagement, an intriguing issue still unanswered (Paskaleva et al., 2017). The vital role that local and regional governments hold in rendering decision-making processes more inclusive is reaffirmed by the 2030 UN Agenda, which stresses the need for coordination among local governments and all stakeholders of urban ecosystems in order for global challenges to be met through properly addressed local responses (Wong, 2014; Simon et al., 2016). Localization of the 2030 UN Agenda actually is – apart from a technical roadmap of implementation at the local level – a political agenda that pushes forward urban actors' empowerment and downscales decision-making, data generation and elaboration as well as design and delivery of citizen-oriented solutions (Gómez-Álvarez et al., 2018). This not only would imply collecting various types of data, but also doing things differently and providing diverse sets of competences, empowerment and resources to different actors and administrations (Zait, 2017). Increasing the smartness of cities and people via ICTs can be of decisive importance in this respect. It boosts accessibility to information and allows local stakeholders to deepen their insight into urban functions, problems and possible ways to remediate them, etc. (Harrison & Donnelly, 2011), thereby strengthening inclusiveness as well as sense of belonging and community.

2.1.4. Embedding Resilience and Disaster Risk Reduction Considerations into the Smart City Realm

Complexity, uncertainty and unpredictability are nowadays prevailing features that affect, inter alia, the sustainable urban planning and policy agenda. This is justified by a wide variety of erratic, sudden or large-scale, turbulent events, such as disastrous climate incidents, terrorist attacks, political upheaval, mass migratory flows, etc.; and by changes that occur due to internal stresses and adversities, with no proportional or linear relationship between the cause and the effects (Davoudi et al., 2012). In such a volatile decision environment, sustainability, at the urban and regional level, seems to be strongly associated with building *resilience* and capabilities to cope with *disastrous events* and reduce inherent *risks*. In fact, resilience is deemed to be both a core component and an essential enabler of sustainable urban development. Therefore, being able to measure resilience can be a major contribution to urban environments' long-term sustainability (International Organization for Standardization [ISO], 2018b).

Resilience is a new buzzword in planning and policy making repertoire, closely related to – or even replacing in many cases – the concept of sustainability; and is tightly linked to concerns such as exposure, vulnerability, and capacity to recover (Davoudi et al., 2012; ISO, 2018b). Although it is conceptually vague and malleable (Brown, 2016), it constitutes a desirable end state for various systems, including the urban ones. As Davoudi et al. (2012) characteristically state, although being resilient is assumed to be good, a clear-cut definition of the term is not available yet. However, resilience is not a newly emerging concept. On the contrary, it is grounded in the field of ecology since the 1960s, along with the rise of systems' thinking; while it has recently acquired multiple meanings, depending on diverse views and scientific traditions. Several definitions that stem from different perspectives and disciplines are thoroughly discussed by numerous researchers, such as Davoudi et al. (2012), Pendall et al. (2010), Brunetta et al. (2019), Farhadi et al. (2022), to name but a few.

Two fundamental urban planning-related definitions of resilience are indicatively mentioned. The first one is introduced by Caldarice et al. (2019), who define urban resilience as a structural property of urban systems, tightly interwoven with their capacity to continually self-organising and adapting when confronted with unpredicted changes and risks, also perceived as "*a positive force to drive innovation, creativity, adaptation, and technological evolution"* (Caldarice et al., 2019, p. 2). The second definition is articulated in 2016 by the World Council on City Data (WCCD) in cooperation with the United Nations Office for Disaster Risk Reduction (UNDDR); and suggests that urban resilience is the capability of cities to prepare for, respond to, and recover from significant multi-hazard *threats* (including climate change and extreme weather, natural disasters, cyber security threats, and so on) with minimum damage to public safety and health, economy and security. Threats, as defined by various studies, can be either chronic stresses or acute shocks, with the latter linking resilience to Disaster Risk Reduction (DRR) (100 Resilient Cities, 2019). Therefore, building resilient communities, infrastructure, etc., is associated with: (i) effectively confronting persistent and ominous trends or the 'unexpected'; (ii) shifting from reactive to proactive action; and (iii) integrating disaster risk assessment, mapping and management into resilient and sustainable development planning. Moreover, resilience implies getting a deep insight into its various dimensions to be fully operationalized; and seeks to build up a systemic framework that integrates DRR and adaptation with mitigation, innovation and development (Caldarice et al., 2019). Effective operationalization of this vague term may transform urban resilience into a powerful tool and a key driver of change, capable of demarcating future sustainable development by re-engineering planning and design; managing modern urban settlements; and serving as a paradigm change, a governance model or a desirable state of being (Normandin et al., 2019).

Disaster risk assessment and resilience are exceptional candidates for their incorporation in the 2030 UN Agenda for sustainable development, given the past experience in the extent of damages and losses in cities, mainly due to climate change; the probable impact of disaster risks on sustainable development efforts; and the estimated increase in losses over the coming decades. In fact, in the *2030 UN Agenda* and particularly in the *Sendai Framework* 2015-2030 for DRR, a supportive tool for the achievement of 2030 SDGs, *resilience* and preparedness against future *disaster risks* are salient features. They are perceived as *core strategies* and *enablers* of sustainable development either directly or indirectly, that tackle issues such as poverty, hunger, healthy lives, education, sustainable water management, resilient infrastructure, climate change, and marine and terrestrial ecosystems (United Nations Office for Disaster Risk

Reduction [UNDRR], 2015). In this regard, currently aspirational global goals have taken a step forward, in comparison to their former counterparts (i.e., Millennium Development Goals – MDGs towards 2015), by incorporating DRR for building resilient future development perspectives; and promoting a rather proactive than reactive approach for dealing with contemporary threats. With reference to the urban context, Goal 11, par. 11b, p. 22 of the 2030 UN Agenda (United Nations [UN], 2015, p. 22) wishes to "substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, and resilience to disasters by 2020; while developing and implementing, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels". Furthermore, Goal 16, par. 16.7, p. 25 (UN, 2015, p. 25) prompts towards "responsive, inclusive, participatory and representative decision-making at all levels". On the other hand, the *Sendai Framework* for Disaster Risk Reduction stresses the states' role in reducing disaster risk and the necessity to share this responsibility with other stakeholders, including local government.

According to the above discussion, the contemporary key urban sustainability concerns with regard to the local and global level focus on the concepts of sustainability, smartness, resilience and inclusiveness, as these are reflected in current global policy documents (Figure 2-3).

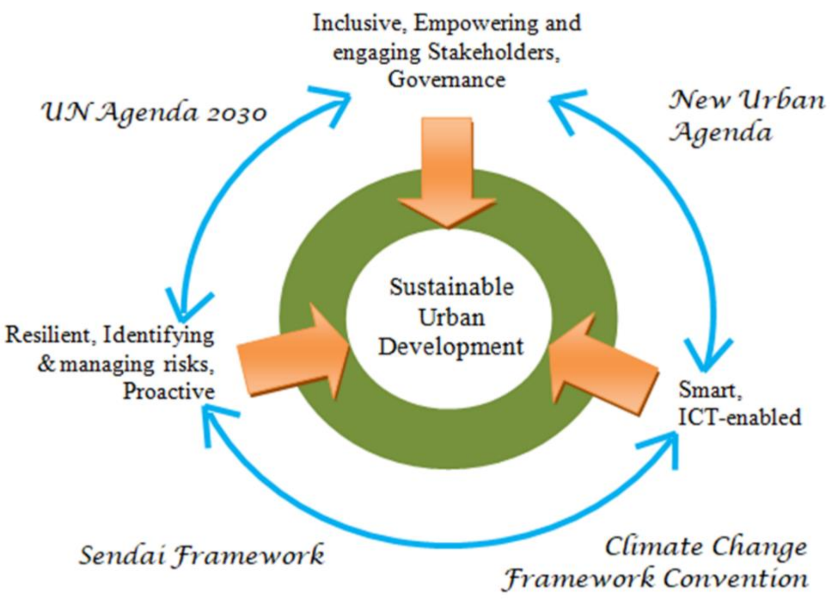

Figure 2-3: Contemporary Concerns of Sustainable Urban Development and Respective Global Policy Frameworks (Source: Panagiotopoulou et al., 2020)

Taking all the former discussion, the extended literature review as well as empirical findings and applications (related to smart cities) into consideration, a certain *revision / rethinking* of the smart city concept has been taking place, with the 'stiff', solely technocratic, technology-driven logic being gradually superseded by a more *holistic* and *integrated* approach to the pursuit of smart and sustainable developmental objectives. This transition is perfectly reflected in the coherent, human-centric definition introduced by Schaffers et al. (2012), which best fits to the planning perspective and is embraced by the present Dissertation:

> The smart city concept is multi-dimensional. It is a future scenario (what to achieve), even more it is an urban development strategy (how to achieve). It focuses on how Internet-related technologies enhance the lives of citizens. This should not be interpreted as drawing the smart city technology scenario. Rather, the smart city is how citizens are shaping the city in using this technology, and how citizens are enabled to do so. The smart city is about how people are empowered, through using technology, for contributing to urban change and realizing their ambitions. The smart city provides the conditions and resources for change. In this sense, the smart city is an urban laboratory, an urban innovation ecosystem, a living lab, an agent of change. Much less do we see a smart in terms of a ranking. This ranking is a moment in time, a superficial result of underlying changes, not the mechanism of transformation. The smart city is the engine of transformation, a generator of solutions for wicked problems; it is how the city is behaving smart. (Schaffers et al., 2012, p. 57)

2.2. A Comparative View of the 'Smart City' Definitions

In line with the aforementioned, it becomes obvious that smart city remains a highly *ambiguous, fuzzy* and *controversial* concept, a fact that is reflected in the absence of an operational definition and the lack of semantic interoperability, as a result of the *"divergence, lack of cohesion, and limited intellectual exchange"* (Mora et al., 2017, p. 11) among researchers and their *"tendency to follow personal trajectories in isolation from one another"* (Mora et al., 2017, p. 18). Most importantly, this definitional impreciseness stems from the very nature of cities, considering that they significantly distinct from each other in terms of their characteristics, peculiarities, needs, aspirations and the challenges they are confronted with (Irungbam, 2016).

Indeed, these divergences have led to a series of different methodological approaches as regards research development and implementation of smart initiatives. In their attempt to shed light on the various definitional streams of the smart city concept, Mora et al. (2018) have conducted a very interesting literature survey, via which they have managed to identify and analyse the links / interconnections among released smart city-related publications (from the beginning of 1992 till the end of 2012), on the basis of the references these cite. Their research findings focus on five distinctive development paths that emerge *"from the intellectual structure of the smart city research field"* (Mora et al., 2018, p. 409) and are briefly delineated below.

Experimental path – Smart cities as testbeds for IoT solutions

This is the broader path and places particular emphasis on the technological dimension of smart cities and more specifically on the importance of the interconnection of electronic devices of any kind through the new opportunities offered by the *Internet of Things* (IoT). Therefore, this development path interprets smart cities as innovative urban environments that serve as testbeds for emerging IoT technologies and pertinent applications, i.e., places where smart projects and solutions are implemented; while, at the same time, it is possible to analyse how these operate in the urban context and measure their potential impact under real circumstances. Santander, in Northern Spain, is the most well-known and representative smart city example of the experimental path, where a plethora of IoT devices have been installed. The 'Smart Santander' project – the city's strategy towards its digital transformation – starts in 2010 and aims at creating a unique, innovative, city-scale experimental facility, in support of research and development of smart applications and services relating to the IoT. The particular facility is developed in Europe's effort to gain leadership in cutting-edge IoT technologies, through the design and deployment of a single platform, consisting of sensors, activators, cameras, monitors and communication infrastructure, which is suitable for large-scale experimentations and evaluation of the IoT concept under real conditions (Sánchez et al., 2013; Tsarchopoulos, 2013). The users of the platform are *researchers*, who are given the opportunity to inspect data collection algorithms, various protocols, etc.; *service developers*, who have the chance to test their applications before these are made available on the market; and finally, *citizens* and *city authorities*, who utilize smart applications and reap all the benefits that emanate from the implementation of state-of-the art technologies. The smart initiatives launched in Santander include parking management, monitoring of urban environment (measurement of temperature, noise and CO_2 levels, etc.) and green spaces, participatory sensing, water supply, and augmented reality services and applications (SmartSantander, n.d.).

Ubiquitous path – The Korean experience of ubiquitous cities

The particular path treats the *smart* and *ubiquitous city* – *"the technical evolution of the knowledge-city concept"* (Mora et al., 2018, p. 412) – as equivalent terms. It perceives smart cities as innovative urban areas, equipped with ubiquitous technologies, that facilitate citizens and visitors' access to digital services from anywhere and at any time. In other words, they are deemed to be places *"with omnipresent information technology where all information systems are linked, and virtually everyone is connected to an information system through technologies such as wireless networking and radiofrequency identification (RFID) tags"* (Shin & Kim, 2010, p. 148). The national-scale project of the Republic of Korea (South Korea), launched in 2007 and focusing on the extended application of cross-cutting technologies in order to transform 53 cities into ubiquitous cities (u-cities) (Jang & Suh, 2010), is the most typical example of the ubiquitous development path. The project's long-term goal is to shape a *ubiquitous society* whose members can connect to the Internet and have access to digital services at any time and from any location (Shin, 2009). The programme has been heavily criticized for adopting an extremely rigid, concentrated, top-down approach that serves the interests of particular companies and industries by sacrificing the public welfare. Moreover, South Korean u-cities are 'accused' of falling *"short of the ontologically bounded accountability of serving as an information society"* (Shin, 2009, p. 516), since the main driving force behind industrial and economic prosperity has to do with constantly upgrading cities' technological equipment and increasing their technological capacity (Shin, 2009).

Corporate path – IBM and the corporate smart-city model

The corporate path considers the technological factor as the key driver for the development of smart cities. Yet, its scope is quite diversified, compared to the experimental and ubiquitous paths. According to the corporate path's philosophy, cities are deemed to be broad systems, composed of several individual sub-systems. The latter are accompanied with numerous inefficiencies that can be fairly addressed through the appropriate design, development and application of innovative platforms and high-tech solutions offered by ICT industries. Private companies invest in research and innovation either by setting up their own dedicated departments or by cooperating with universities and research institutions. IBM, the US multinational tech giant, constitutes a typical example of such companies. In addition to introducing its own operational definition, IBM has also launched a number of initiatives that have drastically influenced the international smart city research realm (e.g., Smarter Planet). Rio de Janeiro in Brazil is a typical case of smart city that adheres to the principles of the corporate path. After the devastating floods and landslides of 2010, the city, in collaboration with IBM, developed a data collection center and an emergency response system as part of the Smarter Planet initiative. The Rio Operation Center, inaugurated in 2010, constitutes an integrated system that collects real-time data through an extended network of cameras and sensors and processes these data streams with the assistance of analytical models, developed by IBM. The system has the ability to monitor and control traffic and public transport within the city, manage power outages, while its alarm system includes a range of digital means of communication (SMS, e-mail) to provide real-time information to citizens and visitors (Barrionuevo et al., 2012). In general lines, Rio Operation Center aims at providing a holistic / integrated picture of the city's current state at any time, but also predicting emergency situations. Nevertheless, this project has been condemned for its persistent focus on citizens' monitoring; the absence of the local community's participation in the implementation of the project; and its strict technocratic approach, which – in many cases – significantly sidelines the social and human dimensions.

European path – Smart city for a low-carbon economy

Urban areas are spatial entities where the highest energy consumption, pollutant emissions and waste generation occur. The particular development path considers cities' environmental footprint as a dominant and extremely pressing contemporary problem; and perceives their struggle to become smart as a direction directly linked to their effort towards transforming their infrastructure and operations into environmentally-friendly ones, while using natural resources in a rational and responsible way. This effort is inextricably associated with the concept of *urban sustainability* that appears in the 1970s (Trindade et al., 2017). ICTs enable authorities, at local and national level, to gain an immediate and deep insight into the environmental conditions of urban settlements, but also to efficaciously manage their systems, setting environmental sustainability as a top priority at the same time. The link between the development of urban systems and the reduction of pollution (especially the reduction of CO_2 emissions), has become pretty evident in the light of new data and forecasts on climate change and the way it may affect human activities.

Holistic path – Digital, intelligent, smart

This path focuses on the need for the various smart city actors (human, social, cultural, environmental, economic and technological) to be treated as equals. Deployed ICTs are first and foremost meant to serve the economic, environmental and social requirements and aspirations of every given area. Furthermore, the strategies / initiatives that target the development and application of the smart city paradigm have citizens' participation in all stages of the planning, implementation and management process at their core. The main differences between the holistic path and the former four are closely associated with the way the latter is implemented, since it adopts an agile, decentralised, bottom-up philosophy, but also a more people-centric approach.

2.3. Conceptual Relatives of the Smart City Paradigm

Although the *smart city* and *smart community* terms have sporadically started to appear since the early 1990s (Nam & Pardo, 2011), they begin to take the world by storm in 2010 when the European Union adopts them in its effort to evaluate the implementation of sustainability programs in urban areas (Dameri & Cocchia, 2013). Moreover, a multiplicity of adjectives used as variations of the term 'smart', such as wired, broadband, digital, networked, intelligent, etc., are met in the literature (Dutton et al., 1987; Castells, 1996; Graham & Marvin, 1996; Droege, 1997; Keenan & Trotter, 1999; Coe et al., 2001; Ishida, 2002; Komninos, 2002, 2006, 2009; Steventon & Wright, 2006; Shin, 2009; etc.). These *alternative smart city forms* (Figure 2-4 and Table 2-1) have been interchangeably used by researchers and academics, thereby further exacerbating the dearth of definitional clarity of the smart city term (Talamo et al., 2019). However, despite their conceptual gaps, they all imply communities that make *"a conscious effort to understand changes and engage in a world that is increasingly connected"* (Albert et al., 2009, p. 8).

The *digital city* concept precedes the smart city notion and is conceived during the early 1990s, when a massive effort to embed Internet technologies in everyday activities and in every aspect of urban life is observed (Ishida, 2002). The main idea behind the digital city concept revolves around the formation and provision of a virtual environment, in which ICTs possess the central role, in order to substantially improve quality of life via the delivery of innovative e-services (Anthopoulos et al., 2012). According to Yovanof &

Hazapis (2009), digital cities refer to *connected communities* that are predominantly based on broadband connectivity, upgraded communications infrastructure and flexible, open, service-oriented computing infrastructure, that intend to meet the needs and aspirations of decision makers, citizens and businesses. The primary goal of the digital city is to provide a breeding ground for the rapid transmission and exchange of information, and the flourishing collaboration among authorities, businesses and citizens.

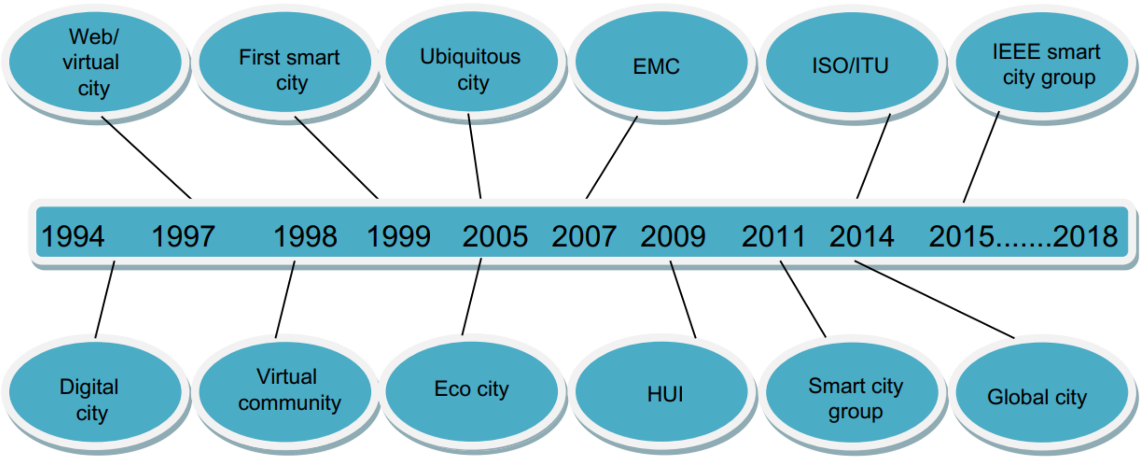

Figure 2-4: The Evolution of Smart Cities (Source: Das et al., 2019)

The *ubiquitous city* (u-city) can be perceived as a branch / continuance of the digital or information city (Lee et al., 2014). The word 'ubiquitous' is borrowed from Weiser (1991), who proposes the idea of ubiquitous computing and is used to describe an *"environment where users can connect to computer or network without being aware of them"* (Jang & Suh, 2010, p. 262) at any time and from any place. It is mainly associated with cities' pursuit of economic prosperity via the interconnection and communication of public authorities / governments, citizens and businesses. As already mentioned, the u-city is founded on the idea of ubiquitous computing, which implies the deployment of an extended network of digital devices (sensors, cameras, computer chips, etc.) throughout the city for directly and effectively satisfying everyday needs. It is, therefore, a technocratic approach exclusively oriented towards the integration of technology – and of the latest IT infrastructure and information services in particular – into the urban space (Shin, 2009).

Table 2-1: Smart City's Conceptual Relatives and the Definitions thereof

Term	Definition
Digital City	The concept of Digital City is to build an arena in which people in regional communities can interact and share knowledge, experiences, and mutual interests. Digital cities integrate urban information (both achievable and real time) and create public spaces in the Internet for people living / visiting the cities (Ishida, 2002, p. 76).
Ubiquitous City	The 'ubiquitous city' has been understood a further extension of the digital or information city in making data ubiquitously available through an embedded urban infrastructure (e.g., through equipment embedded in streets, bridges and buildings) (Lee et al., 2014, p. 81).
Virtual City	Virtual cities can be considered an innovative tool and a modern development interface that serves urban design, planning, development and urban management as a basis for urban analysis and simulation by producing proactive three-dimensional models of cities and urban projects, which helps designers, specialists and decision makers in the early stages in analyzing and evaluating development interventions before implementing them, which reduces the pros and cons of the projects (Karbol & Al-Saadi, 2021, p. 1376).
Wired City	The wired city refers to a vision that arose in the 1970s and led to funding for concrete experiments. The vision was a forecast of how technical advances in cable television could be utilized to make all kinds of electronic communication services available to households and businesses in local communities (Dutton, 2019, p. 1).
Cyber City	Cybercities are cities that leverage modern information technology to better deliver services to their residents … any city that systematically integrates innovative modern information technology in its overall functionality to more efficiently and optimally manage its critical infrastructure would be a cybercity (Oludare & Jokwi, 2018).
Informational City	The informational city is the spatial expression of a new form of social organization that is made up of technology, cultural information, and social information as well as their interaction (Castells, 1991, p. 1).
Knowledge City	Knowledge Cities are cities that possess an economy driven by high value-added exports created through research, technology, and brainpower. In other words, these are cities in which both the private and the public sectors value knowledge, nurture knowledge, spend money on supporting knowledge dissemination and discovery (i.e., learning and innovation) and harness knowledge to create products and services that add value and create wealth (Carrillo, 2005, p. 1).
Instrumented City	The instrumented city offers the promise of an objectively measured, real-time analysis of urban life and infrastructure (Kitchin, 2014, p. 5).
Intelligent City	Intelligent cities and regions are territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management (Komninos, 2006, p. 13).
Green City	The Green City is a city, where all forms of nature – living organisms, biocoenosis, and their habitats – are highly significant components of green infrastructure. In a Green City, these forms of nature are preserved, maintained, and extended for the benefit of city residents. Urban nature is an ideal provider of services, and a key concept for city development (Breuste, 2020, p. 2).
Low Carbon City	A low carbon city is defined as a city that implements low carbon strategies to meet the environmental, social and economic needs of the city. The city measures, manages and mitigates greenhouse gas emissions to reduce its contribution to climate change (Green Technology Application for the Development of Low Carbon Cities [GTALCC], 2021, p. 39).

Virtual city is intertwined with the concept of *cyberspace*. It describes a city that relies on the creation of virtual representations of the entities that appear in it, while it enables real entities to interact with virtual ones, irrespective of the spatial or temporal dimensions as well as the differences between them. Virtual entities bear the characteristics and information of real entities to a degree and scale that depends on the requirements of the application and the capability of the computer storage systems. Consequently, two forms of the same entities coexist within the city, the real and the virtual ones. City services, citizens, the structures that connect them and every urban element have to some extent a virtual footprint, which ensures easier and faster flow of information and data. The concepts of the virtual and digital city are closely related, as the latter is often used to describe digital representations of the physical features of a real or a fictional city (Schuler, 2002).

The vision of *wired cities* emerges in the late 1970s (Dutton et al., 1987) and is strongly associated with the possibility of interconnecting all the different elements of a city. *Interconnectivity* lies at the heart of this term, but, as Hollands (2008) claims, this is not a necessary and sufficient condition to qualify an urban environment as a smart one.

The *cybercity* term is traced to the late 1990s and has been widely used due to the drastic changes induced by the application of the Internet and telecommunications in the city, as it allowed economic and social activities to take place at a distance, a phenomenon aptly described as the *'collapse of distance'* (Graham & Marvin, 1999, p. 91).

Informational city is coined by Manuel Castells (1991, 1996) in his effort to describe the contemporary city as the meeting point of three convergent processes, i.e., the late capitalistic restructuring towards more flexible organizational forms; the constantly growing centralized pattern of production and information management in modern societies; and the radical advancements of information technologies that have been drastically reshaping and redefining the spatiotemporal aspects of the urban landscape. The main characteristics of the informational city are related to *flexibility*, *social polarization* and *fragmentation*.

Knowledge city implies an urban development strategy that intends to strengthen and support *knowledge management* and *dissemination* processes. In order for this goal to be fulfilled, interaction and cooperation between the city's authorities and social groups on one hand and the knowledge-related bodies (universities, institutes, research centers, private companies or individuals) on the other, is absolutely essential. The degree of success of these interactions relies on the city's strategy, its infrastructure (physical and digital) and the educational level of its population. In summation, knowledge cities are highly innovative, urban environments that: (i) possess substantial intellectual capital; (ii) systematically encourage knowledge creation and dissemination as well as learning processes; (iii) are founded on knowledge-driven economy; and (iv) foster intensive cooperation among all urban stakeholders (public and private sector, universities, institutes, citizens, etc.) (Carrillo, 2005; Cigu, 2015). It becomes apparent that the smart city concept includes the notion of knowledge city, as it is directly linked to research and innovation, but also to citizens' education and lifelong learning.

The *instrumented city* heavily relies on ICTs and focuses particularly on the integration of measurement systems into physical objects. These systems offer the possibility of generating and collecting real-time data regarding various urban characteristics. Therefore, cities are deemed to be a broad set of diverse system configurations, which are interconnected through multiple networks and provide continuous flows of data about the movement of people and goods, as well as about the state of urban infrastructure (e.g., buildings) and systems (Kitchin, 2014). Instrumented cities are closely related to the concept of *big data*, but also to the vision of performing real-time, objective analyses on the quality of life and the state of cities' infrastructure, based on unbiased measurements.

The *intelligent city* is grasped as the intersection of the digital city and the knowledge society. It is a vivid urban environment, shaped by a society that places great significance on the development of knowledge and creativity of its population; it considers human capital as its most important asset; while it possesses state-of-the-art communication and information infrastructure. The difference between intelligent and digital cities is rooted in the fact that an intelligent city takes into account citizens' skills and capabilities, but also its ability to support knowledge transmission and dissemination, technological development and promotion of innovation (Nam & Pardo, 2011). In this sense, it can be asserted that not every digital city is an intelligent one, but every intelligent city has elements of a digital city (Albino et al., 2015). According to Komninos (2011a), intelligent city initiatives make conscious efforts towards using ICTs to transform life and work within the area they are applied in a substantial and fundamental way (Albino et al, 2015). Although the definition of intelligent cities includes the human and social factors, its scope appears to be quite limited, compared to the extent that these elements are embraced by the various smart city definitions (Albino et al., 2015).

Green cities often appear as a complementary concept to smart cities and refer to urban environments that are "in balance with nature" (Breuste, 2020, p. 1). More particularly, the meaning of the term revolves around the necessary urban green spaces to ensure a high-quality and healthy life for its inhabitants. However, the almost unlimited possibilities that stem from the rapid technological advancements and modern, dominant planning approaches have further developed and enriched the conceptual depth of green cities, which, nowadays, incorporate complex ways and methodologies of linking the natural with the human-made environment within the city, rather than simply focusing on land use designation.

The *low carbon city* emerges after the first reflections on climate change and the ways in which humanity can reduce air pollutant emissions (especially CO_2 emissions). In general lines, low carbon cities constitute a sustainable urban development approach that targets the reduction of cities' anthropogenic carbon footprint. They promote the notion of low carbon economy and society, while encouraging the establishment of partnerships and coalitions among public authorities, private companies and civil society (Ismaila Rimi & Yakubu Aliyu, 2019). Furthermore, low carbon cities are closely associated with *smart compact urban growth* and *accessibility* (Broekhoff et al., 2018).

According to Nam and Pardo (2011), the conceptual relatives of the smart city term are classified under three broad categories – *technology*, *people*, and *community* (Figure 2-5) – depending on the orientation of their meaning and the pillar / key dimension they place emphasis on.

Figure 2-5: Conceptual Relatives of the Smart City (Source: Adapted from Nam & Pardo, 2011; Singh et al., 2022)

An additional categorization of the abovementioned conceptual relatives is possible, on the basis of their definition’s scope and their connection to the smart city concept. Therefore, two main groups can be distinguished.

The first group comprises those definitions that refer to a part or a specific characteristic of the smart city (e.g., knowledge or instrumented city). Such terms appear quite frequently in the literature due to the fact that every city has its own peculiarities and thus requires ‘customized’ reforms that are particularly focused on specific areas. Chicago is a pretty representative example of this category. The city launched in 2008 a coherent strategy for the overall environmental upgrading of the city center and substantial reduction of carbon emissions, an approach really close to the rationale of the green city (Boak, 2008).

The second group consists of definitions that adopt a more holistic approach and describe the overall developmental direction / trajectory of the city and its interconnection with technology. In such a context, it could be argued that the digital city gives way to the ubiquitous city (Anthopoulos & Fitsilis, 2010), the ubiquitous city gives way to the intelligent city and ultimately, the intelligent city gives way to the smart city (Deakin & Al Waer, 2011). It should be noted that each definition is heavily influenced by the technological advancements, the current, urban, socio-economic ‘regime’, and the shortcomings of implemented strategies. Amsterdam and Bristol fall under the specific category. These cities have been frontrunners in ‘going digital’ endeavors (Amsterdam is the first digital city in Europe); while today they are also pioneers in the smart city realm. This does not, by any means, imply that a tech-based urban system is defined differently in each period, but that it requires a continuous effort to integrate new technologies and align with new strategic directions, i.e., upgrade of its digital features to meet contemporary problems and current standards imposed by the smart city paradigm (Aurigi et al., 2016).

Finally, it should be highlighted that in spite of all the differences on the way the above terms are used, they appear to have a common basis, formed by three cornerstones (Stratigea, 2012): (i) the *communication means* (network infrastructure – ICTs); (ii) the *process* (networking among actors); and (iii) the *goal* pursued (public involvement or other).

2.4. Dissecting the Smart City Concept

The thorough exploration of the wide spectrum of smart city definitions, articulated from time to time, leads to the conclusion that despite the observed slight or more intense discrepancies, the vast majority thereof seem to share several common characteristics, which can describe the smartness of a city and, thus, demarcate the smart city concept. In this respect, smart cities can be perceived as establishments built upon three fundamental *dimensions* (technological, human and institutional), six broadly acknowledged *characteristics* (smart economy, smart environment, smart mobility, smart people, smart living and smart governance), and numerous *domains* that represent various urban functions and services (Figure 2-6). These smart city building blocks are briefly delineated in the following sub-sections.

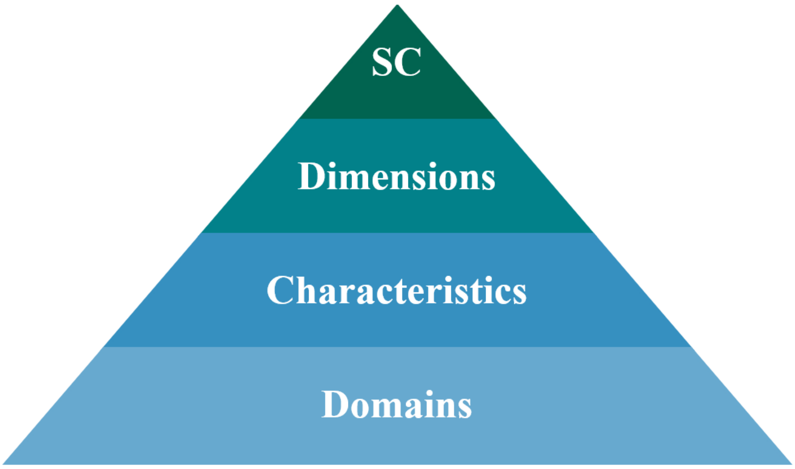

Figure 2-6: Breaking Down the Smart City Concept (Source: Own Elaboration)

2.4.1. Fundamental Dimensions of the Smart City Concept

Despite the undisputed *definitional pluralism*, but also the diversity of the cities themselves in terms of their geographic, climatic, economic, social, political and cultural aspects, a considerable share of researchers describe the smart city as a multilevel territorial innovation ecosystem (Komninos, 2006, 2008), where three distinct dimensions / streams (Figure 2-7) – *technological*, *human*, and *institutional* – converge (Nam & Pardo, 2011; Chourabi et al., 2012; Gil & Navarro, 2013; Roca, 2014; Meijer & Bolívar, 2015; Marava et al. 2018; etc.) serving thus the objective of *"adapting the city to the user needs and providing customized interfaces"* (Nam & Pardo, 2011, p. 283).

The *technological* or the *hard dimension* (Zait, 2017) refers to the necessary infrastructure that forms the backbone of contemporary urban environments and facilitates the implementation of smart city initiatives. This entails the adoption of state-of-the-art and emerging technologies, which are perceived as *enablers* of cities' transformation into more intelligent, interconnected, innovative and sustainable urban spaces (Dirks et al., 2009; Komninos, 2011a); while they also enhance real time awareness and advanced analytics, leading thus to more responsible and well-informed decisions (Washburn et al., 2010). Although the technological dimension has been over-emphasized in several studies (Keeling & Mooney, 2011; Zhuhadar et al., 2017; etc.), especially in the past, it is pretty clear today that this is a necessary but not, under any circumstances, a sufficient condition for a city to become smart. Nonetheless, despite the fact that the particular dimension has received severe criticism regarding its *'technological determinism'* (Castelnovo et al., 2015, p. 5), the pivotal role of digital technologies and the huge potential these can offer towards more informed, data-intensive and efficient urban policy making, have been greatly acknowledged.

The *human dimension* or the *soft component* of a smart city (Zait, 2017) concerns the cognitive and creative capacity and the skills of local population, that constitutes the *human infrastructure* upon which the development of a smart city is based. This key attribute is largely related to continuous learning processes and embedded networked intelligence. The human dimension presupposes a highly qualified and intellectual social capital, capable of using ICT infrastructure, supporting this way cities' transformation into smart, creative, inclusive and innovative places (Albino et al., 2015; Zait, 2017).

The *institutional dimension* promotes more integrated, collaborative and inclusive approaches for addressing social and entrepreneurial needs, by defining the framework (governance, policies and regulations) that boosts and enhances the interaction and partnerships' creation among citizens, organizations and governmental institutions. According to this dimension, a smart city is the product of *cooperative stakeholders' efforts*, collaborating in partnerships of different shapes and forms, in order to create value via collective planning, implementation, monitoring and assessment of city- and citizen-specific smart initiatives, policies, programs, etc. (Stratigea et al., 2015; Marava et al., 2018).

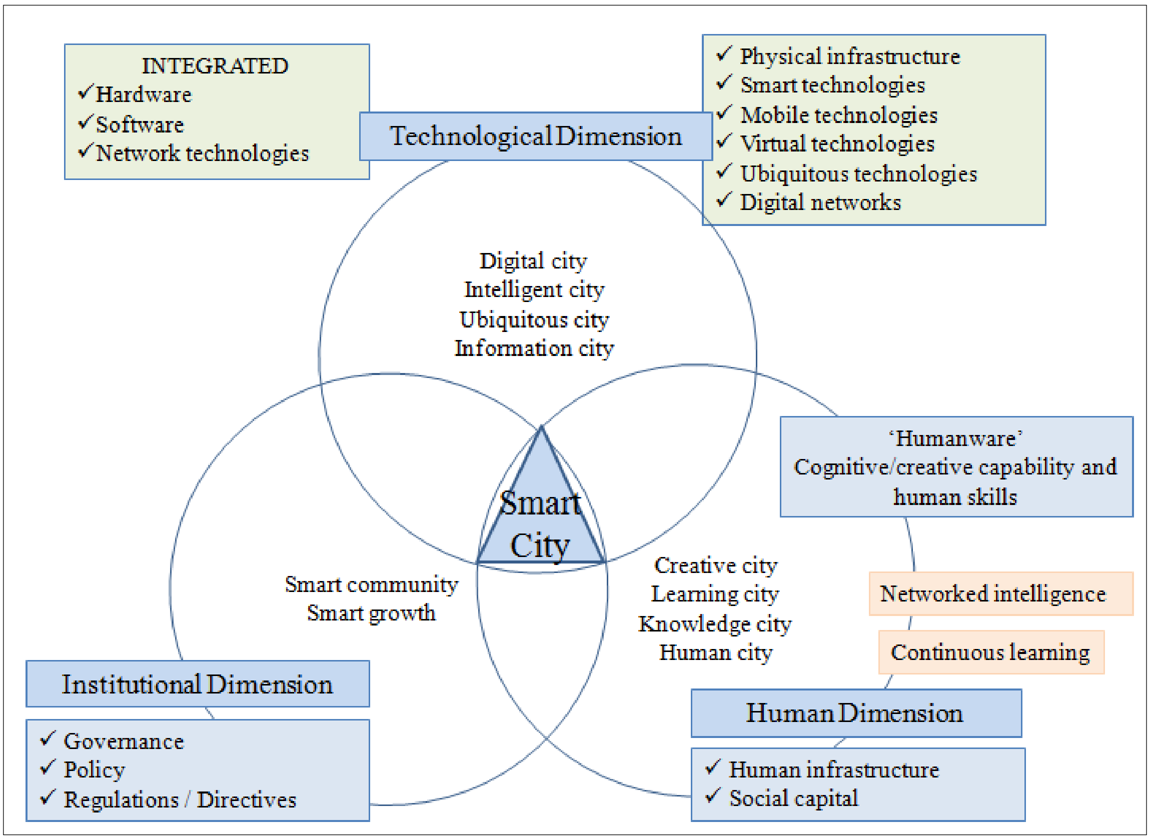

Figure 2-7: The Core Dimensions of Smart Cities (Source: Adapted from Nam & Pardo, 2011)

2.4.2. Foundational Characteristics of the Smart City Concept

The adherence to the smart city paradigm entails the launch of various smart initiatives that significantly differ from each other. However, many of them share several commonalities as far as the scope, the focus areas, the engaged participants, etc. are concerned (Manville et al., 2014). Smart initiatives, in turn, take shape through the application of smart projects that exclusively seek to achieve a specific outcome, attaining this way the initiatives' ultimate goal.

The absence of an integrated city vision constitutes a critical obstruction to the proper selection and implementation of strategic directions and their relevant programmes. Industries, companies and institutes often seem to be detached from the urban reality and choose to follow their own individual trajectories or focus solely on technological factors, defying at the same time critical aspects that form cities' backbone. Such a 'discordance' can easily mislead a city and distract it from the real goals, objectives, and needs of other interested parties or from goals that serve its economic, social and physical status quo (place-specific strategic directions and choices) (Dameri, 2013). Therefore, the 'smart' concept does not always approach the city in a holistic way. Conversely, it may sometimes adopt a quite fragmentary view by focusing on individual urban characteristics (Albino et al., 2015), thereby losing the chance to grasp the bigger picture. This is due to the fact that actual smart cities differ from ideal ones, since they are better described as a *process of change* and *reform*, rather than as an outcome (Manville et al., 2014).

The aforementioned urban individual characteristics appear in various forms and are associated with different elements (objectives, patterns of roles and relations, policy instruments and implementation methods) in the available literature (Manville et al., 2014). This is justified by the diversified approaches of their authors and the time period these are articulated.

The following sub-sections succinctly delineate the fundamental characteristics / dimensions of a smart city, as these are elaborated and proposed by Giffinger et al. (2007). According to them, six characteristics (smart economy, smart mobility, smart environment, smart people, smart living and smart governance) are identified as a basis for the demarcation and the further analysis of the smart city concept (Figure 2-8).

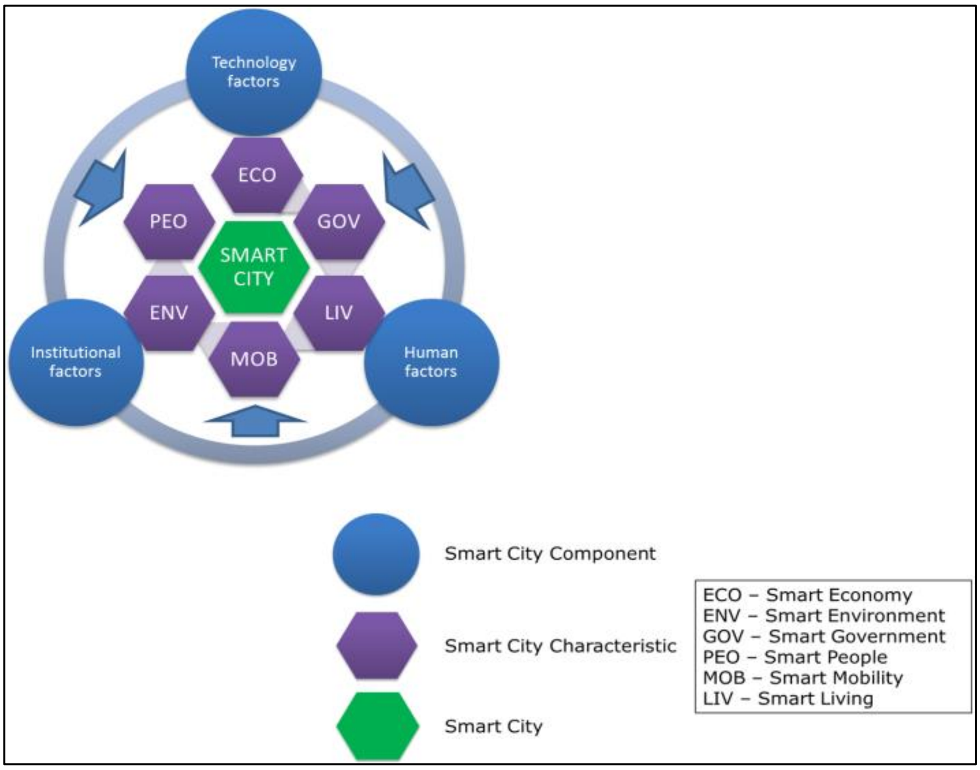

Figure 2-8: Dimensions / Factors and Characteristics of Smart Cities (Source: Manville et al., 2014)

Moreover, the most cited fields of activity met in the literature and related to the smart city term, such as *"industry, education, participation, technical infrastructure and various soft factors"* (Giffinger et al., 2007, p. 10) are taken into consideration. It is worth mentioning that the work of Giffinger et al. "Smart Cities: Ranking of European Medium-Sized Cities" (2007) has influenced a great portion of conducted smart city-oriented research. Furthermore, the suggested six key characteristics appear pretty very often in European policy documents, acting as an *organizational instrument* that "can see the city's current state to identify areas that need special attention for its development" (Singh et al., 2022, p. 68322); but also, as an *assessment tool*, since they form the foundations for the creation of smart city evaluation systems.

Lastly, it should be stressed at this point that the proposed set of smart city characteristics entails the adoption of *multidimensional* strategies that underpin the creation of synergies among them; while diminishing the adverse ramifications that may arise due to alterations / interventions in one characteristic, which, in turn, may cause negative effects to another (Manville et al., 2014). For instance, an initiative that focuses on smart economy should be checked for possible pressures it might exert on the natural environment.

Smart economy

Smart economy implies the 'migration' of businesses and economic practices from the physical to the digital world (e-business, e-commerce), accompanied with ICT-enabled innovation, increased productivity and quality of provided services, boosted national and international embeddedness, labor market flexibility, healthy entrepreneurship, but also with the design and development of technologically advanced products and services (see Figure 2-9) (Manville et al., 2014; Gupta et al., 2017; Singh et al., 2022). Moreover, smart economy is directly linked to the foundation of *smart ecosystems* and *clusters*, to local and international *interconnectivity*, and to the integration of digital elements into the flows of products, services and knowledge (Manville et al., 2014). The need for an urban system to be aware of its comparative advantages in order to craft a clear and effective strategy for its development is deemed to be of paramount significance. At the same time, in the context of the information era, innovation and knowledge production and reproduction have grown in importance due to the rapid increase in global information flows in the fields of economy, culture, environment, etc. (Vinod Kumar & Dahiya, 2017).

Figure 2-9: Smart Economy Fundamentals (Source: Vinod Kumar, 2015)

Smart mobility

Smart mobility refers to the level of local and supra-local accessibility as well as to the integration of ICTs into transport and logistics systems. It aims at rendering transport / mobility more efficacious, environmentally friendly, and as little reliant on motorized options as possible (Figure 2-10). Its goal is to create a safe, sustainable, interconnected, multimodal system, which effectively combines all available means to provide upgraded services, reduce average commuting time, travelling costs and CO_2 emissions (Manville et al., 2014). The concept of smart mobility is strongly associated with *compact cities* and *smart growth*, two quite critical factors for the development of the former, as the latter are described as "terms that have gained currency in the field of urban planning for describing urban development that is compact, resource-efficient and less dependent on the use of private cars" (United Nations Human Settlements Programme [UN-Habitat], 2013, p. 88).

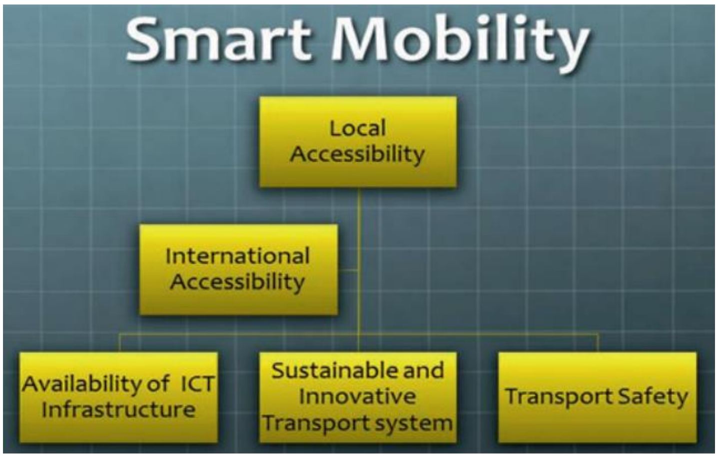

Figure 2-10: Smart Mobility Fundamentals (Source: Vinod Kumar, 2015)

Smart environment

Smart environment includes the natural resources of a city as well as the services that manage them (e.g., energy, electricity, lighting and water supply networks, sewage systems and green spaces) (Manville et al., 2014). The concept of the smart environment appears during the early 2000s and is closely linked to the emerging opportunities of ubiquitous computing. ICTs enable the continuous monitoring of key parameters for more efficient management and operation of urban networks and infrastructure. Its ultimate goal is to secure environmental protection, ensure sustainable resource management, diminish pollution levels, and increase the quality of offered services with the help of cross-cutting technologies and various innovations (see also Figure 2-11) (Gupta et al., 2017; Singh et al., 2022).

Figure 2-11: Smart Environments Fundamentals (Source: Salleh et al., 2022)

Smart people

The *smart people* dimension describes citizens' e-skills, their ability to access education, learning and training structures, and their opportunities to work in ICT-related fields, while living in a vivid urban environment that promotes creativity, innovation and active participation (Figure 2-12) (Manville et al., 2014; Gupta et al., 2017). People – the *human capital* – play a pivotal role in cities' going smart efforts, since they are both the *producers* and *consumers* (*prosumers*) of smart applications and services. Moreover, their importance is further amplified considering the fact that, apart from being responsible for the proper education, training and adaptation (to changes of any kind) of their residents, smart cities should also act as poles of attraction for high-skilled and well-educated human capital (Meijer & Bolívar, 2016).

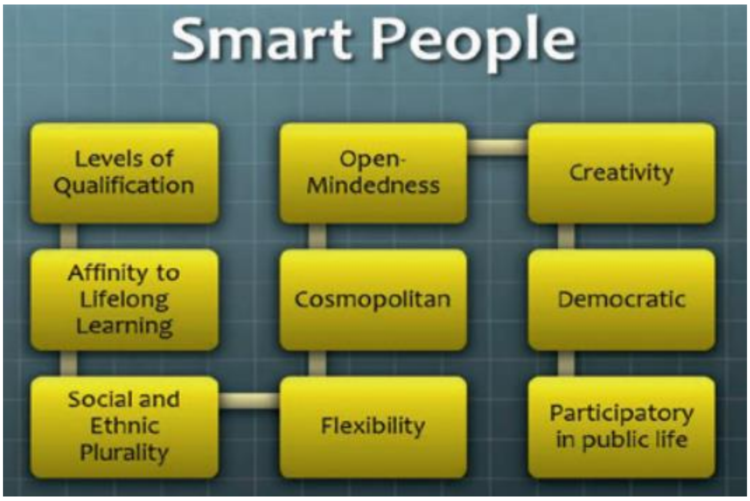

Figure 2-12: Smart People Fundamentals (Source: Vinod Kumar, 2015)

Smart living

Smart living envisages a safe, healthy and inclusive lifestyle within a multicultural city, where the integration of ICTs contributes to the improvement of housing quality, while it also instigates drastic alterations to citizens' behavioral and consumption patterns (Figure 2-13). In other words, it assists in upgrading human living standards by incorporating innovative applications and systems that fundamentally change the way of life. However, smart living is not a narrow-defined term that focuses exclusively on housing-dedicated applications, in the sense that it should not be considered identical to the transformation of the building stock into smart buildings and smart housing. On the contrary, its meaning goes far beyond this view and extends to the exploitation and development of social capital and to high levels of social cohesion, recognizing that people are social beings and that their very existence constitutes a collective matter (Manville et al., 2014). *Multiculturalism* and *social cohesion* are perceived to be key issues for smart cities. Amsterdam, a smart city frontrunner at the international level, is among the pioneers to have adopted a strategic approach in this direction since 2009 by implementing a series of policies and practices to render diversity and tight social relations the city's developmental levers (European Commission, 2011).

Figure 2-13: Smart Living Fundamentals (Source: Vinod Kumar, 2015)

Smart governance

Smart governance describes the "joined up within-city and across-city governance, including services and interactions which link and, where relevant, integrate public, private, civil and European Community organizations so the city can function efficiently and effectively as one organism" (Manville et al., 2014, p. 28). The term alludes to the (i) interconnection, integration and interaction among public authorities, the private sector and the civil society; and (ii) delivery of highly innovative public services by leveraging novel technologies to develop advanced digital tools for information provision, establishment of communication channels and promotion of dialogue among urban actors (Talamo et al., 2019). ICTs lie at the heart of this dimension, as they allow for easier interconnection of interested parties, while they also establish smarter process schemes and easier data collection procedures. Smooth, uninterrupted and faster connectivity promotes and facilitates the incorporation of stakeholders' participation (citizens, businesses, etc.) in all the stages of the planning process, thereby increasing the degree of information provision and interaction potential (Evans-Cowley & Manta Conroy, 2006; Stratigea et al., 2015; Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018). *Transparency*, *free access* to data, *e-governance* and *(e-)participation* in decision-making are deemed to be the fundamental constituents of smart governance (Figure 2-14) (Gupta et al., 2017).

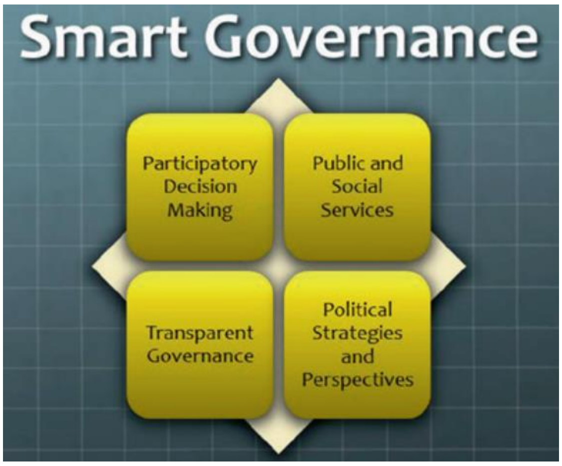

Figure 2-14: Smart Governance Fundamentals (Source: Vinod Kumar, 2015)

2.4.3. Smart City Domains

Smart city fundamental characteristics can be further classified into a number of domains that correspond to basic urban sub-systems – totally essential for cities' functioning – such as energy, transportation, water, health, safety, etc. Pursuant to a considerable share of the available literature, the proposed domains reflect areas of investigation of possible IoT and Big Data applications in order to "optimize and innovate the current management models both at the strategic and at the operative levels" (Talamo et al., 2019, p. 8). The most critical smart city domains refer to buildings and infrastructure, energy, governance, healthcare, mobility, environment, safety and security, etc. (Figure 2-15).

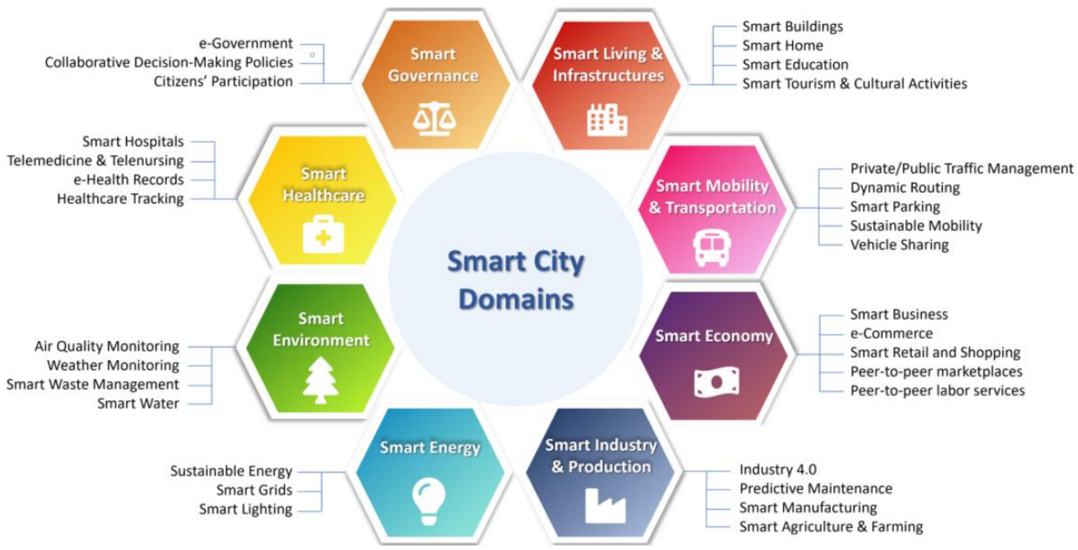

Figure 2-15: Indicative Smart City Domains and Possible Application Areas (Source: Bellini et al., 2022)

2.5. Success Factors for Selecting and Implementing Smart City Initiatives

As already analysed in the previous section, smart city characteristics fall under three fundamental dimensions, i.e., technology, human capital and institutions, that reflect three very broad focus areas of smart cities. However, such a rough classification prevents urban actors from comprehending and elaborating on the steps needed for developing a smart city and, more specifically, those required to identify the domains of interest for bringing the smart city vision to life.

Smart city strategies involve a wide spectrum of initiatives with different orientation, field of interventions, participants, time horizon, etc., which, in turn, translate into specific projects for their implementation (Figure 2-16).

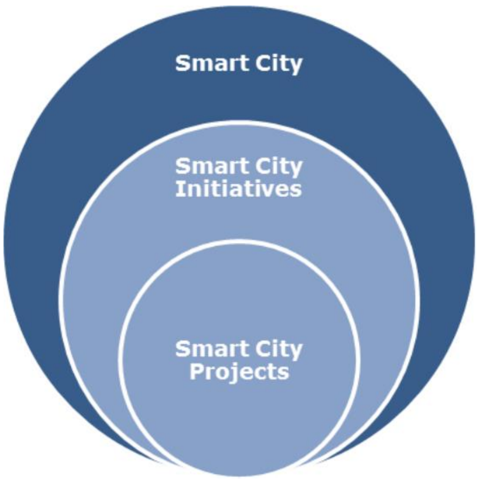

Figure 2-16: Relationships among Smart City Strategies, Smart City Initiatives, and Smart City Projects (Source: Manville et al., 2014)

Cities, as nodes of international and national urban networks, are physically and digitally connected to other urban systems. The relationships developed within these networks should be taken into serious consideration when selecting initiatives and crafting relevant implementation policies at the local level, as the former directly determine the effectiveness of the latter (Kourtit & Nijkamp, 2012).

Chourabi et al. (2012) propose a comprehensive set of eight factors that can be used to understand smart city initiatives and projects; and guide interested parties towards selecting the most appropriate ones, on the basis of every single urban context. Figure 2-17 presents a graphic representation of these factors, as well as their different degree of influence, considering that some of them are more influential than the rest. More particularly, the proposed factors refer to (Chourabi et al., 2012):

- management and organization;
- technology;
- governance;
- policy context;
- people and communities;
- economy;
- built infrastructure; and
- natural environment.

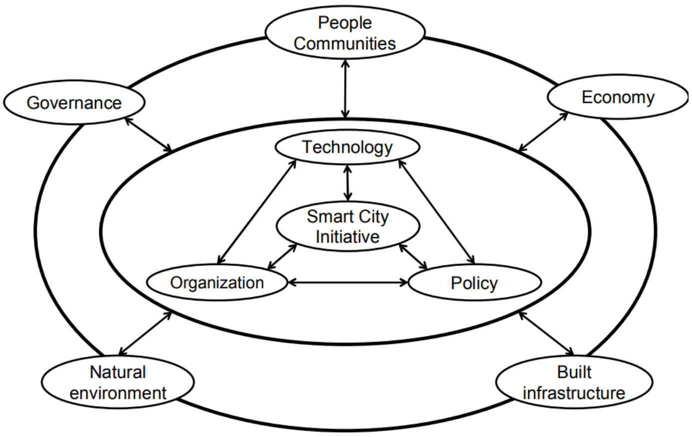

Figure 2-17: Success Factors of Smart City Initiatives (Source: Chourabi et al., 2012)

2.5.1. Management and Organization

The particular factor is related to the obstacles and challenges that arise during the implementation phase of smart city initiatives. Managerial and organizational issues of smart city projects are really critical, given their close bond with both ICT and city governance schemes. The degree of success of smart city projects, as far as the management and organization aspect is concerned, relies on the severity and handling of emerging problems, such as: size of the project; project managers' attitude and behavior; diversity of users and/or organizational structures; harmonization gap between project's objectives and organizational goals; possible resistance to change; and potential conflicts (Chourabi et al., 2012).

2.5.2. Technology

A smart city is primarily based on the application of a multitude of smart computing technologies to its critical infrastructure. The technological factor explores the availability and implementation of ICTs to smart projects' fields and domains. These technologies enable the collection and overall management of real-time data, which immensely contribute to the reliability of urban functions and support more effective and informed decision-making. However, beyond the boundless possibilities offered by ICTs, their deployment may also have a social impact, which is not easy to grasp, let alone foresee. This is mainly justified by the rise and expansion of social segregation and isolation phenomena, instigated by citizens' technological illiteracy. Therefore, this factor is associated with opportunities, but also with threats and barriers – pertinent to the lack of familiarity with ICTs – both at the organizational and the social level (Chourabi et al., 2012).

2.5.3. Governance

In the context of the implementation phase of a smart city initiative, interested parties / stakeholders are multiple and vary from project to project and from application to application. These stakeholders can be broadly classified as *administrative authorities*, *citizens* and *businesses*, yet, many variations within these categories are detected. The principal goal of governance is to shape a framework within which *collaboration* among stakeholders is promoted and *consensus* on conflicting issues is possible to be reached. In many cases, cities capitalize on the profound technological opportunities by incorporating ICT applications in the field of governance, establishing thus the so-called *smart governance*. In this respect, smart governance represents a set of technologies, people, policies, practices, social norms and information; elements that constantly interact to support urban governance (Chourabi et al., 2012). In order to label a city's governance as smart, the deployment of ICTs should conduce to the development of appropriate infrastructure, totally harmonized with the local community that supports transparent and accountable decision making. This infrastructure ought to facilitate and promote cooperation, exchange of views and data, and seamless communication among all stakeholders.

2.5.4. Policy Context

The launch of the necessary measures and projects to implement a smart city initiative might possibly require alterations to several existing laws and regulations. This is due to the impact of technological developments on the institutional framework and the operation of political and institutional bodies. Furthermore, the adoption of ICTs affects and changes policy directions and the way these are implemented; while policy strategies influence the way new technologies are applied in the various urban sectors. A thorough analysis of the current policy framework constitutes, therefore, a significant factor for the appropriate and integrated implementation of any given smart initiative. Critical issues, in this regard, are deemed to be the sufficient inspection of: the current situation from a legal and institutional point of view; the directions that stem from hierarchically higher policy frameworks (e.g., regional, national, international); practices and rules which, although not established, are treated as widely accepted guidelines for the local value system (Chourabi et al., 2012).

2.5.5. People and Communities

A technocratic approach to the issue of smart cities usually focuses on the potential of novel technologies, with the human dimension appearing to be linked only to the positive impact that the implementation of ICTs is expected to have on the urban fabric. However, literature review reveals a number of factors that can influence both the design / planning and successful implementation of smart initiatives, and are related to the human factor. Such factors include citizens' educational level, the extent of citizens' participation in the political dialogue and decision-making processes, familiarity with technology and ability to adequately use ICTs, accessibility to city services, communication, and quality of life (Chourabi et al., 2012).

2.5.6. Economy

The economic factor is deemed to be the most powerful driving force behind cities' going smart efforts. Pursuant to Giffinger et al. (2007), *smart economy* is tightly interwoven with the concepts of *innovation*, *entrepreneurship*, *attractiveness*, *trademarks*, *productivity*, *labor market flexibility*, *national and global embeddedness* and *ability to transform*. Despite the different approaches followed for the implementation of smart initiatives, the urban economic environment / context always holds a central role (Chourabi et al., 2012). The goal of the economy-oriented smart initiatives places emphasis on job creation, development of workforce, increased productivity, promotion of investments and innovative entrepreneurship.

2.5.7. Built Infrastructure

Implementation of ICTs in an urban environment, whether this refers to sensor networks or analytical algorithms and computer programs for city data management, requires the existence of the appropriate infrastructure (broadband infrastructure, fiber optic networks, Wi-Fi networks, etc.) to support them. The availability, quality, and condition of this infrastructure plays a key role in shaping the smart city, as it deeply affects the applicability as well as the range and performance of particular technologies.

Challenges associated with the technological sector in smart cities fall into three categories (Chourabi et al., 2012). The first one is related to the ICT infrastructure per se, and more specifically to the observed integration gap among governmental systems; the lack of interoperability; availability and compatibility problems among different systems, software and applications; etc. The second category refers to the rising security and privacy issues, as several pieces of collected, processed and transmitted data may be extremely sensitive. Reliability is also a key concern. Therefore, issues pertinent to data protection from viruses or hackers, the high costs of developing security systems and accessibility restrictions are critical. Finally, the third category focuses on the economic aspect of ICTs and involves all related operational costs (e.g., costs of developing, maintaining and operating the infrastructure, training costs and costs of IT experts).

2.5.8. Natural Environment

Smart city initiatives address the issue of the efficacious management of the urban natural environment by delving into its current status on one hand, and into its desired state –

what the city envisages and expects – on the other; with ICTs lying at the heart of every endeavor to boost sustainability and upgrade environmental management. In this context, elements related to environmental protection and pertinent infrastructure (green spaces, bioclimatic design, waste management systems, water supply systems, etc.) should be taken into serious consideration, as they can remarkably enhance cities' sustainability and quality of life (Chourabi et al., 2012).

2.6. Discussion and Conclusions

Nowadays, most urban environments around the world, envisaged as vivid places where freedom, innovation, creativity, opportunities, and prosperity thrive (Schaffers et al., 2012), seem to be far away from their desired state. Moreover, considerable risks and threats, confronted by modern cities, jeopardize their efforts towards attaining sustainable future states. *Sustainable urban development*, albeit in the spotlight for several decades, remains a fundamental *policy goal* and a *moving target* for battling against contemporary, pressing challenges and has been further exacerbated by the unprecedent intensity of urbanization, the dominant trend of the 21st century (Suzuki et al., 2010).

In a bid to craft strategies and pertinent policy interventions that aim at serving urban sustainability objectives in the information era, the concept of *smart city* emerges as a new *technologically-enabled paradigm* for sustainable urban development, supporting competitiveness, local prosperity, and social inclusion. The widespread use of the concept is related to the pivotal role it can play in addressing the threats that stem primarily from the globally escalating urbanization phenomenon (Walters, 2011; UN, 2015a).

However, a notable plurality as regards the meaning attributed to the notion of *smart city* is observed, reflecting the different perceptions of the various scientific streams and the lack of consensus on the semantics of the term. At the same time, a huge gap in the establishment of a commonly accepted definition by the academic community is also detected. Deficient comprehension of the smart city concept may lead to its inefficient implementation; and thus, to its failure to meet the high expectations placed upon it, as underlined by the results obtained from real smart city case studies (Komninos et al., 2015).

Smart cities, the promise land of technological advancements, innovation, increased efficacy, competitiveness, boosted sustainability, and substantial improved quality of life, have become a popular concept in urban planning and development, inter alia; and a major topic of intense discussion and research for many years now. Nonetheless, smart cities have received their fair share of criticism from various sources. To begin with, they have been blamed for "unproblematically adopting some of the assumptions from the IT model of urban development" (Hollands, 2008, p. 310) and thus being "technologically determined". In other words, they are criticized for relying an entire complex system of urban development on a single parameter, technology in this case. Despite the fact that state-of-the-art technologies' impact on the shaping of urban areas is well documented (Graham & Marvin, 1996), perceiving and establishing them as the sole driving force behind urban development is, by all means, unjustified and unrealistic. In addition to this remark, as Calzada (2016) argues, the assumption that smart economies should be increasingly guided by purely technology-based innovation and entrepreneurship proves to be groundless. Treating smart cities as isolated technical systems (silo mentality) is a definite recipe for failure, taking into account that every urban environment is a perplexed, adaptive system of systems that influences and is affected by individual and collective factors.

Several common criticisms received by smart cities focus on their potential to instigate social inequalities or sharpen the already existing ones. Excessive dependence on advanced ICT systems, services and tools will possibly lead to severe *technological exclusion* (*digital divide*), as some social groups may not be able or willing to follow the hardcore technological path. Such an approach attributes a quite shallow conceptual depth to the term of smartness and conceives it as just the capacity to work with technology. Graham and Marvin (2001) call this phenomenon *splintering urbanization*, since development affects only selected groups, while increasing fragmentation and polarisation at the same time.

Sticking to smart cities' societal aspect, the deployment of disruptive technologies, services and applications (automated transportation systems, environmental sensors, surveillance cameras, urban dashboards) can result in increased monitoring and control of urban spaces. This, in turn, might have a disproportionate impact on marginalized communities that may already face discrimination and surveillance pressures by law enforcement agencies. For example, in the United States of America, many smart city initiatives have been accused of perpetuating racial and socioeconomic disparities. A report by the Brookings Institution reveals that smart city technologies have been used to facilitate policing and surveillance in low-income and minority communities, leading thus to growing concerns about over-policing and violation of civil liberties (Lai & Tanner, 2022).

Another critique of smart cities claims that the embedment of technology in various urban functions is not a necessary and sufficient condition that can guarantee their smartness (Hollands, 2008), considering that technology is never neutral and has the potential and the ability to be socially and politically used for completely different purposes, other than the common good.

Moreover, certain skepticism in relation to the driving force behind developments and theories around the future of smart cities has been expressed by Kitchin (2014), who suggests that the smart city vision is driven by

> an underlying neoliberal ethos that prioritises market-led and technological solutions to city governance and development, and it is perhaps no surprise that some of the strongest advocates for smart city development are big business (e.g., IBM, CISCO, Microsoft, Intel, Siemens, Oracle, SAP) that, on the one hand, are pushing for the adoption of their new technologies and services by cities and states and, on the other, are seeking deregulation, privatisation and more open economies that enable more efficient capital accumulation. (Kitchin, 2014, p. 2)

In close connection to the above remarks, numerous smart city polemics have also raised concerns about the lack of transparency, democratic processes and active citizens' participation. Many smart city projects are initiated and led by private companies, rather than by local governments or communities, thereby sidelining the public welfare and fostering biased decision-making procedures.

Furthermore, smart cities are judged on their potential to aggravate environmental problems instead of mitigating them. While technologies are often touted as a radical solution to climate change and other environmental challenges, there is a risk that they could be used to justify further urbanization and resource consumption. For instance, smart transportation systems may encourage more car use, rather than promoting sustainable modes of transportation like public transit or biking. Additionally, smart buildings that use automation systems and sensors to optimize their functions may actually increase overall energy consumption if they are not used in conjunction with broader strategies for reducing energy demand.

While the abovementioned concerns are valid and should be taken into serious consideration, it is also important to acknowledge the potential benefits of smart cities. The adoption of emerging technologies can increase efficiency, improve public services, and enhance the overall quality of life for urban dwellers. However, in order to fully realize these benefits, it is essential that smart city initiatives are developed and implemented in a way that prioritizes transparency, democratic participation, as well as social and environmental justice. Moreover, participatory approaches that involve local communities and stakeholders throughout the planning and implementation process should be adopted. This can ensure that smart city initiatives are responsive to the needs and priorities of local residents, rather than being imposed from above by private companies or governmental agencies. Another key strategy is to secure that smart city initiatives are guided by principles of social and environmental justice. This means prioritizing the needs and perspectives of marginalized communities, promoting sustainable development, and avoiding the reinforcement of existing power structures.

The whole discourse on the smart city concept leads to the conclusion that a smart city can be conceived as “a testing ground to investigate ways to exploit and take advantage of new ICT-based solutions, as well as new approaches to urban planning and living” (Talamo et al., 2019, p. 2). However, it is not a one-size-fits-all urban development solution. Different cities have different needs and priorities, and what works in one city may not work well in another. Therefore, it is essential to develop customized developmental strategies that take the unique characteristics of each city context into account.

Their successful development requires a collaborative effort that engages various stakeholders, including the government, the private sector, and the civil society. Moreover, smart cities should be designed with the vulnerable population groups in mind. In many cases, sensitive populations, such as the elderly, disabled, and low-income communities, are often left behind in the rush towards smart developments. In this respect, smart cities must ensure that the needs of these populations are addressed and that they are not further marginalized by technological advances.

Ultimately, it could be argued that the smart city concept should be perceived as a developmental strategy instrument that involves all urban actors into a multidimensional approach. Every smart city model ought to focus on the well-being, quality of life, and intelligence of its citizens. Therefore, cities are not smart because they are driven by ‘invisible’ computers of a remote central government that is trying to guide the general population from afar. Conversely, they are smart because their citizens have discovered new ways of thinking, interconnecting and understanding their own data and information, thereby changing their behavioural patterns.

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CHAPTER 3: THE TECHNOLOGICAL EVOLUTION AND ITS CONTRIBUTION TO THE SMART, SUSTAINABLE, RESILIENT AND INCLUSIVE URBAN DEVELOPMENT – THE PARTICIPATORY SPATIAL PLANNING SCOPE

Synopsis*: The concept of 'smart cities' – imbued in recent years with approaches of sustainability, resilience and inclusiveness – has come to the surface as a new ambitious paradigm for urban development and management, capable of leveraging the novel technological advancements and putting them at the service of contemporary cities' sound functioning. The issue of citizens and stakeholders' participation, whose contribution to the collection of empirical knowledge, identification and prioritization of urban inefficiencies as well as selection and implementation of city- and citizen-specific smart applications and policies for confronting them, is of critical significance and constitutes an integral part of this emerging paradigm. Digital environments, immensely supported by Information and Communication Technologies (ICTs) and their applications, have marked a noteworthy shift towards e-Planning and e-Participation, thereby setting the ground for more knowledgeable policy implementation of smart city solutions that are mostly citizens- and city-oriented, rather than solely technology-pushed. The present chapter focuses on the rise of participatory e-Planning as a digitally enabled perspective for effectively communicating various spatial planning problems to citizens and stakeholders and actively involving them in decision-making processes. Along these lines, the most prevalent state-of-the-art technologies and tools – that are currently available in planners' arsenal for optimally implementing participatory spatial planning exercises in the smart city context – are concisely described.*

3.1. Demarcating the Technological Background – The Advent of the Fourth Industrial Revolution

The principal reasons behind the popularization of the smart city planning paradigm are mainly associated with the major challenges that arise due to intensive urbanization trends and adverse climate change impacts – especially in a period of severe economic recession – and which cities are called upon to deal with. Moreover, they also relate to *structural changes* that occur in the: (i) systems of production and innovation of various sectors; (ii) way production and distribution of goods and services is implemented; and (iii) explosive evolution of human-machine communication and interaction. However, such changes do not constitute an unprecedented phenomenon. Historically, the new approaches and methods that are 'imposed' on the structure of the production process, by virtue of the emergence and rapid expansion of novel technologies, significantly alter the social status quo, the possibilities and necessities of people's communities, and therefore the functioning of urban systems.

The introduction of the *steam engine*, at the end of the 18th century, marks the beginning of the *first industrial revolution* (*industry 1.0*), which completely transforms the scenery of employment and society; and contributes immensely to the acuteness of urbanization, since the new production potentials, that come to the surface, require increased human labor as well as drastic market restructuring. In other words, this technological breakthrough is conducive to the transition of the European societies from a basically agrarian and handicraft, to an early industrial reality. The industrialization that takes place during this period is directly related to the increase of the scale, but also the range, of processed products (Balasingham, 2016).

Later on, the *electrification* of the manufacturing sector (*second industrial revolution – industry 2.0*) results in remarkable boosting of productivity and redefinition of the way of working per se. Mass production is achieved through the further division of labor and the specialization of functions, by establishing the *assembly line* as the basic production model. This increased production capacity acts as a *pull factor of urban migration* in light of the fact that it attracts significant flows of people to cities, who seek more and better jobs, higher wages, adequate facilities, satisfactory living conditions and improved quality of life in general (Alarima, 2018).

In the early 1970s, the advent of *electronic and information systems* and their subsequent integration into the manufacturing sector (*third industrial revolution – industry 3.0*), facilitates the automation of processes, but also of the work content in many cases; thereby instigating a series of fundamental changes in the employment landscape. In the following decades, automation continues to rapidly proliferate, owing to the constant upgrade of systems' capabilities, the devices' size reduction, and the familiarization of population with new tools, techniques and technologies.

The aforementioned profound technological booms delimit the three *industrial revolutions* (Figure 3-1). The adoption and application of the new technologies are followed by rapid and radical changes on the way, time, content and other special features of employment and production. Obviously, these changes have deeply affected human societies, inter alia, as production and economy constitute essential aspects of human life and are inseparably entwined with the rest of them (demographic, cultural, political, legal, etc.).

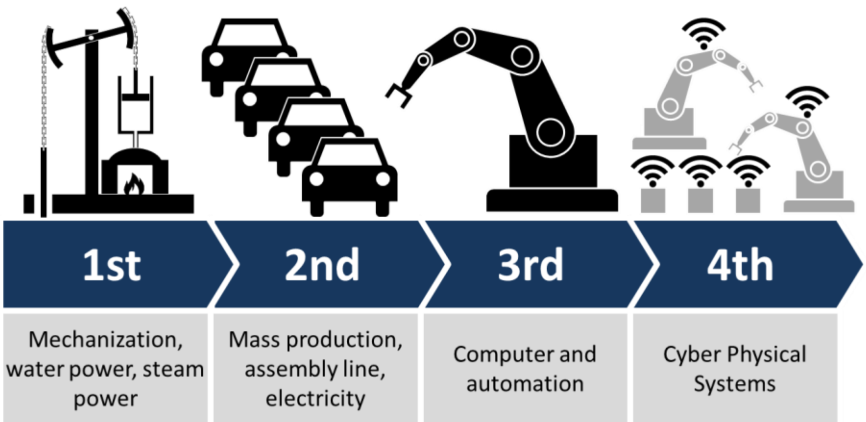

Figure 3-1: The Four Industrial Revolutions (Source: Roser, 2015)

Nowadays, there is a sparking debate on whether humanity is witnessing a new industrial revolution, the so-called *fourth industrial revolution* or *industry 4.0*. It is broadly acknowledged, by industry and research, that the fourth industrial revolution is triggered by the Internet, which supports communication and interaction among people as well as machines in cyber-physical systems (CPS) [i.e., systems that allow communication between the physical and the virtual world without human intervention (Kim & Park, 2017)], via the development of large networks (Brettel et al., 2014). CPS are deployed in numerous sectors and are used in myriads of applications beyond the production process. They have the ability to optimize their operation through *planned actions* (process automation, predictive maintenance, etc.) and *corrective decisions* (process optimization, problem solving, etc.) (Nexus Integra, 2020). Apart from the propagation of CPS, industry 4.0 is also founded on other innovative technological developments that hold a key role, such as the widespread application of (Davies, 2015): *Information and Communication Technologies* (ICTs); *communication networks*; *big data* analysis and management; *simulation*, *modeling* and *virtualization*; *cloud computing*; *Augmented Reality* (AR); *Artificial Intelligence* (AI) and *Machine Learning* (ML).

All these technological miracles (and many more) compose the compass that guides contemporary cities towards their 'becoming smart' journey and are further analysed in the following sections of this chapter.

Obviously, the emergence of state-of-the-art technologies does not happen in a vacuum. Conversely, it is the result of mounting theoretical models and applications that appear in numerous scientific fields. Therefore, the debate on cities' need to become smart, also reflects their necessity to constitute the testbeds of the new production methods that arise.

3.2. Linking the Technological Evolution to Spatial Planning and Urban Reality

The shared vision of the city of tomorrow conceives the future urban environment as (European Commission, 2011, p. vi):

- a place of advanced social progress with a high degree of social cohesion, socially-balanced housing as well as social, health and 'education for all' services;
- a platform for democracy, cultural dialogue, and diversity;
- a place of green, ecological, or environmental regeneration;
- a place of attraction and an engine of economic growth.

In other words, cities represent a *'promise for the future'*, founded on concepts such as freedom, innovation, creativity, opportunity and prosperity (Schaffers et al., 2012).

The abovementioned aspiration is far from the present reality and actually constitutes a highly ambitious goal to be accomplished. In fact, modern cities are confronted with considerable and pressing challenges that threaten their developmental trajectories towards sustainable future end states. In this respect, policy makers and planners are those in charge of elaborating on these urgent issues, so as to come up with effective and sustainable solutions for successfully addressing them. Therefore, *sustainable urban development* is currently deemed to be an overarching planning goal and has drawn much attention due to the *key drivers of change* that have drastically altered the international scenery, such as (European Commission, 2011; Stratigea, 2012; Tao, 2013; Stratigea et al., 2015):

- demographic (population growth and aging) and cultural shifts;
- globally intensifying urbanization patterns;
- climate change impacts that are jeopardizing urban ecosystems' sustainability;
- high rates of non-renewable resources' consumption;
- constantly deteriorating social cohesion, which is expected to be further exacerbated, owing to the evolving migratory flows that are triggered by political upheaval, economic recession, austerity, wars, etc.

In these circumstances, the radical developments on ICTs and their applications, that can underpin myriads of urban functions and provide upgraded services to citizens, businesses, as well as public and private agencies, have induced significant changes to a profusion of scientific fields and pertinent processes, including *spatial planning*. As a consequence, policy makers and planners, in a bid to craft efficacious planning strategies towards cities' sustainable future, are largely supported by the technological evolution and the new potential this can offer for economic development, organizational performance, effective governance, social equity and quality of life in urban environments. Moreover, this technological revolution has led to the 'discovery' of new, innovative approaches, procedures, tools and techniques for pursuing sustainability objectives; and has substantially broadened the perspective of citizens and stakeholders' engagement in such an endeavor (Panagiotopoulou & Stratigea, 2017). The latter is perceived by many researchers as quite critical for the successful management of contemporary urban problems (Duany et al., 2010; Bizjak, 2012; Seltzer & Mahmoudi, 2013; De Pascali, 2014; Steiniger et al., 2016).

Intensive and ubiquitous deployment of ICTs in the urban context heavily affects the interaction capacity among various actors and generates considerable *public value*. They provide access to worldwide knowledge and information (re)sources, and a broad range of tools and applications that allow the establishment of networks and synergies among them (locally and globally), thereby removing space and time barriers. This brings to the surface the concept of *smart cities*, as innovative urban environments which, via embracing digital technologies, support competitiveness, local prosperity and social inclusion. As already stated, despite the fact that a multitude of smart city definitions have been introduced from time to time, a clear and commonly accepted one does not still exist. Some of them are totally technology-oriented, considering thus ICTs as the dominant developmental lever for urban environments; whereas others adopt a broader and more integrated view by incorporating aspects of society, economy and governance, as well as participatory approaches towards attaining sustainable urban development (Manville et al., 2014; Panagiotopoulou et al., 2019).

In the face of the aforementioned heterogeneities, it is widely recognized that a smart city uses ICTs (both mature and state-of-the-art) in an innovative, creative and efficient way so as to (Panagiotopoulou & Stratigea, 2017): (i) manage urban problems and infrastructure; (ii) support competitiveness and local prosperity; and (iii) create knowledgeable, digitally intelligent, aware, creative and active citizens, thereby transforming them into *carriers of urban change*, a challenging issue that is significantly enhanced through their involvement in decision-making procedures.

3.3. The Participatory Urban Planning Paradigm

Planners and decision makers are constantly called to encounter *wicked problems*, i.e., problems that are quite difficult to be solved mainly due to the (Panagiotopoulou & Stratigea, 2017): incomplete, contradictory or changing stock of knowledge; number of people and opinions involved; heavy economic burdens these bear; and the strong interconnected nature of these problems with others (e.g., poverty is linked to education, while nutrition is associated with poverty and economy is considered a decisive factor for nutrition, and so on). According to Balint et al. (2011), confrontation of wicked spatial planning problems is fraught with many difficulties that primarily stem from two types of uncertainty: (i) scientific uncertainty of proposed remedies to these problems; and (ii) uncertainty as to the way these remedies will be grasped and accepted by the recipients i.e., the various societal and stakeholders' groups, driven by different perceptions, motives, behaviors, values, etc. (De Roo & Porter, 2007).

Dealing with wicked spatial planning problems, a fact quite common in evolving urban environments, has brought to the forefront the need to develop or adopt *new, innovative, alternative* and *creative ways of thinking* (Panagiotopoulou & Stratigea, 2017). Such ways should be grounded in an in-depth and multidimensional analysis of current and possible or desired future states of cities and the interrelations among them, as well as on the investigation of the potential paths that link, in a sustainable manner, current state and desired future ends. Moreover, they need to be founded on a thorough exploration of how the different social groups will finally react to the various planning interventions, given the power relationships that are developed within urban environments, which can dramatically affect the implementation of planning propositions by either supporting or opposing to them. Ultimately, effective handling of wicked problems, in ever-changing urban environments, needs to incorporate new *methodological approaches* that are far away from the rational planning thinking of the past; are capable of shedding light to *nascent opportunities*; and underpin *innovative and inclusive solutions* to complex problems, ensuring at the same time wide consensus and commitment to planning outcomes (Panagiotopoulou & Stratigea, 2017).

Additionally, urban problems need to be tackled within a volatile external environment, mainly characterized by *complexity* and *uncertainty* as well as rapid pace of mostly unpredicted changes in all respects, wherein identified solutions should be implemented as fast as possible before becoming obsolete. As Friend and Hickling (2012) claim, planners, while seeking solutions to wicked problems, are confronted with *three types of uncertainty*, namely:

- uncertainty related to the *value system* of the planning endeavors' recipients (values, priorities, visions, ethics, etc.), which constitutes the 'lens' whereby planning interventions are grasped and understood;
- uncertainty as to the developments taking place in the *external environment* – the decision environment – that are framing the context in which planning decisions will be reached; and
- uncertainty as to the *decisions made*. In this case, the planning problem is largely interconnected with other problems, while various decision-making bodies, that are met at different hierarchical levels, can affect (through their choices) the efficacy of the planning exercise.

Facing the above categories of uncertainty has pushed forward, inter alia, the current stream of *participatory planning*, that aims at exploring underlying principles of spatial entities' value systems. *Value orientation* constitutes a core element of the spatial planning process, as it affects decision-making to a great extent and leads to outcomes that best fit to the peculiarities of the territorial entity under study (*place-based* and *place-specific* solutions) (Hennen, 1999; Kanji & Greenwood, 2001; Pereira & Quintana, 2002; Puglisi & Marvin, 2002; Mostert, 2003; Innes & Booher, 2004; Hines & Bishop, 2006; Stratigea, 2015; Panagiotopoulou et al., 2018; Panagiotopoulou & Stratigea, 2021). Indeed, the efficient city planning and management in an uncertain, erratic and rapidly evolving world, as well as the battle against wicked problems, implies the gathering of *collective intelligence* (Conklin, 2005). This, in turn, entails the collection of *distributed* and *indigenous knowledge*, which refers to the perspectives, understandings, perceptions and intentions of various different actors who are involved in urban ecosystems. The delineation of their thoughts, motives, judgments, points of view, etc., is really crucial since they express diversified – even contradictory in many cases – opinions on the nature of the planning problem per se or on what constitutes an acceptable solution to this problem. A deep insight into these opinions / perceptions, as well as a methodic effort towards reaching a certain compromise among the actors and finally ending up with a *shared view* of the planning problems and related solutions, coupled with *commitment* to their implementation, is a fundamental prerequisite for effective spatial planning nowadays. In order for this goal to be attained, it is necessary to address and understand *social complexity*, i.e., the number and heterogeneity of actors (citizens and stakeholders) who are directly or indirectly affected by or can contribute to the solution of a problem and associated value systems; and successfully integrate this acquired knowledge into the planning process (Conklin, 2005).

In recent times, *participatory planning* is deemed to be one of the leading approaches or a *new paradigm* in the spatial planning realm, that conduces to the achievement and encouragement of peoples' engagement in decision-making and policy formulation in various problems and spatial scales. It actually represents a transition from a *top-down*, primarily hierarchical, control- and command-based planning model, to a *bottom-up*, more *'human centric'* structure of decision-making processes (Panagiotopoulou & Stratigea, 2017, 2021; Panagiotopoulou et al., 2018). Therefore, participatory planning aims at establishing, promoting and/or stimulating: problems' co-identification and co-validation, as well as joint priority setting; cooperation in the elaboration and articulation of appropriate solutions; and collaboration on the implementation stage of sustainable development strategies and pertinent policy frameworks, which is expected to result in the successful application of the suggested solutions (Kanji & Greenwood, 2001; Innes & Booher, 2004; Baker et al., 2010; Stratigea, 2015; Stratigea et al., 2015; Panagiotopoulou et al., 2018). It can also contribute to the collection of valuable, illuminating and multidimensional pieces of information, that stem from urban actors' partnerships within highly interactive environments; and may reveal different views, visions, desires, fears, etc. Pursuant to numerous researchers (Pereira & Quintana, 2002; Puglisi & Marvin, 2002; Mostert, 2003), such interaction constitutes a major step forward in the *integration* of different opinions; increases awareness as to shared, massive, imminent challenges; fosters mutual understanding and close networking; while it can lead to new innovative knowledge production and synergies' creation, capable of coping with perplexed problems.

The integration of spatial planning and decision-making with participatory approaches is perceived as a considerable step up, since different societal groups' views and expectations can be effectively embedded in the final planning outcome; and uncertainties, pertinent to the exploration of value systems as well as the validity of decisions made, may be satisfactorily overcome. Furthermore, it marks a substantial shift from traditional consultation of planners with experts, towards consultation with a broad range of local actors (experts, citizens, local stakeholders, associations, institutions, etc.), a fact that actually reflects the particular focus of participatory planning on "planning with the community rather than for the community" (Pettit et al., 2006, p. 22.4).

The above-described new ICT-enabled perspectives have remarkably accelerated the growth of *participatory democracy* in urban planning, a transition that implies a highly intensive use of Web-based interaction among decision makers, planners and local communities. Strengthening the participatory context in decision-making at the urban level has led to the current evolution of *spatial governance models*, applied to both urban and regional planning studies (Pereira & Quintana, 2002; Zwirner et al., 2008). Based on these models, new urban and regional planning processes, characterized by the vast assortment of ICT-enabled local stakeholders' engagement, are developed; and serve different objectives and related outputs, in an effort to deal with *resource scarcity* and *sustainability goals* in extensively wired environments.

3.4. The Rise and Expansion of ICT-Enabled Participatory Planning – E-Planning and E-Participation

The breathtaking technological advancements of recent years have driven remarkable changes that have entrained immense ramifications from an economic, social, environmental and political point of view (Hackler, 2006). More specifically, rapidly evolving, digitally-enabled environments have initiated innovations and have altered processes in the political, technological, economic, environmental, cultural and social sceneries (Panagiotopoulou et al., 2018). Within these environments, new challenges have emerged for decision makers and planners, a fact that was prophetically questioned early enough by Castells (1992) in his seminal article "The World has Changed: Can Planning Change?"

When dealing with wicked planning problems in highly perplexed, intensively interacting and unpredictable urban environments, the role of ICTs and their applications is nowadays greatly appreciated mostly due to the effective *digital communication and interaction bridges* they establish among decision makers, planners and local societies; and the new potential they offer towards managing and visualizing *large spatial data sets*.

Spatial planning processes are particularly complex, they combine data and information from different knowledge domains, which – most of the times – lack homogeneity (e.g., statistical data and spatial data); they are dynamic in nature; and, in general, it is hard enough to communicate them to less skilled stakeholders (Hansen & Prosperi, 2005). Moreover, participation in spatial planning requires access to information that is strongly dominated by visual media in the form of *maps* and *images*, with textual description being an important subcomponent of such information (Hudson-Smith et al., 2002). In this respect, the maturity of Geographic Information Systems (GIS) technologies, that permit their extensive use beyond very technical environments, is of great help and has drastically enhanced the potential for spatial data management and visualization. Furthermore, Web developments have allowed *interactive Web-based GIS* exploitation as a bidirectional interactive approach (Hansen & Prosperi, 2005), which can: ensure equal access to information; render participation wider and more substantial, owing to the better grasping of spatial data and problems; uncover new perspectives for social inclusion; and reinforce democratic procedures that support efficacy of spatial decision-making (Stratigea, 2015; Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018). Interactive visualization and (Web-)GIS applications can be adopted / used in order for various pieces of information to be presented in an understandable and coherent way; and the investigation of spatial interrelationships and pertinent problems to be facilitated. In this way, users' apprehension of a spatial planning problem can be ameliorated, and thus opportunities for essential and value-adding *public participation* may be broadened (Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018).

Current technological advances are envisaged to further strengthen *data-intensive* urban planning and policy, mainly due to the huge potential they provide via the implantation of a *'digital skin'* (i.e., sensors) into urban environments (Rabari & Storper, 2014), or the overlay of the physical space with a digital layer, which facilitates *quantitative data collection* on a plethora of urban dimensions through networks of sensors. Such a wired environment also enables the gathering of an unprecedented amount of *qualitative data*, a fact that is significantly underpinned by the evolving new spirit of participation and the modern forms of crowdsourcing and digital interaction among different actors, such as residents, governments, professionals and businesses, civil society organizations, etc. (Panagiotopoulou et al., 2018). This, in conjunction with the pervasive role of ICT-enabled planning (e-planning) potential, leads to a remarkable change in planning practice; and conduces to the blurring of planners and urban actors' discrete roles, in respect of *information production and consumption* (Hudson & Smith, 2002; Roche et al., 2012; Stratigea, 2015; Panagiotopoulou et al., 2018). Therefore, planners' traditional role as information producers is gradually scaling back; whereas the role of local actors as both producers and consumers – *prosumers* – of information is considerably upgraded (Wallin et al., 2010; Stratigea, 2015; Stratigea et al., 2015, Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018).

According to numerous researchers, qualitative data collection will, in the near future, be further enhanced as a result of the presently experienced *participatory revolution* (Davidoff, 1965; Fung & Wright, 2001; Duxbury et al., 2015). This brings to the surface the concept of *crowdsourcing* as "an online, distributed problem-solving and production model" (Brabham, 2008, p. 75); or a specific form of public (e-)participation in urban projects (Brabham, 2009), that serves a *twofold goal*: (i) the acquisition of non-expert data, information and knowledge for feeding and therefore enriching the spatial planning process; and (ii) the exploration of efficient and viable solutions to spatial planning problems and challenges, which derive from the public's proposals. In the one or the other form, crowdsourcing can be used for conveying empirical knowledge and views on planning problems from local communities to decision makers and planners; identifying positive and negative dimensions of these problems regarding the way they are grasped by communities; rating these dimensions, etc., thereby contributing to the *integration* of institutional (decision makers), scientific (planners) and indigenous (communities) knowledge; but also to the *integration* of qualitative and quantitative data, shedding light thus on tangible and intangible (e.g., cultural) aspects of planning issues (Stratigea, 2015; Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018).

The evolving ICT-enabled *interaction patterns* among decision makers, planners and local communities steer changes in the ways political voice and debate as well as decision-making processes for managing urban issues occur, with the ultimate goal of public (local communities') participation being focused on the: empowerment and engagement of local actors; promotion of collaboration and conflicts' resolution; enhancement of governmental procedures' accountability and transparency; and support of more knowledgeable decision-making, governance and service delivery. At the same time, they possess an important role in the achievement of resource optimization, sustainability and high quality of life (Stratigea, 2015; Stratigea et al., 2015; Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018). This interaction scheme seems to largely affect planning and governance aspects, whose effectiveness is assessed on the basis of the solid and qualitative participation in decision-making they are able to promote.

The continuous progress of spatial planning witnesses its adaptation to various broad developments as regards its theoretical basis, the tools and approaches adopted / utilized, but also its practice per se (Silva, 2010), positively answering thus to Castells' (1992) concern. Today, spatial planning, implemented in a globalized environment and distinguished by uncertainty, complexity and, most importantly, the massive explosion of ICTs, has been pushed forward by effectively reading the new 'signs' and taking a further step ahead towards the migration / relocation of participatory planning processes to the Web. In this way, the ground for the rise and establishment of *e-planning* and *e-participation* paradigms as valuable complements to classical (traditional), face-to-face, participatory approaches, is set (Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018). The emergent *e-planning paradigm*, i.e., online spatial planning, focuses on the successful combination of participatory approaches and ICTs and their incorporation in the (urban) planning discipline. This, of course, presupposes the existence of adequate technological and organizational infrastructure, in order for unhindered access of social groups to information and pertinent planning services to be ensured, thereby highlighting the vital role of ICTs and their applications as well as the readiness of relating decision-making structures to follow such developments.

E-planning constitutes a new challenge in the scientific realm of spatial planning and "an instrument for collective action in the urban arena" (Silva, 2010, p. 4). It can be conceived as an *interaction* but also a *social learning platform*, that satisfies two distinct purposes, namely (Silva, 2010):

- to facilitate all the work carried out during the different, discrete stages of the planning process, marking in this way the transition towards *e-planning*, which is underpinned by GIS technologies for managing spatial data (Quan et al., 2001) and the Web for interacting and communicating; and
- to encourage and broaden public participation during the different steps of the planning process, contributing thus to the shaping of *participatory e-planning*. Tools and technologies deployed at this stage offer the public the possibility of e-participation, while interactive Web maps are available so as to both improve information provision to the public and elicit information or spatial data from the public (Craig et al., 2002; Goodchild, 2007).

In such a context, the utilization of the Web enables online communication and interaction among all parties involved, while GIS technologies provide / add the spatial dimension of planning problems, their possible solutions as well as their ramifications, enabling thus the better comprehension of problems and their potential remedies. All the above imply the expansion of e-planning and e-participation potential regarding all the three discrete planning stages, namely (Khakee, 1998):

- The *learning stage* which incorporates: an in-depth analysis and understanding of the socio-economic and physical context – various layers of urban environments – within which the planning process is taking place; the identification and prioritization of inherent problems; the delineation of respective goal and objectives; etc.
- The *evaluation stage* that focuses on: the building and evaluation of alternative solutions so as the goal and objectives set to be attained; the assessment of alternative solutions and their prioritization as to the goal and targets' fulfillment, together with the assessment of the policy framework, which optimally implements the prevalent solution.

- The *implementation stage* which refers to the application of the selected planning solution through specific policy options that derive from the evaluation stage.

ICT-enabled tools and technologies that can be applied for facilitating and boosting e-participation when following the aforementioned spatial planning stages are (Stratigea, 2015; Panagiotopoulou & Stratigea, 2017):

- Tools and technologies for engaging citizens via the Web – e-Participation (applies to learning, evaluation and implementation planning stages).
- Tools and technologies for gathering and managing information, such as crowdsourcing, Web-GIS, etc. (learning stage).
- Tools and visualization technologies for presenting planning solutions and relating impacts, such as geo-visualization tools, Web-GIS, etc., setting thus the ground for collecting stakeholders' views (evaluation stage).
- Evaluation tools, such as multi-criteria analysis (MCA) for the online assessment and rating of the proposed alternatives by participants (evaluation stage).
- Tools and technologies for disseminating and communicating planning interventions and policies to citizens (implementation stage).

According to the abovementioned arguments, the implementation of e-planning is closely related to the adoption and exploitation of ICTs in the various planning steps, from the information collection and elaboration stage to that of alternative solutions' building and evaluation, in order to come up with the optimal solution. At the same time, it is also closely related to the use of geospatial databases, which allow the spatial representation of the planning problems (Kubicek et al., 2007), so as every participant can be fully aware of the problem under study. Finally, it requires an online service delivery system, a quite crucial issue for the successful implementation of e-planning. Additionally, participants, via an e-planning platform, are given the chance to continuously monitor the progress of various planning steps, but also to be actively engaged in the planning process by expressing their opinions, expectations, aspirations etc.; and elaborating and/or approving planning decisions and relative policies (Shiode, 2000).

Numerous researchers hold the opinion that the integration of Web and GIS technologies may significantly benefit spatial planning (Shiffer, 1995; Kingston et al., 2000; etc.), since the participation of different societal groups is greatly broadened through e-Participation; and relative procedures are rendered 'open', thereby supporting transparency and liability of decision-making processes. Nevertheless, it should be noted that the use of tools and technologies for e-Participation and e-Planning does not relieve designers of a series of decisions and steps to be followed for the implementation of a participatory process. Such decisions relate to the planning of the participatory process per se, and are associated with a series of questions raised, such as who benefits from the spatial planning process? What is the citizens' role in this process? How can communication and interaction among different groups of participants be enhanced? In which stage of the planning process should stakeholders be engaged? What is the scope of participation? (Stratigea, 2015). Pursuant to Ferraz de Abreu (2002), when it comes to e-Participation and e-Planning, planners must make choices regarding:

- The participatory process per se, focusing on issues such as timing of communication with the public; engagement of the public before, during or after the planning process; delineation of the planning stages in which the public will be involved; type of information collected by planners; format of this information (e.g., textual or visual information, comments or sketches on a map, etc.); type of participation they pursue (passive or active), etc. Key questions in this context are: why public should be involved? Who should be involved in order for the objectives set to be achieved? How will participants be engaged (choice of classical or online participation tools or combination of both)? When will the public be engaged?
- The type of technologies that will enable e-Participation and e-Planning on the basis of the objectives set and the special characteristics of these particular technologies; the technological and organizational infrastructure that support the entire process; but also, the current communication pattern and standards of the specific society, within which e-Planning is implemented.

3.5. Crossroads between Smart Cities and Technology

The rapid development of new technologies is used to improve urban functions and services provided by local administrations. Available analysis, control and communication technologies facilitate the transformation of urban operations, thereby positively affecting the promoted policies, as well as the cities' overall management. This mainly justifies the notion that technology constitutes a *key driver* of smart urban environments, owing to the exploitation of ICTs, which can radically change life in them (Hollands, 2008). Cities are now changing through the development of broadband networks, software applications, online services, revolutionary Web-based technologies, open standards and data sets, etc. These technological advances trigger the emergence of new forms of cooperation and contribute to the development of new fields of innovation. In this way, "the urban innovation system is enriched, its nodes acquire digital companions, and networking is intensified locally and extended globally" (Komninos, 2018, p. 784). Creating a smart urban environment entails specific technological requirements, such as well-equipped telecommunications networks (fiber optic channels and Wi-Fi networks), public Internet access points (wireless hotspots, kiosks) and information-oriented services (Anthopoulos & Fitsilis, 2010).

Broadband networks are perceived to be one of the key constituents of ICT infrastructure and the basis of smart city planning, for they allow connection and access to all users and ensure high speed Internet. The installation of high-speed networks and their proper utilization by both the city administration as well as the business and educational sectors, lead to the shaping of smart urban environments and trigger innovation that may offer unexplored developmental opportunities (Komninos et al., 2013). The penetration of smart devices at the city level is also considered a fundamental element in the field of ICTs, as it permits the access to services via wireless connection. Hernández-Muñoz et al. (2011) argue that ICTs possess a critical role in urban development today, since they enhance the quality of provided public services in sectors such as health, education, security and governance. Smart cities can be seen as a combination of ICT-based *spatial intelligence* technologies, a place where services and applications are delivered more efficaciously. At the same time, the redesign of Internet applications allows the provision of electronic services, which activate the interaction between the public sector and the citizens.

Pursuant to Castells (2015), the use of ICTs in smart cities includes three main stages that are closely related to the flow of information.

The first stage refers to the *collection of the appropriate data*, as the city's management system needs access to information about the state of the urban environment per se, in order for the appropriate decision-making processes to be effectively carried out. Data and information may be obtained through the city's infrastructure, and more particularly via already established mechanisms (monitoring systems); or via the deployment of new sensors, especially wireless, for they allow the measurement of evolving urban phenomena in combination with their location. Moreover, the rise and propagation of Internet of Things (IoT) offers the ability to integrate data that derive from multiple – and heterogeneous in many cases – sources. Citizens are also able to collect data, due to the frenetic use of mobile devices, which makes it possible to receive information through social networks or other applications. Furthermore, surveys and online participatory fora enable data and information acquisition, as well as citizens' awareness.

The second stage is about *storing and accessing data*. The existence and operation of sensor networks create significant challenges in properly managing the collected data. Their effective use by citizens or urban actors (administrations, businesses, management systems) is based on selective access to pieces of information of interest and, if necessary, to the whole dataset. Efforts to store and access data – in the context of smart cities – should pursue the following goals:

- decentralized lists of information;
- availability of data, pertinent to the user's location;
- use of data standards that are open to the public;
- existence of appropriate framework and licensing to ensure citizens' access to information, in accordance with the Open Data philosophy.

The third stage involves *information dissemination*. At this stage, once the information has been collected and processed, it must be freely available to the public. The type of information received can be chosen by users, while current technologies allow the use of not only mobile devices but also built-in systems in vehicles. One of the main challenges in this regard is the creation of systems for access to multiple devices based on Web technologies, which take advantage of the data shared by municipalities and their citizens, offering them high quality services, closer to their needs.

The broad adoption / use of ICTs in contemporary urban environments may significantly contribute to the (Harrison & Donnelly, 2011):

- limitation of resource consumption, resulting thus in CO_2 emissions reduction;

- better use of existing infrastructure, therefore improving quality of life and avoiding the need for additional, traditionally constructed, projects;
- provision of new and innovative services to the public;
- boost of the business community through the release of real-time data regarding the operation of city services;
- strengthening of city resilience through the rational management of water and energy demands, transport requirements, etc.

Taking all the above into consideration, it becomes apparent that technological advancements have revolutionized the way city services are designed and delivered, rendering thus urban functions much more effective, transparent, and accessible.

3.6. Technologies and Tools for Implementing the 'Digital Layer' of Contemporary Smart, Sustainable, Resilient and Inclusive Cities (S2RICs)

The present section provides a brief delineation of the most fundamental and salient technologies and tools that are deployed in smart urban environments and form the backbone of their digital space. These mainly refer to various types of ICTs, whose combined use leads to innovative design and effective delivery of online services; and are classified into five broad categories:

- *Network technologies* use "data systems to handle as well as deliver digital resources through a computer network" (WatElectronics, 2021, para. 1) and support the creation of broadband communication networks, which are of vital significance for the provision of digital city services.
- *Technologies that enable the interconnection between the physical and the digital space* and have led to the establishment of an *integrated spatial intelligence* based on sensors, augmented reality, real-time information, and huge amounts of data that emerge from cities' functioning. This new form of spatial intelligence has a direct impact on the location-based services offered by cities; but also, on the optimization of urban networks.

- *Web-based technologies* improve the quality, the efficiency and the way e-services are delivered. They are generally used on the Web and offer a particular added value in the case of smart cities.
- *Spatial data management and visualization technologies and tools* are related to geospatial data collection, processing, analysis, and visualization; content management; 2D and 3D modelling; etc.
- *E-participatory and e-governance tools* strengthen citizens and stakeholders' engagement in public affairs.

It should be noted that the above classification is not definitive and, also, technologies and tools are not limited to the aforementioned categories. The list is exhaustive and contains a tremendously wide variety of available technological resources that comprise the digital skin of smart, sustainable, resilient and inclusive cities.

3.6.1. Network Technologies

Network technologies form the communication background for the interconnection of all autonomous units installed in the city (e.g., sensors and actuators) with themselves and with the citizens. These technologies enable data transfer and, consequently, the exchange of information among the nodes of a city's digital layer. They also ensure high speed fixed and wireless Internet connection. Network technologies are an integral constituent (together with Internet technologies and service infrastructure) of what Pentikousis et. al (2011) have described as the "lower part of the smart city innovation stack" (p. 111). In case this foundation is not solid enough, the whole notion of smart cities falls into the void.

As already mentioned, network technologies are tightly interwoven with *broadband communication networks*, since the first facilitate the development of the latter. *Broadband access* refers to several "high-capacity transmission technologies that transmit data, voice, and video across long distances and at high speeds" (Fernando, 2021, What is Broadband? section, para. 1). Moreover, broadband access implies high-speed and high-bandwidth communication infrastructure; entails high-speed online services; provides high-quality and quick access to data and information, thereby boosting numerous critical sectors such as education, healthcare, mobility, innovation, entrepreneurship, etc. (Fernando, 2021).

Today's cities, in their endeavor to procced to the new digital era and provide appealing and efficient online services and applications to the public, should be armed with the appropriate network infrastructure, that: i) allows for the distributed development of existing and future network applications and information services; ii) enables stable and uninterrupted connection; iii) meets applications' requirements in terms of bandwidth, feedback and availability; and iv) has the capacity to get continuously upgraded – at a small additional cost – in order to keep covering the new and pressing needs, which result from the rapid technological evolution. In this way, it is possible to provide fast Internet connection at competitive prices, without inherent limitations in the transmission systems and the terminal equipment.

Broadband access technologies are classified into two general categories: wired and wireless (see also Figure 3-2). Wired technologies include digital subscriber line (DSL), cable modem, leased line (T1), fiber optic cable and broadband over powerlines (BPL); whereas wireless technologies mainly refer to satellite access, fixed wireless technologies, Wi-Fi, Worldwide Interoperability for Microwave Access (WiMAX) and cellular networks (3G, 4G, 5G).

At this point, it should be stressed that the extensive analysis of network technologies goes beyond the scope of this Dissertation. However, the author holds the opinion that the fifth-generation cellular networks (5G), that constitute the quintessential network technology, should be concisely described.

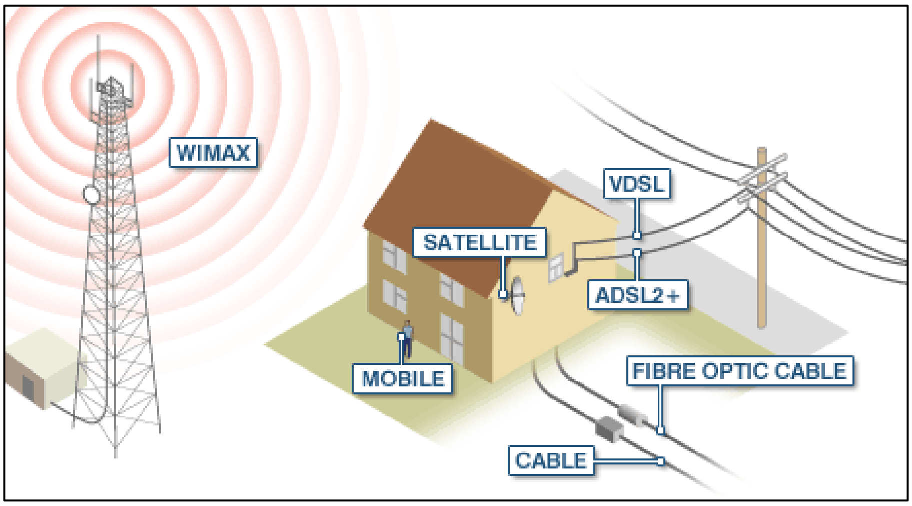

Figure 3-2: Wired and Wireless Broadband Technologies (Source: BBC News, 2007)

Fifth-generation cellular networks (5G)

The advent of wireless communication dates back to the early 1970s and its ongoing development has led to the evolution of different generations of networks (Karki & Gariya, 2016). Nowadays, the concept of smart cities is closely linked to the development of 5G networks, a cross-cutting technology that is deemed to be the necessary infrastructure for the implementation of smart systems, as 5G is an enabling technology for IoT, and smart cities heavily depend on IoT for their proper functioning (Gade, 2021). According to Cisco, connected devices are expected to reach 12 billion by 2021, a humongous number that cannot, by any means, be sufficiently supported from the current network infrastructure (Santos et al., 2018). 5G comes to fill this gap, since it is designed to deliver much greater speeds, wider data bandwidth, lower latency, more reliability, increased availability, and significantly more improved capabilities, compared to its predecessors (EMnify, 2020; Gade, 2021).

During the last 40 years, the world has experienced a spectacular transition from the first generation of networks (1G), which only allowed voice transmission of poor quality, to the fourth generation (4G), that makes the transfer of huge volumes of data – that are not only limited to audiovisual material – possible (see Figure 3-3). 5G networks are expected to achieve data transmission speed greater than 1 gbps, clearly higher than 4G's respective speed of 50 mpbs. Therefore, they will be able to provide faster communications, high-quality, interactive multimedia services, but also services relative to IoT, virtual and augmented reality, etc. (Karki & Gariya, 2016).

The deployment of 5G networks is anticipated to reduce network latency, from 50 milliseconds – calculated for 4G networks – to one millisecond (Vora, 2015). This remarkable decrease, combined with innovations in the fields of machine learning and artificial intelligence, conduces to the effective application of intelligent systems, such as autonomous vehicles. As a concluding remark, "5G is the communications system that can finally achieve what has long been promised – anyone anywhere can get in touch with whoever or whatever – in a human-centric system that is meeting the user needs" (Skouby & Lynggaard, 2014, p. 875); and is anticipated to monopolize the interest of smart cities in the foreseeable future.

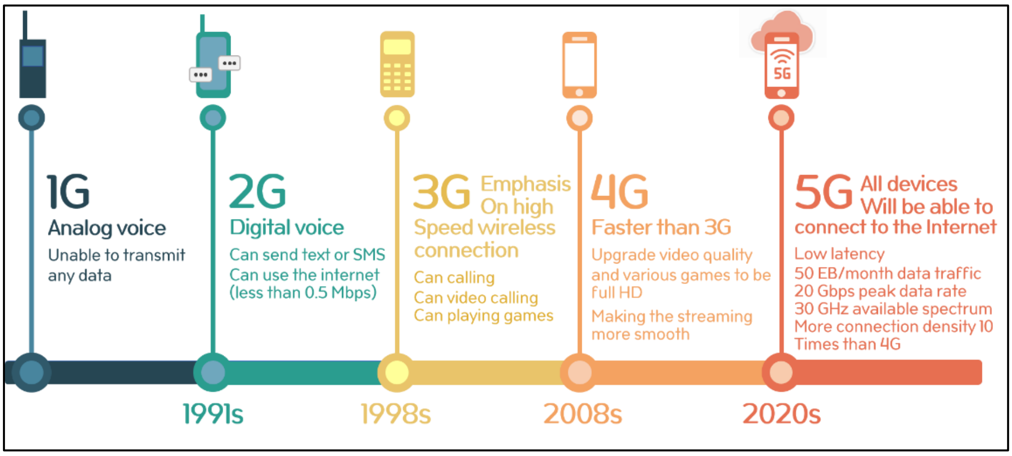

Figure 3-3: Cellular Network Evolution (Source: TechModena, 2021)

3.6.2. Technologies that Enable the Interconnection between the Physical and the Digital World

These technologies are related to the Internet of Things (IoT), whereby it is possible to monitor – in real time – what is happening in the city in general and in its individual systems in particular. Augmented Reality (AR) technologies, that enhance the understanding of the city by superimposing relevant digital information on a ‘physical’ background, are also included. Lastly, the present sub-section focuses on the delineation of location-aware technologies, which are necessary for the development and delivery of location-based services.

Internet of Things (IoT)

The Internet of Things (IoT), sometimes referred to as the Internet of Objects, is, perhaps, the most radical technological development in the field of smart cities, as sensors, actuators, and Radio Frequency Identification (RFID) tags are broadly used in all city sectors, in order to identify and control a multitude of urban entities.

Mark Weiser is the first who envisages a human - computer interaction model – by introducing the term *ubiquitous computing* – according to which information processing is integrated into everyday objects and activities without being perceived from human beings. As he characteristically emphasizes “the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it” (Weiser, 1991, p. 94).

Santucci argues that IoT "must be seen as a vision where 'things', especially everyday objects, such as nearly all home appliances but also furniture, clothes, vehicles, roads and smart materials, and more, are readable, recognizable, locatable, addressable and/or controllable via the Internet" (Santucci, 2009, Abstract section).

International Telecommunication Union (ITU) perceives IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things, based on existing and evolving interoperable information and communication technologies" (International Telecommunication Union [ITU], 2012, p. 1).

According to Cisco, IoT

> is the network of physical objects accessed through the Internet, as defined by technology analysts and visionaries. These objects contain embedded technology to interact with internal states or the external environment. In other words, when objects can sense and communicate, it changes how and where decisions are made, and who makes them. The IoT is connecting new places – such as manufacturing floors, energy grids, healthcare facilities, and transportation systems – to the Internet. When an object can represent itself digitally, it can be controlled from anywhere. This connectivity means more data, gathered from more places, with more ways to increase efficiency and improve safety and security. (Cisco, 2014b)

Clark states that IoT

> is the concept of connecting any device (so long as it has an on/off switch) to the Internet and to other connected devices. The IoT is a giant network of connected things and people – all of which collect and share data about the way they are used and about the environment around them. (Clark, 2016, What is the Internet of Things? section, para. 1)

Pursuant to Figure 3-4, IoT can be perceived as a revolutionary technology that extends the idea of peoples' connectivity to objects. Its rationale is based on the notion that everyday objects not only are able to connect at any place, anytime, but they also connect to anything and anyone, via – if possible – any network and service.

In general, IoT constitutes an integral part of the Future Internet (FI) and describes the networking and communication among Internet-enabled devices and other Web-based gadgets. It, actually, refers to a new technological reality, where everyday life products / devices are equipped with sensors, electronic components and software, which allow them to interact / communicate with people, with each other, but also with computer systems. The unprecedented proliferation of electronic systems, and their embedding into ordinary devices, provides easier access and interaction (Zanella et al., 2014). This new way of interconnecting a system's individual parts first appears in the structure and operation of 'smart factories' – in the context of the fourth industrial revolution – and is considered to be the cornerstone for the implementation of the cyber-physical systems' operation principles.

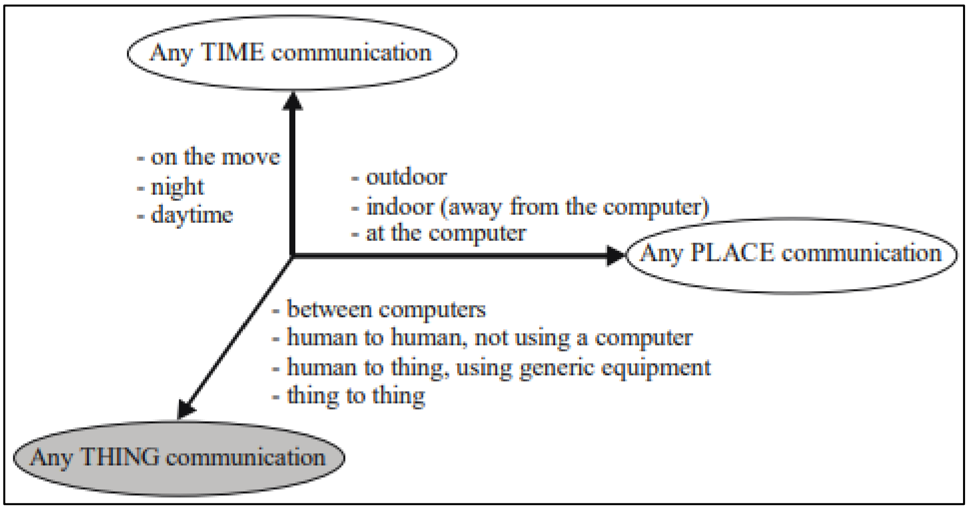

Figure 3-4: The Dimensions of Internet of Things (Source: ITU, 2012)

However, the usefulness of IoT is not limited to the aforementioned. Bearing in mind that IoT aims at collecting, sharing, and communicating data among interconnected objects (Gubbi et al., 2013; Ishida, 2017; Papadokostaki et al., 2017), this technology – when applied in urban environments on a grand scale – may offer a plethora of new and innovative smart city services (Mehmood et al., 2017). Such services can significantly upgrade myriads of subsystems within the urban fabric, since they improve current infrastructure, mobility, air quality, noise pollution, energy supply, waste and water management, etc., with the ultimate goal being the total enhancement of quality of life in contemporary cities (Gubbi et al., 2013; Zanella et al., 2014; Patti & Acquaviva, 2016; Hui et al., 2017; Ramirez et al., 2017).

According to Rjab and Mellouli (2018), IoT possesses four vital roles in the context of smart cities: (i) guarantees ubiquitous connectivity among different objects; (ii) allows real-time data processing, since it is capable of collecting, crunching, storing and sharing large volumes of data; (iii) improves services' quality and accessibility; and (iv) boosts security, considering that it is broadly used for monitoring purposes. Moreover, through a thorough examination and analysis of 125 'smart city-oriented' studies, Rjab and Mellouli (2018) identify five critical sectors that attract the majority of IoT applications: home, transport, healthcare, urban environment, and industry (see Figure 3-5). Therefore, IoT can be embedded in numerous heterogeneous systems and can be applied in every smart city sector / area.

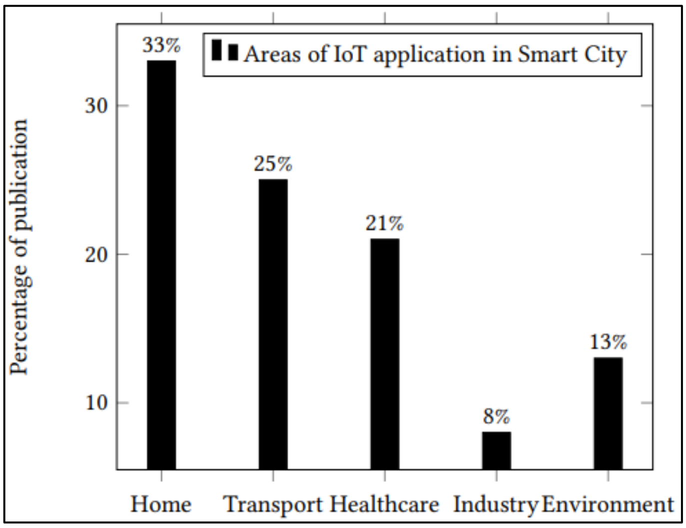

Figure 3-5: The Five Sectors of IoT Applications (Source: Rjab & Mellouli, 2018)

Taking all the above into account, it is inferred that the possibilities of IoT go beyond the human - machine interaction. They extend to the realm of *data collection*, but the most defining fundamental element of IoT is related to innovations regarding the automation of communication among machines [machine-to-machine (M2M) communication]. Owing to IoT, communication between different machines and systems has become faster and easier, without the need for any human intervention. This, in combination with the development of artificial intelligence and machine learning, causes a qualitative alteration in the way decisions are made and systems are updated.

Augmented Reality (AR)

Augmented reality (AR) refers to the view of the physical, real-world environment, whose elements are supplemented with computer generated input (sound, video, graphics, or GPS data). According to Azuma (1997), AR interfaces allow users to experience the real world at the same time as virtual displays can be superimposed upon or composited with real locations and objects. Put simply, AR enhances users' current perception of reality by overlaying virtual assets on it (see Figure 3-6). Therefore, AR can be conceived as an intercalary level between users and the physical environment – a level imposed by technology – that enriches their view of the world with virtual features.

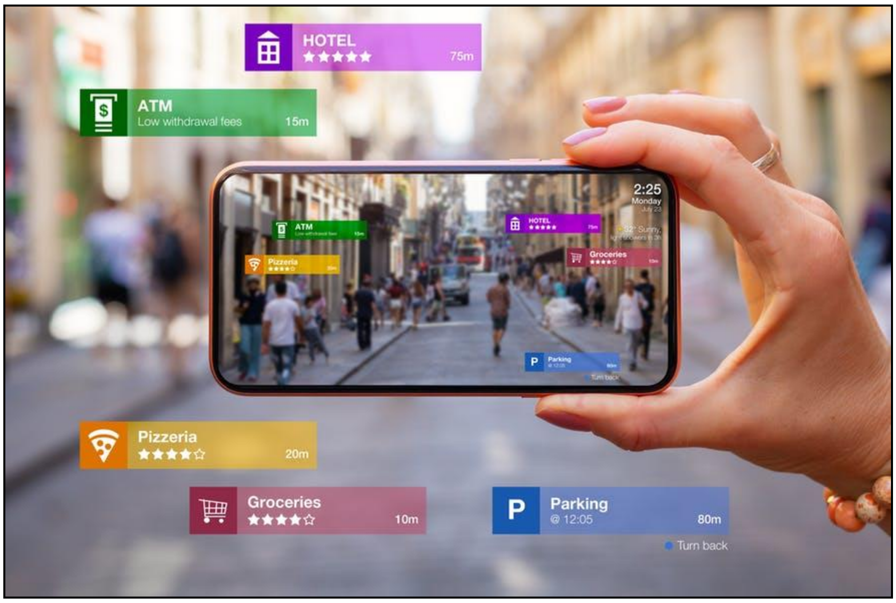

Figure 3-6: Overlay of Digital Information on the Physical World (Source: Lundberg, 2022)

Due to the fact that the provision of *contextual information* transforms users' interactions within their physical environment, research focuses on several domains that are expected to enable the development of AR applications, which will broaden individual and collective intelligence. Indeed, research in the area of AR covers a really wide spectrum, as it ranges from real-time information services to special AR glasses; and AR use cases extend from training and education, to entertainment, gaming, tourism industry and even retail (Houston, 2020).

Some of the defining characteristics of AR are briefly described in the following (Azuma, 1997):

- *'Marriage' between the real and the virtual world*: refers to the fact that both worlds can be experienced at the same time.
- *Context awareness*: superimposed information is directly related to the information users see with their own eyes.
- *Real-time interaction*: any action on behalf of the user has an immediate impact on the recreated scene with AR.
- *Registration and alignment in 3D*: Virtual objects are presented with perspective, giving thus the feeling that they acquire the physical capacity of their surroundings (they appear fixed in space).

Two broad categories of AR applications can be distinguished at large (Softtek, 2021):

- *Marker-based AR*, or *recognition-based AR* or *image recognition* applications rely on target images / labels (markers) to function. Markers refer to distinct patterns that can be easily recognized and processed by cameras, while they are visually independent from their surrounding environment. Maker-based AR works by scanning a marker, which triggers an augmented experience to appear on the device (object, text, video, or animation). It usually requires software in the form of an app, which enables users to scan markers from their smartphones.
- *Markerless AR*, contrary to marker-based AR, offers more control to the users, as it allows them to choose where they would like to place the content; whereas they don't require prior knowledge of their environment to overlay virtual assets into a scene and hold them to a fixed point in space (Schechter, 2020). Simply put, markerless AR places digital content in the physical space, depending on its real features, eliminating thus the need for object tracking systems. This AR category is highly dependent on smart phone features, such as sensors, cameras, processors, GPS, accelerometers, etc.; and is divided into: (i) location-based AR, (ii) projection-based AR, (iii) overlay AR, and (iv) contour AR.

Digital twins

A digital twin is roughly defined as the virtual image (virtual representation) of real-world objects, processes, behaviors, and relationships (natural, built or both). The accurate digital 'copy' contains all the properties, information, and states of the original object and behaves similarly to it when subjected to simulated real-life conditions. This assists in predicting, exploring, and analysing the ramifications imposed on real things when specific circumstances are in effect, much earlier, by exposing their digital counterparts to the exact same conditions (Gade, 2021; Triantafilou, 2021).

Before the term digital twin was even born, urban planners were heavily dependent on computer-aided design (CAD) software and maps, powered by geospatial analytics. The rise and prevalence of IoT completely changed the scenery and digital twins began to gain significant popularity due to their applicability, cost-effectiveness, and ease of use (Miskinis, 2019).

A smart city's digital twin is a data-rich virtual replica of this city that simulates all its vital systems and operations / processes (e.g., transportation network and facilities, building infrastructure, ICT infrastructure, open spaces, online services), combined with real-time data feeds that stem from an extended network of sensors and other sources (see Figure 3-7). This simulation model possesses the role of the facilitator towards planning, managing, and optimizing cities, since it can be applied to myriads of different cases, from urban planning and land-use optimization to utilities and engineering. They actually allow the simulation of scenarios / plans / projects before implementing them (cases of emergency, disaster management scenarios, rescue operations, changes in the environment, etc.), revealing thus possible obstacles or negative ramifications that may appear (Miskinis, 2019; Gade, 2021). Therefore, the adoption / use of these virtual models can lead to: more efficient and knowledge-based decision-making; accurate predictions regarding maintenance issues; reduction of downtime of critical infrastructure, etc.

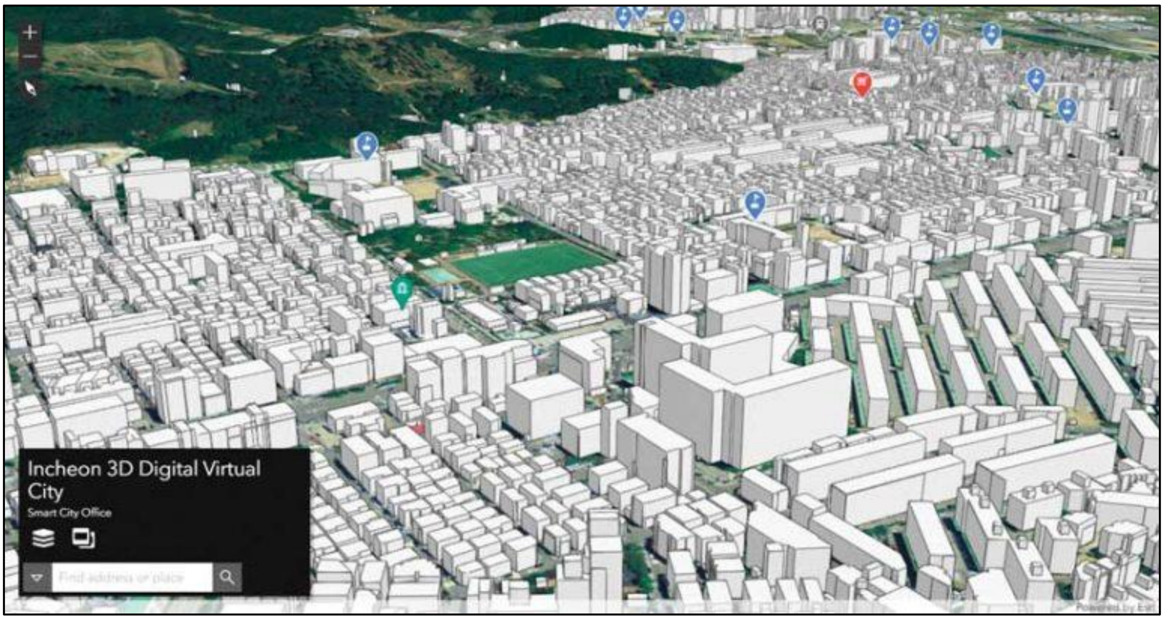

Figure 3-7: Incheon Metropolitan City (Republic of Korea) Digital Twin (Source: Milner, 2021)

Cities that are capable of leveraging this revolutionary digital tool can reap significant benefits in various sectors that range from energy consumption, waste and infrastructure management to mobility and safety / security; thereby becoming more sustainable, resilient and technologically advanced.

Location-aware technologies and location-based services

The accurate detection of a user's location is an extremely important aspect for a prodigious number of smart city applications. This is made possible by the use of *location-aware technologies*, a term that generally refers to technologies that can actively or passively calculate the geographic position of a person, device, phenomenon, or any other moving object "and then manipulate this data to control events and information" (Techopedia, n.d., What Does Location-Aware Technology Mean? section). The most popular example of location-aware technologies is the Global Positioning System (GPS), a navigation system extensively used by vehicles, which calculates their position based on their distance from three satellites.

Location can be calculated on the basis of various diverse methods, such as GPS, Wi-Fi positioning system (WPS), cell tower triangulation, IP address, Bluetooth, etc., which are characterized by different levels of accuracy, response time and battery consumption (Incognia, n.d.).

Location-based services leverage location-aware technologies and imply applications that integrate geographical location (i.e., spatial coordinates) with the general notion of services; or, in other words, services that integrate a mobile device's position with other information, so as to provide added value to a user (Schiller & Voisard, 2004). Examples of such applications include emergency services, car navigation systems, tourist tour planning, 'yellow maps' information delivery (combination of yellow pages and maps), etc.

3.6.3. Web-Based Technologies

Web-based technologies drastically contribute to the overall improvement of quality of urban life, by offering contemporary cities the potential to respond immediately and effectively to the growing demand for more innovative, productive, sustainable, and inclusive service delivery.

The most significant Web-based technologies, that are succinctly described in the following sections, refer to cloud computing, fog computing, semantic Web, open data, and open standards. The application of such recent advancements may lead to the upgrading of the already existing city services and infrastructure; while, at the same time, it can boost the efficacy of critical sectors, such as administration, education, healthcare, public safety, transport, real estate, utilities, etc.

Cloud computing

The mounting volumes of data, but also the continuously growing number of people who use the Internet to serve their needs, force service providers to constantly boost their systems' computing power and to respond efficiently to fluctuations in demand. In that context, cloud computing allows the separation of data analysis, management, and storage from the operating systems from which these data are collected.

According to the European Network and Information Security Agency (ENISA), cloud computing constitutes the most recent and radical milestone in the evolution of computer systems architecture. It is deemed to be more of a new model of delivering computing resources, rather than a new technology per se (European Network and Information Security Agency [ENISA], 2012).

As evidenced by Figure 3-8, cloud computing mainly affects how end users perceive the way information infrastructure and platforms are created, developed, and provided (Laszewski & Nauduri, 2012).

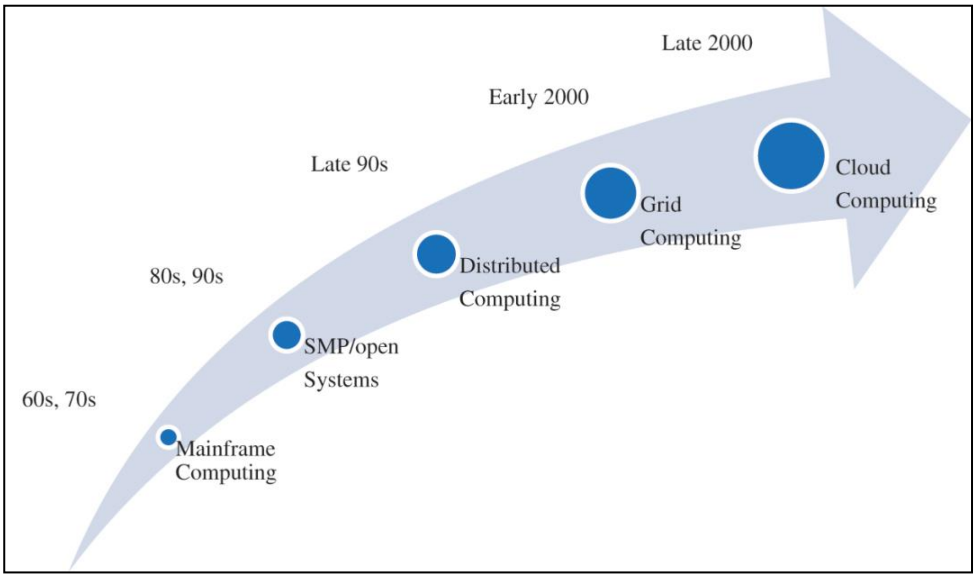

Figure 3-8: The Evolution of Computer Systems Architecture (Source: Alenezi, 2021)

Cloud computing is something akin to a 'cloud-like' infrastructure, located anywhere in the world that provides businesses and other users with on-demand access to a wide variety of applications (Buyya et al., 2009). In this respect,

> computing is being transformed to a model consisting of services that are commoditized and delivered in a manner similar to traditional utilities such as water, electricity, gas, and telephony. In such a model, users access services based on their requirements without regard to where the services are hosted or how they are delivered. (Buyya et al., 2009, p. 599)

Pursuant to the definition proposed by the US National Institute of Standards and Technology (NIST), cloud computing is "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell & Grance, 2011, p. 2).

Another generic definition of cloud computing perceives it as a range of Information Technology (IT) services (infrastructure, platforms, applications) that "could be arranged and used through the Internet" (Kaur & Singh, 2015, p. 215).

The term 'cloud' originates from the network diagrams that are used to represent the Internet, or various parts thereof, as schematic clouds. Cloud computing was coined for describing what happens when applications and services 'migrate' to the Internet (Dialogic, 2017). It actually is a "large-scale distributed computing paradigm" (Foster et al., 2008, p. 60), that makes the online and on-demand access to computing power, storage, platforms and services, feasible.

To put it simply, cloud computing refers to the various types of services and applications that are provisioned via the Internet, while – in many cases – the devices used to access these resources do not need to be equipped with any special applications.

When urban environments are immensely focused on implementing smart city solutions (mostly related to the integration of software into physical objects and the digitization of municipal services), they are called to deal with three basic obstacles (Deloitte, 2017): (i) the urgent need to increase the capacity of their computer systems for data analysis and storage; (ii) the lack of in-house ability to design, implement and manage state-of-the-art technologies; and (iii) the respective funding for the implementation of those solutions. In this regard, apart from the improved capabilities it provides to city authorities, cloud computing constitutes a key pillar in the endeavor to digitize city services, functions and systems; enables the access of businesses, citizens, organizations and non-governmental organizations (NGOs) to enormous computing power and storage (Nowicka, 2014); "allows cities to use managed services to scale their limited resources and reduces the total cost of ownership for smart city solutions" (Deloitte, 2017, p. 10).

Bearing in mind that cloud computing permits the sharing and scalable deployment of services, from almost any location and the fact that customers / users are billed according to the actual usage of the cloud ('pay as you go' billing system or pay-per-use / charge-per-use basis), some of its essential characteristics are described in the following (Mell & Grance, 2011; ENISA, 2012; Schouten, 2014; Novkovic, 2017):

- *On-demand self-service*: computing capabilities (computing power, storage space, database instances, etc.) can be provisioned automatically to costumers, without any human interaction with the service providers.
- *Broad network access (or heterogeneous access)*: cloud computing resources are available over the network and accessible via standard mechanisms [standard-based application programming interfaces (APIs)] that promote usage by heterogeneous user interface devices [e.g., personal computers (PCs), mobile phones, tablets, laptops, and workstations] / diverse client platforms.
- *Multi-tenancy and resource pooling*: the providers' computing capabilities (e.g., computing power storage, memory, network bandwidth) are designed to support a multi-tenant model, with various physical and virtual resources being allocated dynamically, depending on consumer demand. In most cases, customers have no sense or any control or knowledge over the exact location of the provided resources. More specifically, multi-tenancy refers to the fact that numerous users can share the same applications or the same physical infrastructure while, at the same time, privacy and security over their information are ensured. It is similar to tenants dwelling in an apartment block, who share the same building but, at the same time, they have their own apartments and privacy within this infrastructure. Resource pooling implies that the same physical resources serve multiple customers.
- *Rapid elasticity and scalability*: cloud computing resources can be adjusted rapidly, and in some cases automatically, by being scaled up or down in response to demand. These available resources often seem to be unlimited and can be offered in any quantity, at any time.
- *Measured service*: cloud systems automatically control and optimize resource usage, while they also provide reporting and billing information via a

measurement process, that depends on the type of the requested service (e.g., storage, computing power, bandwidth, active user accounts). Thus, transparency to both the service provider and the consumer is ensured and users are billed for services based on the 'pay for what you use' cost model, which implies that payment is based on the actual consumption.

Cloud computing contributes significantly to the real-time processing of data and the simultaneous development of multiple applications (Kakderi et al., 2016). However, its most important element is related to the *'as a Service'* principle, upon which cloud computing is founded (Perera et al., 2014; Shawish & Salama, 2014). This new way of doing things appears to be more and more relevant to the concepts of smart city and smart planning and encourages the disconnection of consumers from the ownership of the object they need. Therefore, users are not obliged to buy the service they desire, but instead, they pay a fee to a provider that offers it. This contributes to the extremely rapid transformation of the computing world towards developing software as a service that can be consumed by millions of customers, rather than running individually on their computers. In a nutshell, the *'as a Service'* rationale promotes the disconnection / separation of a system's different functions and is closely related to efforts towards creating novel, more efficient and environmentally friendly production and consumption models.

Depending on the type of service offered (ranging from ready-to-use software to software infrastructure), three distinct *cloud computing service models* emerge (Lin & Shih, 2010; Mell & Grance, 2011; ENISA, 2012; Shawish & Salama, 2014) (see also Figure 3-9):

- *Software as a Service (SaaS)*: refers to the client's ability to use the provider's applications (software)΄, which run on the cloud infrastructure. The applications are accessible from various devices, either through a Web browser or through a special program. The user does not manage or control the cloud infrastructure (network, servers, operating systems, storage, or even application-specific features), with the possible exception of limited access to particular application settings. In summation, consumers purchase the ability to access and use an application or service that is hosted by the cloud. SaaS examples include Gmail, Google Docs, Microsoft® Office 365, Salesforce.com, etc.

- *Platform as a Service (PaaS)*: allows customers to provide third parties – via the cloud infrastructure – with new applications they develop, using programming languages, libraries, services and tools offered by the provider. Stated differently, PaaS model offers a ready-to-use environment, which facilitates writing and execution of high-quality code in order for customized applications to be created (Stacksale, 2021). The client does not manage or control the cloud infrastructure (network, servers, operating systems and storage), but has control over the developing applications and, perhaps, the configuration settings of the hosting environment. In summation, consumers purchase access to the platforms so as to deploy their own software and applications in the cloud. Typical PaaS examples are Microsoft Azure, Force and the Google App Engine.
- *Infrastructure as Service (IaaS)*: provides the customer with computing power, storage, networking, virtualization and other fundamental computing resources. Thus, users may develop and run software of their preference, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure, but has control over operating systems, storage and developing applications, and possibly limited control over selected network components (e.g., Firewalls and virtual switches). IaaS examples include Amazon EC2 and S3, Windows Live Skydrive, Dropbox, and Rackspace Cloud.

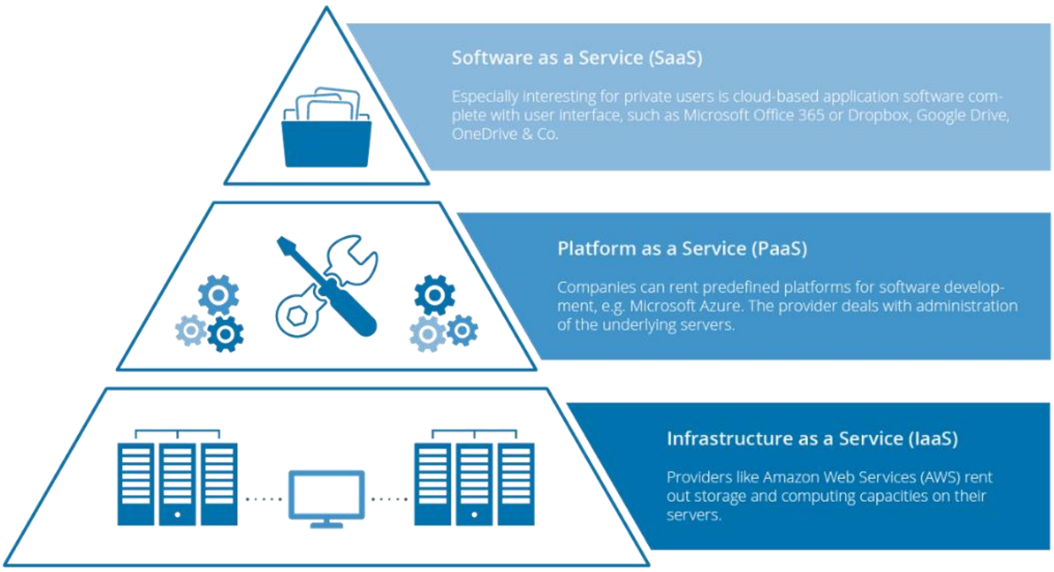

Figure 3-9: The Cloud Computing Stack (SaaS, PaaS, IaaS) (Source: Saifullah, 2019)

Cloud deployment models imply the way cloud services are made available to users. The four deployment models related to cloud computing are the following (Mell & Grance, 2011; Winkler, 2011; ENISA, 2012; Laszewski & Nauduri, 2012; Rountree & Castrillo, 2014; Shawish & Salama, 2014):

- *Private cloud.* On- or off-premises cloud infrastructure that is being exclusively deployed, maintained, and operated for a particular organization with multiple consumers. Ownership, management, and operation may fall under the responsibility of the organization per se, a third party, or a combination of both.
- *Community cloud.* On- or off-premises cloud infrastructure, which is shared among several organizations with similar interests and requirements. This way, capital expenditure costs – pertinent to the establishment of the cloud – are limited, since numerous organizations are involved. Ownership, management and operation may fall under the responsibility of the organization(s), a third party, or a combination of them.
- *Public cloud.* The cloud infrastructure is available to the general public for open use and is located at the providers' premises. It may be owned, managed, and operated by an enterprise, an academic institution, a governmental organization, or a combination of them.
- *Hybrid cloud*. Refers to the integration of two or more clouds (private, community or public) into a single, unified and flexible cloud; thereby allowing data and applications sharing among them. It should be noted that the combined clouds "remain unique entities, but they are bound together by standardized or proprietary technology that enables data and application portability" (Shawish & Salama, 2014, p. 49).

Fog computing

Fog computing, originated by Cisco, is a relatively recent 'perspective' on the way cloud computing works and interconnects with devices; and actually, constitutes an extension of the cloud, since its benefits and power are brought closer to the devices that produce data (Cisco, 2015). Fog computing is founded on the *edge networking* method, which transfers functions from the central nodes to the edge of a network (end devices). This new approach taps into the twofold problem of the massive spread of computing devices and the consequent challenges that arise from the data these devices generate, by locating certain resources and functions at the edge of a network. The term ‘edge’ of a network involves mobile phones, computers and, generally, devices with the ability to receive, transfer and process data. It should be noted that fog computing cannot, by any means, replace cloud computing. Conversely, it complements it, as the latter lags behind in terms of safety and/or speed (Bonomi et al., 2012; Vermesan & Friess, 2014; Cisco, 2015; Sethi & Sarangi, 2017).

The definition introduced by Cisco, describes fog computing as “a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network” (Bonomi et al., 2012, p. 13).

Yi et al. (2015), in a bid to articulate a more integrated definition, claim that:

> Fog computing is a geographically distributed computing architecture with a resource pool that consists of one or more ubiquitously connected heterogeneous devices (including edge devices) at the edge of network and not exclusively seamlessly backed by cloud services, to collaboratively provide elastic computation, storage and communication (and many other new services and tasks) in isolated environments to a large scale of clients in proximity. (p. 74)

According to Figure 3-10, fog computing is a virtualized and decentralized computing infrastructure in which data, storage, applications and other computing resources are located somewhere between the provider (cloud) and the end users (devices). As a result, a three-layer service delivery model is formed.

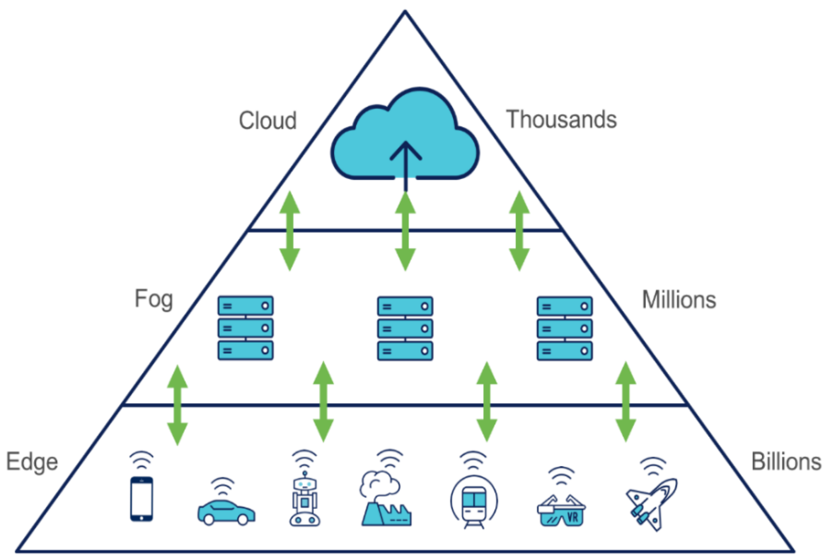

Figure 3-10: Cloud, Fog and Edge Computing (Source: Afonso, 2018)

The philosophy behind fog computing is based on interlaying an auxiliary layer between the nodes of cloud and the edges of the network. Its building blocks are called nodes (fog nodes) and consist of elastic resources (computation, storage and networking) (Yi et al., 2015). The basic function of fog nodes is data sorting, implying the procedure of determining which data should be transferred to the central node of the cloud and what kind of processes can be implemented locally. In other words, end devices are connected to fog nodes, where data preprocessing takes place, thereby improving efficacy and reducing data volumes that finally end up to the cloud for processing, analysis and storage.

Obviously, as already stated, fog computing is not intended to replace cloud computing, but to complete it by extending its capabilities, since its implementation can ensure: (i) reduction of the data volumes that are transferred to the central nodes; (ii) faster response; and (iii) the operation of IoT networks, in cases where the connection of objects to the Internet is unstable.

Fog computing is characterized by several salient attributes that distinguish it from other existing computing architectures (Yi et al., 2015; Syed et al., 2016; Sethi & Sarangi, 2017; Iorga et al., 2018; Jalowiczor et al., 2021):

- *Low latency*. Bearing in mind the proximity of the fog computing platform to the end users, latency-sensitive applications and services' proper functioning and efficiency are immensely supported, as computing resources are located close to the edge of the network.
- *Contextual location awareness*. The geo-distributed fog nodes 'know' their own location in the context of the entire systems; and due to their close distance to the end-nodes, they can easily adapt their features according to diverse end-nodes requirements and provide a high level of location awareness regarding devices that are mobile and spatially dispersed.
- *Distributed nodes / geographical distribution*. Unlike the centralized deployment of cloud nodes, fog nodes are geographically distributed.
- *Support of mobility*. Fog computing greatly supports mobility, taking into account that many end devices are not stationary.
- *Real time response*. In sharp contrast to the cloud nodes, fog nodes are able to respond almost immediately (very low latency).

- *Heterogeneity*. Fog computing supports the collection and management, in a uniform and consistent way, of data that derive from heterogeneous sources (sensors, actuators, cameras, routers, switches, end user devices, etc.).
- *Interaction with the cloud*. Fog nodes can further interact with the cloud by transferring only the necessary data to it.

According to the aforementioned, the deployment of fog computing immensely contributes to (Luan et al., 2016; Jalowiczor et al., 2021):

- *Improved service quality to mobile users*. Fog computing ensures increased data rate, as well as low latency and response time. Moreover, interaction with the fog nodes – which are close to the end of the network – in lieu of the backbone network, entails reduced bandwidth costs.
- *Improved network efficiency*. This is the outcome of the collaboration between the cloud and the fog layers, considering that many functions (data processing, storage, etc.) are moved from the cloud to the fog and inversely, only when necessary. That way the backbone bandwidth remains unaffected, but also energy consumption and carbon footprint of the involved networks are substantially diminished.

Semantic Web

The world is witnessing a tremendous information explosion during the last decades. The Internet is inundated with data and information from a prodigious number of sources of different origins, formats, purposes, scopes, reliability, etc., a phenomenon wisely described by Shneiderman (1997, p. 5) as "the tragedy of the flood of information". Gross (1964) coins the term *'information overload'*, in a bid to express the overabundance of information which – in most cases – prevents people from perceiving reality as is, by complicating the information process and causing cognitive inability. Alvin Toffler, in his futuristic bestseller "The future shock", released in 1970, establishes the word *'over-choice'* to delineate the state in which the perks of diversity are negated by the intricacy of decision-making process. Simon (1971) states that

> in an information-rich world, the wealth of information means a dearth of something else: a scarcity of whatever it is that information consumes. What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention

and a need to allocate that attention efficiently among the overabundance of information sources that might consume it. (pp. 40–41)

Considering all the above, it becomes crystal clear that the effective management of huge and heterogeneous data published on the Web is of crucial importance nowadays. The transition from the Web 1.0 to the Web 2.0 era has already occurred and today's world is on the verge of a new Internet era, marked by the transition from the Web 2.0 to the Semantic Web.

The term *Semantic Web*, reflects the evolution of the current Web (World Wide Web – WWW), as envisioned by its creator, Tim Berners-Lee, according to whom and his partners "the Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation" (Berners-Lee et al., 2001, p. 35) (see also Figure 3-11).

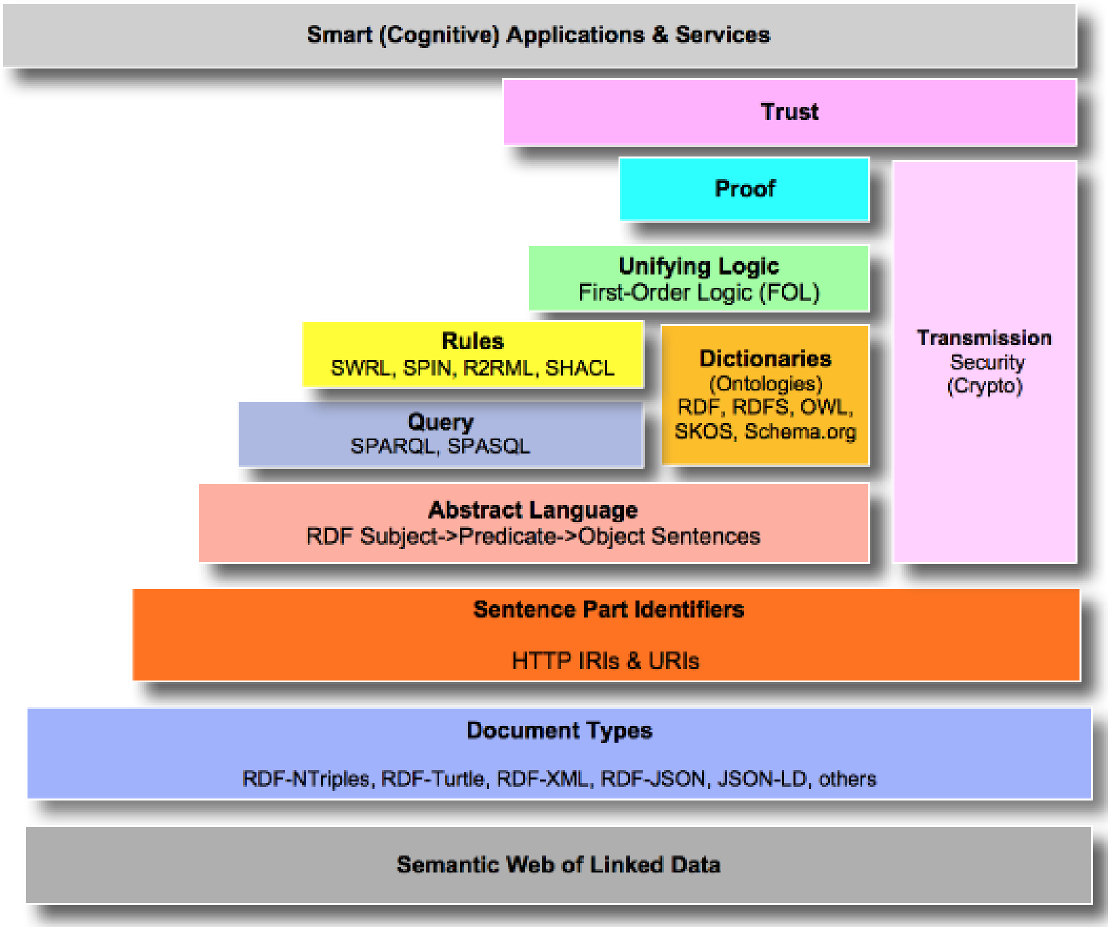

Figure 3-11: Tweaked Semantic Web Tower (Source: Idehen, 2017)

Apart from the semantics of information, Tim Berners-Lee envisages the deployment of millions of specialized reasoning services, which, based on accessible information, support successful task completion. In other words, PCs, laptops, smartphones, etc., will have access to structured information (a common global database); and to a set of inference rules, in order to automatically draw conclusions.

The Semantic Web offers the potential of "tagging content on the Web with computer code that will make finding documents much faster and more precise" (Mancamara, 2010, p.7). The rationale behind this approach is to create metadata to describe the data, thereby attaching meaning to them in a form that can be processed by computers. In this way, convoluted semantic optimization problems can be resolved (Iskold, 2006). Consequently, as Mancamara claims, "in the future, even if links are not clicked and keywords used in searches do not appear in documents, information will be delivered to users based on conceptual matching and profiling" (Mancamara, 2010, p. 7).

In the context of the Semantic Web, data are linked and structured in a common way, so that they can be directly and indirectly processed by machines. Additionally, they may be shared and reused by different applications, organizations, and communities. Therefore, it becomes obvious that the Semantic Web constitutes the biggest project for smart systems' integration, so that they can collaborate interoperably.

The development of the Semantic Web is an extremely ambitious endeavor and constitutes a collective and coordinated effort, led by the World Wide Web Consortium (W3C) (international standards organization for the World Wide Web), together with a large number of research institutes and industries. Its primal goal is to attach semantic content to Web pages and transform the current Web, dominated by unstructured and semi-structured data, into an *'information Web'* (published information will contain metadata that will be available to everyone and machine-readable).

The Semantic Web is, therefore, a grid of interconnected data that contain semantic meaning, which, in turn, can be described by formalisms or vocabularies called *ontologies*. Ontologies provide two essential functions that are necessary and of catalytical importance for the development of the Semantic Web. On one hand, they define the formal semantics of information, facilitating thus its processing by computers. On the other hand, they define the semantics of the real world, thereby allowing the connection of machine-processed content with the meaning attached to it by humans (based on commonly accepted terminology).

Moreover, it is possible to combine data from different sources that share the same ontology. In addition, terminology problems may be effectively confronted, as the meaning of the terms displayed on a Web page can be defined by pointers to the ontology.

Ontologies are able to improve the functioning of the Internet by increasing the search accuracy, as long as the required piece of information refers only to specific concepts and not to some relevant keywords. They can also be used to relate the information of a website to corresponding knowledge structures and logical rules. Finally, common ontologies assist in exchanging data and meanings among different Web-based services. Simply put, a Semantic Web application tries – exactly just like human beings – to comprehend information and draw conclusions (Busse et al., 2015).

Web Ontology Language (OWL) is a family of formal ontological languages that focuses on the representation of complex knowledge (descriptive language) and is designed to be used by applications that are meant to process the content of information, rather than presenting the information per se. OWL enables the implementation of a broad range of descriptive applications, such as management of portals and collections and content-based searches. It is founded on the Resource Description Framework (RDF) (descriptive framework that enables the encoding, exchange, and reuse of structured metadata), but includes a richer vocabulary to describe classes, relationships between classes, properties, etc. OWL supports a much greater degree of web content interoperability, compared to Extensible Markup Language (XML), RDF, and Resource Description Framework Schema (RDF-S), by providing additional vocabulary combined with formal semantics (McGuiness & Van Harmelen, 2004).

OWL languages can be used in myriads of different applications, while the first to adopt it are bioinformatics and healthcare enterprises, private companies, and governments. They are an important step towards rendering Web data more machine-processable and reusable across; and are already being used as an open standard for the development of large-scale ontologies on the World Wide Web.

Open data and open standards

The support of open access to data is a fundamental prerequisite for achieving their interconnection, in the context of the Semantic Web. According to the Open Data Handbook, "Open data is data that can be freely used, re-used and redistributed by anyone – subject only, at most, to the requirement to attribute and sharealike" (Open Data Handbook, n.d., What is Open Data? section).

In order for data to be classified as open, they should satisfy some vital requirements (Open Data Handbook, n.d.):

- *Availability and access*: data must be available as a whole, in a convenient and modifiable form, and at a reasonable reproduction cost.
- *Re-use and redistribution*: data must be provided under terms that allow re-use and redistribution, including the intermingling with other datasets.
- *Universal participation*: everyone should have the right to use, re-use and redistribute the data, without any discrimination against area of activities, particular persons or groups.

Availability of open data ensures *interoperability*. In the context of smart cities, interoperability, which refers to the ability of different systems to work together, is pretty critical for it permits the communication (exchange of data) among the different components that operate in them. This ability to connect various components and share data among them is the cornerstone for building larger and more complex systems.

In contemporary cities, the public domain offers access to databases, thereby encouraging the development of applications for information retrieval and decision-making. Open data that derive from various sources (public administration, sensors, citizens, and businesses), create opportunities for advanced analysis and visualization, facilitate pattern detection, create alerts, display information on the physical space and, ultimately, predict future developments.

Open data go hand in hand with *open standards*. According to the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T)

> Open Standards are standards made available to the general public and are developed (or approved) and maintained via a collaborative and consensus-driven process. Open Standards facilitate interoperability and data exchange among different products or services and are intended for widespread adoption. (International Telecommunication Union's Telecommunication Standardization Sector [ITU-T], n.d.)

The above definition implies that not only are open standards available for anyone to read and implement, but also, the procedure of creating them per se is open to participation.

In conclusion, open standards are an extremely important aspect, especially in the context of smart cities, as they guarantee publishing, access, sharing and use of better data; as well as interoperability among different applications and systems.

3.6.4. Spatial Data Management and Visualization Technologies and Tools

An urban environment is deemed to be a complex spatial *system of systems* (Gardner, 2016) [a joint, integrated system that links individual systems (e.g., energy, water and sewerage, food, transport, health, biodiversity, as well as economic, social, and cultural systems) and allows them to operate together in tandem] (Hirst et al., 2012). More specifically, when it comes to smart cities, these are conceived as "places generating spatial intelligence and innovation, based on sensors, embedded devices, large data sets, and real time information and response" (Schaffers et al., 2012, p. 6).

Planning for such intricate and interconnected systems calls for an *integrated approach*, which, in turn, implies the need for efficiently managing *big data* (extremely large volumes of various and complex data – both structured and unstructured – that inundate a business, organization, etc. on a day-to-day basis) which reflect spatial, sectoral, temporal, etc., urban aspects / attributes. The ability to manage and properly display these data relies on the availability of modern technologies and tools, some of which are briefly presented in the following sub-sections.

Geographic Information Systems (GIS) technologies

Technology has revolutionized the information realm in all scientific areas. After the birth of computer science, the world experienced the advent of information systems, i.e., a set of computer tools capable of providing information about anything through computer programs. A distinct category of those information systems, that has helped to retrieve, manage, and display data from the physical world, is known as Geographic Information Systems (GIS).

According to Folger (2009), the term GIS refers to contemporary computer systems that integrate hardware, software, and data for importing, capturing, storing, managing, analysing, and displaying all forms of geographically referenced information (information with spatial reference). Environmental Systems Research Institute (ESRI) – an international supplier of GIS software, Web-GIS and geodatabase management applications – states that GIS "is a spatial system that creates, manages, analyses, and maps all types of data … it helps users understand patterns, relationships, and geographic context. The benefits include improved communication and efficiency as well as better management and decision-making" (Environmental Systems Research Institute [ESRI], n.d., What is GIS? section).

GIS applications have grown exponentially over the last two decades and are nowadays broadly used in a spectacularly wide spectrum of activities and fields, since they have been introduced in all productive sectors, in central, regional, and local administration, as well as in citizen's services. Bearing all the above in mind, the main goal of a GIS is to support decision-making processes pertaining to land use planning and management, natural resource and environmental management, transport, public health and epidemiology, public safety and defense, urban services, etc. Thus, it constitutes an extraordinary medium for surveying / mapping / communicating local problems and inefficiencies.

The most significant advantages of using GIS include (Artz, 2009; Jensen, 2010):

- *Efficient decision making* – decisions are made easier and have a high degree of objectivity, due to the availability of specific and detailed information.
- *Significant time and financial gains* resulting from greater efficacy.
- *Improved communication* between any involved party, as the visual data and information are easily comprehended by all.
- *Easy recordkeeping, data revisions and corrections*.
- *Managing geographically* – knowing what is going on and where helps plan a course of action.
- *Improved maintenance* of geographic data.
- *Easy searching, analysing, and displaying geographic data*.
- *Increased productivity*.
- *Creation of products with significant added value*.

Web-GIS

The term Web-GIS implies the integration of the Web with the field of GIS, an important development which enhances interactivity with maps and spatial analysis, expanding thus user's potential for participating in decision-making processes.

In fact, Web-GIS is an advanced form of a GIS, available in a Web platform. The exchange of information takes place between a server (GIS) and a client (Web browser, mobile or desktop application, etc.), thereby bringing GIS into the hands of ordinary people pretty easily. Web-GIS provide a platform for integrating GIS into other business systems and thus enable cross-organizational collaboration; while they also allow organizations to properly manage all their geographic data (VizExperts, n.d.).

Their application is expected to rapidly escalate in the future, as highlighted by several researchers (Craig et al., 2002; Silva 2010); and has triggered further developments, especially in the area of participatory planning.

Geographic visualization – Mapping

Geographic visualization or geo-visualization is associated with a set of methods, techniques and tools that facilitate the visual exploration, analysis, synthesis, and presentation of geospatial data through the use of interactive maps; and "serves two important functions, namely communication and analysis… It augments human visual ability in perceiving high complex structures, detecting, exploring and exploiting salient patterns" (Jiang & Li, 2005, p. 3).

Mapping generally refers to the representation of data (e.g., spatial, geological or geopolitical data) and information through the exploitation of their characteristics, their interrelations, and their relations with the geographic space and the entities that exist and take action into this space. Specifically, in the case of spatial data and geographic information "a spatial data modeling process is adopted as a process of representing geographical reality" (Goodchild, 1992, p. 401) and mapping is conceived as "a process that associates a set of spatially related data with another set called a representation or model or map, while preserving spatial arrangements and by simplifying detail" (Lapaine, 2019, p. 3).

Spatial Decision Support Systems (SDSS) and Web-based Spatial Decision Support Systems (WebSDSS)

Spatial Decision Support Systems (SDSS) are interactive computer-based systems, designed to support decision makers in solving complex spatial problems, such as site selection, urban planning, and routing (Sugumaran & Sugumaran, 2007). SDSS incorporate GIS functionalities (spatial data management, cartographic display, etc.), analytical modeling capabilities, flexible user interfaces, and complex spatial data structures (Goodchild, 2000). A Web-based Spatial Decision Support System (WebSDSS) includes a Web-based GIS as a problem solver; and facilitates geographic data retrieval, display, and analysis (Sugumaran & Sugumaran, 2007).

3.6.5. E-Participatory and E-Governance Tools

The recent radical technological advances, the plethora of emerging applications as well as the new potential that derives from them for economic growth, environmental protection, social inclusion, and improved quality of life, have broadly supported planners and policy makers in shaping a smart, sustainable, resilient and inclusive future for urban environments. Moreover, the advent of Web 2.0, which is aptly described by Fuchs et al. (2010, p. 43) as “a medium for human communication”, has offered users the opportunity to interact, communicate and collaborate with each other; and has rendered them creators of user-generated content, thereby broadening engagement and e-Participation.

When planning in convoluted and highly uncertain urban environments, the role of the public – as a valuable and essential source of multidimensional information for developing successful alternative plans – is greatly acknowledged. As participants can and should become contributors to projects that affect their lives and surroundings, it is crucial that the right framework, as well as the necessary technologies and tools, are put in place. In this way, a more effective and pervasive participation context is supported, in alignment with the multi-agent and multi-perspective nature of spatial planning and the need for broadening its scope (Panagiotopoulou & Stratigea, 2017).

In recent decades, cities need to deal with increasingly complex socio-economic issues, whose proper and efficient management has led to the development of respective strategies, based on the creative and innovative exploitation of state-of-the-art technologies. Thus, ICTs are deployed by local governments in order to strengthen citizen participation, public policy implementation or public service delivery (Giffinger et al., 2007). The availability of ICT infrastructure boosts information provision and promotes the development of new applications and services, thereby shaping a novel city environment, which favors innovative collective management and problem solving (Khodabakhsh et al., 2016). Indeed, the application of ICTs in city administration has revolutionized the manner services are delivered, by turning them into smarter, more accessible, and available online. Therefore, local governments interact with citizens via the Internet so as to offer efficacious services and fulfill their requests as soon as possible (López-Quiles & Rodríguez Bolívar, 2018).

Moreover, the introduction of ICTs forces local administrations to follow new and innovative ways of governing. These nascent city models can be identified as multi-system networks, tightly interwoven with human needs. Their effective implementation requires the articulation of a comprehensive and integrative city vision, as well as active citizens' participation (Innes & Booher, 2010).

In fact, public participation acts as a catalyst for transforming cities and rendering them more 'open', friendly and accessible to citizens (Meijer & Bolívar, 2015). Citizens' cooperation and participation in activities related to spatial planning and planning of public services – at all city levels – has attracted considerable attention. These two elements are closely linked with feelings of empowerment and self-efficacy (Danielsen et al., 2005); they strengthen social capital, interpersonal bonds, and trust (Overdevest et al., 2004); they increase awareness and perceptions of place and create a sense of attachment to that place (Evans et al., 2005). Public involvement has also rapidly expanded due to the contribution of new means of communication and interaction, such as social networks, digital platforms, etc., which enable and/or enhance the two-way flow of information between (national, regional, and local) administrations and citizens. Owing to the international economic developments and the financial crisis, the limitation of social policies and the domination of new standards for information and knowledge dissemination, citizens' demand for more active engagement as well as relevant administrative actions, unveil an escalatory bidirectional commitment. Therefore, various ICT applications (mobile applications, digital participation platforms, transparency websites, social media platforms, etc.), have been developed, in order to reach out to citizens and facilitate participation. These 'tools' help city administrations to create *areas of cooperation* in terms of city management (Falco & Kleinhans, 2018).

Taking the above into consideration, it becomes crystal clear that an imperative need for enriching planners and decision maker's arsenal with contemporary digital tools, that decisively contribute the boosting of citizens and stakeholders' *engagement* in public affairs, is coming to the fore. These tools can be adopted / used for supporting planners to (Stratigea, 2015; Stratigea et al., 2015; Panagiotopoulou & Stratigea, 2017, 2021):

- grasp cities' particular economic, societal and environmental attributes (urban context), but also their interrelationships;
- explore, identify and visualize various (spatial) urban problems;
- communicate problems and disseminate potential solutions and policies to the recipients of the spatial planning endeavor (citizens, stakeholders, etc.), while seeking, at the same time, to build consensus and thus achieve a more effective and broadly accepted implementation of the planning outcome; and

- identify policy priorities in each different urban environment, that is totally harmonized with the prevalent value systems.

Towards this end, a brief description of several digital tools, deployed for strengthening public engagement in planning the future of smart, sustainable, resilient and inclusive urban settings, is presented in the following sub-sections, accompanied with distinctive and representative examples.

Basic Web-based participatory tools

The democratic nature of Web 2.0 has rendered it a prominent facilitator for carrying out participatory and collective decision-making processes, by use of a wide variety of appropriate digital tools. Such tools extend from preference functions, wikis, chat rooms, blogs, mailing lists, and rating systems to voting mechanisms and online surveys. They offer strong e-participation potentials and they drastically enhance interaction among different societal groups regarding the outcomes of the planning process. Emerging Web-based participatory tools can be used in urban planning in order to enrich the context and achieve better results of public participation exercises (Kingston et al. 2000; Wilson 2008).

Digital participatory platforms

Digital participatory platforms are meant to promote public participation, civic engagement, and collaboration / interaction. They permit users to create content, while they include several functions (analysis, geographic and cartographic representation, data entry and export, ranking of ideas, etc.) that go beyond and differ significantly from other similar applications, such as social networking sites. On the basis of the level and intensity of participation they allow, these platforms are distinguished in three broad categories (Falco & Kleinhans, 2018): *consulting platforms*, *digital platforms for co-production* and *self-organization platforms*.

Consulting platforms enable citizens to express their views, comments and preferences through consultations and surveys; whereas they do not usually provide information on how public input is utilized by the local governments. The dearth of a two-way relationship results in a substantial interaction and feedback gap between citizens and administrations; and therefore, leads to decisions that are made by following a strict top-down approach (Falco & Kleinhans, 2018).

Digital platforms for co-production allow governments and citizens to work together and tap into each other's assets in the best possible way, so as to reach better outcomes, shared solutions / plans / priorities and improved efficacy (Bovaird & Loeffler, 2012). The widespread use of such platforms highlights the intensified need for developing interactive, collaborative and co-productive digital products, as they promote a socially innovative way of governance, highly marked by citizens and governments' roles convergence towards co-creation (Falco & Kleinhans, 2018). *Spatial representation* of initiatives and projects constitutes a salient feature of co-production platforms. Citizens are able to comment, design and co-create new options and alternatives in specific geographical locations and with special reference to the spatial context. Thus, mapping and geo-visualization tools have a significant impact on engagement practices, as they allow participants to be more precise and specific in both discussion and problem-solving processes. The broad adoption and use of these tools leads to the better understanding of the: urban issues under study; feasibility of proposed solutions; spatial relationships among different elements (Marzouki et al., 2017).

Self-organization platforms, which deal mainly with neighborhood issues of public interest, encourage citizens to create their own solutions on a particular issue, which, afterwards, have to be recognized, facilitated or adopted by local administrations. This type of platforms is less common than the other two (Falco & Kleinhans, 2018).

Crowdsourcing

The term *crowdsourcing* (synthesis of the words 'crowd' and 'outsourcing') was coined by Jeff Howe (2006a) in his famous article "The Rise of Crowdsourcing", published in Wired magazine in 2006 and is defined as *"the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call"* (Howe, 2006b). Additionally, Howe, in his book 'Crowdsourcing', describes four primary types of crowdsourcing, on the basis of how various applications function (Howe, 2008): (i) *crowd wisdom* utilizes collective intelligence of people so as to solve complex problems; (ii) *crowd creation* takes advantage of the ability and insights of the crowd in order to create new products; (iii) *crowd voting* enables the community to vote for their favorite idea, proposal or product; and (iv) *crowdfunding* implies the practice of raising money from a large number of people (crowd) for funding a project, a venture, etc.

Later on, Brabham, in a bid to decipher Howe's definition, claims that "crowdsourcing describes a new Web-based business model that harnesses the creative solutions of a distributed network of individuals through what amounts to an open call for proposals" (Brabham, 2008, p.75). Moreover, Brabham strikes again in 2013 and imbues the crowdsourcing term with new concepts by stating that crowdsourcing is "an online, distributed problem-solving and production model that leverages the collective intelligence of online communities to serve specific organizational goals" (Brabham, 2013, p. xix).

Estellés-Arolas and González-Ladrón-de-Guevara (2012) grasp crowdsourcing as

> a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task. The undertaking of the task, of variable complexity and modularity, and in which the crowd should participate bringing their work, money, knowledge and/or experience, always entails mutual benefit. The user will receive the satisfaction of a given type of need, be it economic, social recognition, self-esteem, or the development of individual skills, while the crowdsourcer will obtain and utilize to their advantage what the user has brought to the venture, whose form will depend on the type of activity undertaken. (p. 197)

Despite the definitional plurality, crowdsourcing reflects a problem-solving approach, which presupposes the involvement of the crowd and results in the selection or shaping of the optimal solution, through the collection of distributed knowledge (Surowiecki, 2004). Pursuant to the aforementioned argumentation, crowdsourcing can be conceived as a form of participatory process that leads to the development and selection of proper solutions, involving, at the same time, various participants with different expertise, knowledge backgrounds, opinions, ideas, etc. It should be noted that, although crowdsourcing was initially introduced and 'flourished' in the business sector, it can be easily adopted / used as a specific kind of public participation (e-participation) as well, for the implementation of urban projects (Brabham, 2009), in the sense that it takes advantage of 'non-expert' knowledge so as to find solutions to spatial planning problems and challenges or to acquire data and knowledge that can feed and enrich the spatial planning process.

Newcastle Smart Mobility Challenge is a typical example of crowdsourcing platforms deployed in the context of smart cities. The challenge was conducted by the city of Newcastle – Australia as a part of its 'Smart Move Newcastle: Intelligent Mobility, Energy and Data' project. Local entrepreneurs, researchers, scientists, students, and anyone able of visioning modern and feasible ideas were called to participate by sharing novel and innovative solutions, notions and ways of thinking regarding the future of the city's transportation system (Herox, 2018).

Volunteered Geographic Information (VGI)

In the field of Geographic Information Science (GIScience), the concept of public participation first appeared in the form of collective mapping. Goodchild (2007) introduced the term *Volunteered Geographic Information* (VGI) so as to describe and attach meaning to the particular phenomenon of volunteered production and provision of geographic information by individuals. More specifically, he defines VGI as a *"special case of the more general Web phenomenon of user-generated content"* (Goodchild, 2007, p. 212). The trend of producing and using VGI has rapidly escalated over the last decades and has even led to the foundation / establishment of new research fields, such as neogeography (Hardy et al., 2012).

The concept of VGI is founded on the perception that citizens can be compared to sensors. According to this rationale, people act both as receivers and transmitters of the information that surrounds them; and thus, they may contribute to the geographic and thematic coverage of large volumes of data with spatial reference (Goodchild, 2007). It should be noted that these data are not only limited to the classic geographic vector data (land use, road network, urban planning zones, etc.); conversely, they can be any kind of data provided by the public and may have direct or indirect spatial reference.

The most well-known application of VGI is, perhaps, *OpenStreetMap*, a collaborative project in which contributors (mappers) add point, linear and surface elements for a specific area, through a map editor. The goal of the project is focused on developing a free, editable, geographic database of the world, based completely on crowdsourced data.

GIS enabled Discussion Forum (GeoDF)

GIS enabled Discussion Forum (GeoDF) constitutes a powerful tool for conducting *spatially-related discussions* among participants who are involved in a planning project, by integrating an online discussion forum with a Web-GIS (Tang, 2006). More specifically, GeoDFs empower citizens to express their opinions on a range of spatial problems, by utilizing user-friendly Web mapping and analysis features and tools. For the purpose of facilitating communication, better understanding and effective interaction, they offer participators the opportunity to express (submit) and share their views as well as raise issues – pertinent to the spatial planning problem that concerns them –; and thus, instigate new discussions with the other involved parties (Zhao & Coleman, 2006). The dominant feature of a GeoDF is the *geographical reference* of participants' comments, through the expression of their views with text messages, notes, sketches, annotations, etc. on a map. Additionally, in order to render the dissemination of users' views more widespread and effective, the system has the capacity to store the different map layers in which a user is intervening and share them with the rest of the 'players'. Views and interventions expressed by each single user (comments, sketches, annotations, etc.) are organized and presented in a manner that instigates vivid discussions and encourages the articulation of innovative and socially-acceptable ideas and propositions that can be incorporated (completely or partially) in the various stages of the participatory process (Zhao & Coleman, 2006). Moreover, discussion contributions can be classified by issues in chronological order, while their distribution is presented on a map (Tang et al., 2005).

Argumentation maps, introduced by Claus Rinner (1999, 2001), refer to an experimental combination of Web-GIS with an online discussion forum, in order to achieve multi-way and structured communication among participants (Tang, 2006). An argumentation map, actually, constitutes an object-oriented model that describes the relationships between a discussion and a map; and is built upon discussion contributions (argumentation elements) and geographic reference objects, totally independent from each other (Keßler et al., 2005).

Urban living labs

Urban living labs are defined as user-centered, open-innovation ecosystems, that operate in the city context, which integrate research and innovation processes within a *public-private-people partnership* (PPPP) (Von Hippel, 1986; Chesbrough, 2003; Komninos, 2006, 2009). Living labs, in this respect, can be perceived as *experiential environments*, where users are immersed in a creative social space for exploring, designing, assessing, and refining their own future, as well as the policies that lead from the current state to the desired one. An interesting city living lab example is the *22@ Urban Lab* in Barcelona. Its goal is to promote the use of public spaces in the city of Barcelona in order tests and pilot programs on products and services with an urban impact to be conducted (sensorization, urban planning, mobility, tourism, education, etc.) in grand-scale, real-life environments (Schaffers et al., 2012).

Public Participation Geographic Information Systems (PPGIS)

Participation in spatial planning requires information that is strongly dominated by visual media (3D representations, maps, images, etc.), since these provide a close representation of reality, with textual description being an important subcomponent (Hudson-Smith et al., 2002). Additionally, bearing in mind that people perceive and understand the information they receive according to their own cultural and social experiences (Lewis & Sheppard, 2006), the adoption of visual media is considered necessary, since they entail limited linguistic and cultural barriers compared to written or verbal messages (Steinitz, 2010). In this respect, geographical visualization of space (urban, rural, insular, regional areas, etc.) is deemed to be a significant means of communicating the different discrete steps of the spatial planning process to the public and stakeholders; while it, also, constitutes a powerful technique for engaging them in decision-making processes (Pettit et al., 2006; Warren-Kretzschmar & Von Haaren, 2014; Panagiotopoulou & Stratigea 2017, 2021; Panagiotopoulou et al., 2018). Moreover, it should be stressed that visualization methods and techniques offer powerful enabling tools that support different tasks in the various stages of a participatory spatial planning exercise. For example, they can be used during the in-depth analysis of the current state of the area under study, so as to trigger public's interest in the spatial planning problem concerned and / or provide a common basis for the exchange of indigenous information and knowledge. They can also be deployed during the alternative scenarios' building process, since participants can use visualizations to illustrate planning solutions and collaboratively develop a shared vision for the future (Warren-Kretzschmar & Von Haaren, 2014).

Despite the fact that traditional communication tools in spatial planning, such as static maps, diagrams and texts still constitute the most common media for diffusing and communicating information, these exhibit great limitations regarding their ability to convey a deeper spatial understanding to lay audiences (Tress & Tress, 2003; Lewis & Sheppard, 2006), mainly due to the absence of interactivity with users. In this respect, interactive visualization techniques and Web-GIS applications can be adopted so as to present various pieces of (spatial) information in a more comprehensible way; and facilitate the investigation of spatial relationships. Consequently, users' awareness and apprehension of a spatial planning problem can be increased, and thus the opportunities for essential public participation are broadened. Users may also contribute by providing additional data through crowdsourcing.

Pursuant to the aforementioned, the concept of Public Participation Geographic Information System (PPGIS) has emerged and focuses on

> community empowerment through measured, demand-drive, user-friendly and integrated applications of geospatial technologies.... It promotes interactive participation of stakeholders in generating and managing spatial information and it uses information about specific landscapes to facilitate broadly-based decision-making processes that support effective communication and community advocacy. (Rambaldi et al., 2006, p. 2)

The development of such systems originates in the 1990s (the term PPGIS was conceived in 1996 at the meeting of the National Center for Geographic Information and Analysis – NCGIA); and aims at *bridging the gap* between public participation and technology, as well as integrating GIS technologies into participatory spatial planning (use of Web-GIS by lay people). Atzmanstorfer and Blaschke (2013) highlight that PPGIS, as an approach which strengthens citizens' empowerment and participation in spatial planning and decision-making at large, may become a substantial tool in favor of Spatial Decision Support Systems (SDSS).

In accordance with Figure 3-12, PPGIS refer to the involvement of non-expert stakeholders in the spatial planning process (Ghose, 2007; Ramasubramanian, 2010), by combining community participation and geographic information on various urban aspects (Steinmann et al., 2004). In other words, they attempt to bring the academic practice of GIS and mapping to the local community, enabling that way citizens' participation in the planning process and effective management of their living environment. In a nutshell, the scope of PPGIS is the *empowerment* and *inclusion* of local and marginalized populations in spatial planning and decision-making processes. PPGIS activity usually involves either community mapping and database development, outside the formal government norms; or seeks expansion and enhancement of public participation and community collaboration in governmental processes for e.g., environmental planning and management (Brown, 2012).

Taking all the above into account, PPGIS constitute a Web-GIS platform used by citizens in the context of various participatory spatial planning exercises. They support online data collection and processing in order to produce new (spatial) knowledge, relevant to a specific planning problem (Craig et al., 2002; Brown, 2012). In a nutshell, it can be perceived as a set of methods, techniques and technologies that allow the integration, inclusion and mapping of indigenous knowledge and various views expressed by participants, in the spatial context to which these refer. In this sense, the enabling and boosting of online interaction and communication with citizens, incorporated in GIS technologies, constitutes a crucial step towards significantly broadening the e-Planning perspective; and greatly supports the effective use by the public, in contrast to the traditional use by the experts (Talen, 2000; Ghose & Elwood, 2003).

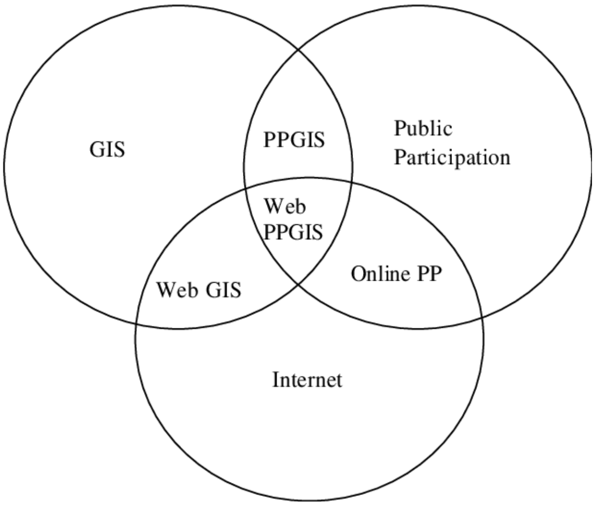

Figure 3-12: GIS, Public Participation, Internet and their Integrations (Source: Tang & Waters, 2005)

Deployment and use of PPGIS offer citizens the opportunity to interact with the planning propositions via a visualized (map) and interactive (online communication) manner, which is impossible when following traditional participatory methods. At the same time, public involvement may potentially result in the enrichment of spatial data, by introducing data and information related to the participants' value system, local culture, history and tradition, etc. Consequently, the final product is far away from a shallow and rigid spatial representation of proposals and interventions that derive from the spatial planning process per se. Conversely, it is a holistic proposal, which encompasses citizens' value system and principles in this spatial representation, serving thus the objectives of participatory planning (Stratigea, 2015).

PPGIS applications may focus on (Panagiotopoulou & Stratigea, 2017; Panagiotopoulou et al., 2018):

- collecting data from various societal groups in order to enrich the spatial planning procedure; and producing new maps, pertinent to the planning problem under study;

- broadening citizens’ empowerment and involvement in the spatial planning process by assigning to them a more meaningful and active role.

Making GIS technologies and systems available to the public (local and less privileged societal groups) for empowerment purposes is certainly a distinctive attribute of PPGIS practice. In this respect, their capacity to generate, manage, communicate and disseminate indigenous knowledge is enhanced; while, at the same time, citizens’ engagement / involvement in spatial planning decision-making is broadened. Finally, PPGIS and can be used in various cases, such as (Rambaldi et al., 2006):

- conflict management among various local groups and between communities and local authorities concerning access, exploitation, control and allocation of resources;
- collaborative research;
- collective resource use planning and management;
- preservation of intangible cultural heritage;
- identity and vision building by local groups;
- transparent and consensual governance in (spatial) decision-making;
- awareness, education and social learning for new generations; and
- promotion of equity in regard to ethnicity, culture, gender, environmental justice and hazard mitigation, etc.

It is worth noting that apart from the typical PPGIS Web applications, communication with users / groups can also be implemented in a conventional way, through interpersonal sessions (Craig et al., 2002); while PPGIS are deemed to be a valuable complement to traditional participation methods (Steinmann et al., 2004).

An indicative PPGIS initiative was successfully launched in Barcelona via *Repara Ciudad* application, an Open Data Cities (ODC) PPGIS platform, which mainly addresses environmental issues. The application allows citizens to report damages and incidents observed in the urban environment to the local administration. The initiative’s aim is twofold: on one hand it attempts to bring inhabitants and public authorities close together so as to strengthen their environmental co-responsibility; and on the other hand, it contributes to the shaping of a more participatory, transparent and efficient public administration (Turiera & Cros, 2013).

3.6.6. Additional Technologies

The particular sub-section delineates two fundamental technologies that are widely used in the context of smart cities and cannot be classified into the aforementioned categories. These refer to artificial intelligence and blockchain technology.

Artificial intelligence

Artificial intelligence (AI) is "the science and engineering of making intelligent machines, especially intelligent computer programs" (McCarthy, 2007, p. 2). It focuses on the design and development of computer programs that can mimic the human cognition skills; thereby displaying characteristics, which are usually attributed to human behavior, such as learning, understanding of natural language and problem solving.

The term 'artificial intelligence' has been established since the advent of computers. Dating back to 1950, Alan Turing, in his seminal article "Computing Machinery and Intelligence" raises the monumental question of whether machines can think. AI began as a systematic effort to simulate human intelligence through machines and computers. Nowadays, it reflects a way of processing data and drawing inferences faster than humans, resulting thus in more accurate predictions. Google's director of engineering, Ray Kurzeil, claims that machines will be on a par with human intelligence by 2029; whereas, by 2045, humanity will have reached *technological singularity* (Davidson, 2019).

The main research streams / disciplines of AI focus on natural language processing (NLP), knowledge representation, automated reasoning, machine learning (ML), automated planning, computer vision and robotics (see Figure 3-13). Two fundamental parameters, *'intelligence'* and an *'artifact'*, always lie at the heart of AI. The computer has been the artifact of choice, as it is widely accepted as the most appropriate for demonstrating intelligence (Russell & Norvig, 1995).

Three distinct types of AI are distinguished. *Artificial Narrow Intelligence* (ANI), *Artificial General Intelligence* (AGI) and *Artificial Super Intelligence* (ASI). ANI or *'weak' AI* refers to any AI that can complete "a narrowly defined and structured task" (Larkin, 2022, What is Narrow AI? section, para. 1) without any human assistance. The above definition implies that the task is a single, predetermined function (e.g., Internet search, language translation, image recognition, self-driving cars, etc.), hence the characterization 'narrow' or 'weak'. Any knowledge gained from carrying out this task is not automatically applied to other tasks (Techopedia, 2022). ANI applications cannot think for themselves, instead they imitate human behavior on the basis of specific rules, axioms, parameters and contexts imposed on the learning algorithm, exhibiting thus a pretty limited scope (Larkin, 2022; Kanade, 2022).

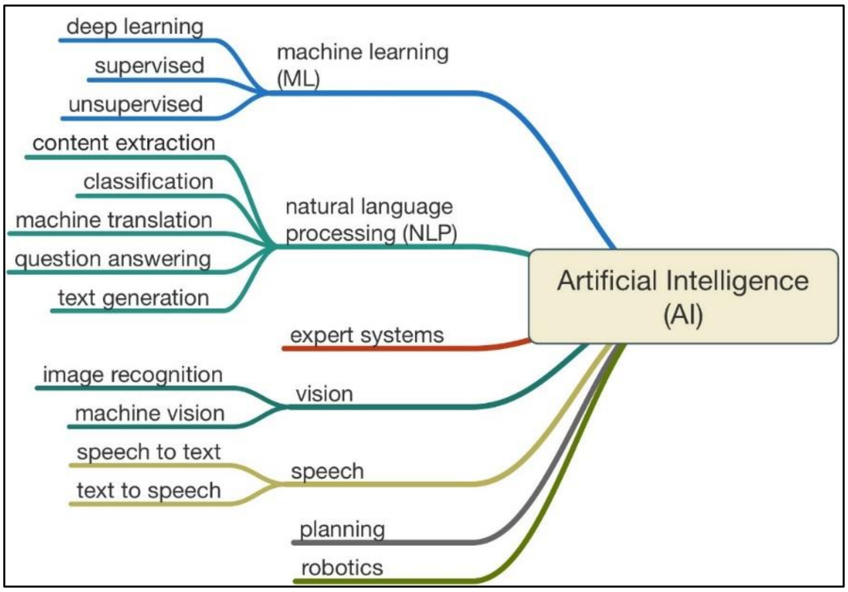

Figure 3-13: Sub-Fields of AI (Source: Neota Logic, 2016)

An AGI or *'strong' AI* system refers to a notional system that has reached parity with the human intelligence, as it is capable of performing any cognitive function that a human being may have. In other words, AGI allows a machine to apply knowledge and skills in different contexts, promoting in this way autonomous learning and problem solving (Davidson, 2019; Larkin, 2022).

According to the aforementioned, ANI is the mankind's technological reality – where it is standing today – and AGI is the technological desired state – where it is moving towards. However, considering the extreme complexity of the human brain but also the immaturity of the state-of-the-art technology, the replication of its biological functioning still remains a desideratum.

Lastly, ASI refers to systems that exceed human capabilities, thereby performing any task better than people. In this hypothetical state – also known as singularity – machines transcend human intelligence, comprehend emotions and experiences, have will, sentiments, and desires of their own, etc. (Kanade, 2022). Such a scenario has deeply polarized scientists, researchers, entrepreneurs, and the public. On the one hand, the optimists focus on the tremendous technological possibilities and opportunities that will emerge; whereas, on the other hand, the pessimists describe a dystopian future, where machines take over and humanity – as we know it today – could cease to exist.

Pursuant to Rjab and Mellouli (2018), AI is closely intertwined with the concept of smart cities since the former can greatly contribute to: (i) intelligent monitoring; (ii) behavioral modelling; (iii) intelligent networks; (iv) treatment of natural resources; (v) interaction with citizens; (vi) industrial automation; and (vii) big data management. Additionally, through a systematic analysis of 125 ‘smart city-oriented’ studies, Rjab and Mellouli (2018) identify 12 basic sectors that draw the most interest, as far as AI applications are concerned: healthcare, home, government, learning, security, transport, human - machine interaction, offices, decision-making, robotics, e-services, and agriculture (see Figure 3-14).

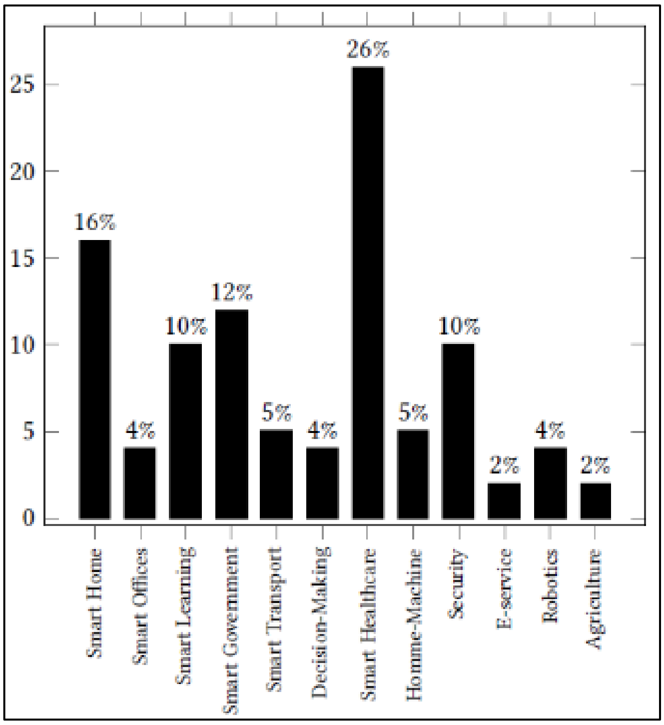

Figure 3-14: The Most Popular Smart City Sectors for AI Applications (Source: Rjab & Mellouli, 2018)

Blockchain

The new media for digital transactions and the rise of cryptocurrencies, such as Bitcoin and Ethereum, have brought to the fore the blockchain technology. As the name implies, blockchain refers to a concatenation of digital blocks that contain data and are distributed among the users.

It can be perceived as a special kind of database / an open decentralized ledger (Marr, 2018) where "immutable records of transactions that do not require to rely on any external authority to validate the authenticity and integrity of the data" (Rodriguez, 2018, The Blockchain: What Is It? section), are kept. Blockchain is designed in such a way that each block (i.e., every link of the chain) is inextricably linked to the previous block, by use of cryptographic methods. As a result, if someone tries to alter / modify a block somewhere in the middle of the chain, all the following blocks have to change as well, in order for the blockchain to remain valid; otherwise, all the digital blocks that come next will be negated.

In this regard, blockchain offers a solid decentralized security framework that allows safe, undisputed, and transparent transactions among users that are carried out directly and without any intermediaries (e.g., financial institutions).

Blockchain has brought drastic changes to a multitude of industries and sectors and is no longer related only to cryptocurrencies (Treiblmaier et al., 2020). It can play a significant role in creating more secure, transparent, efficient, and resilient urban settings by improving their day-to-day operations, particularly in cases where additional trust is required (see Figure 3-15). Therefore, it proves to be a useful technology for smart cities – especially when used in combination with AI, IoT and/or 5G (Treiblmaier et al., 2020) – that can largely conduce to (Joshi, 2022):

- *advanced cybersecurity*, as the risk of cyberattacks is remarkably diminished;
- *enhanced healthcare*, considering that distributed systems for patient health records and transparent medicine supply chains can be developed;
- *improved waste management*, since blockchain provides real-time tracking of numerous parameters pertinent to waste management;
- *simplified education* by creating a centralized, immutable database to which educational institutions have access, while they are also able of sharing information across the blockchain network;
- *increased energy saving* by monitoring energy consumption and demand; and
- *efficient mobility*. Blockchain, combined with IoT devices and systems, can be used for constant real-time tracking of vehicles and passengers. It, also, enables users to securely pay for transportation services; while it acts as a facilitator for mobility-as-a-service solutions (car-sharing, payments, insurance, etc.).

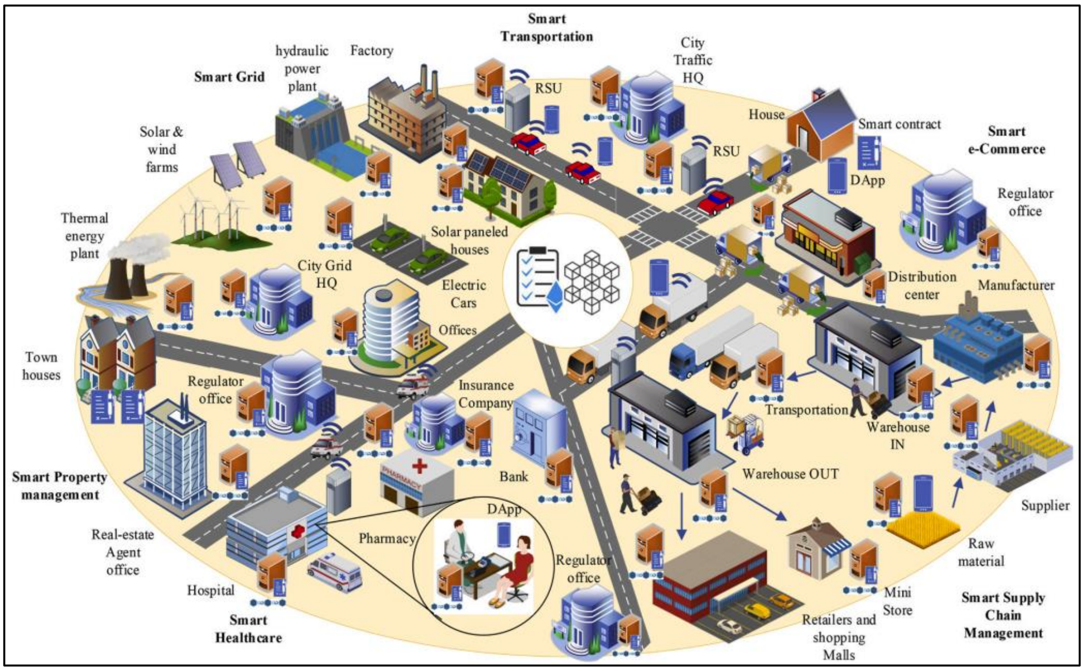

Figure 3-15: Role of Blockchain Technology in Various Smart City Sectors (Source: Majeed et al., 2021)

3.7. Discussion and Conclusions

The evolution of the Web and the cyber space has set the ground for the: (i) illimitable knowledge diffusion; (ii) promotion of innovation; (iii) on-line problem solving; and (iv) dynamic interaction among people. ICTs have permeated almost all aspects of modern globalized world, thereby acting as integrating and enabling technologies (Caperna, 2010) and establishing a new digital era, where “individuals are required to use a growing variety of technical, cognitive and sociological skills in order to perform tasks and solve problems in digital environments” (Eshet-Alkai, 2004, p. 93).

The Incorporation of technological developments and their applications in spatial planning has brought the concepts of *e-Planning* and *e-Participation* to life. These concepts are constantly gaining popularity, since they are deemed to be novel approaches that can fully convey the whole spatial planning process to the Web, thus facilitating public participation and attracting the interest of a wide range of participants. In this respect, modern technologies are considered as means of expanding the planning knowledge base, but also exploring the variety of different views expressed by various societal groups, in order for them to be embedded into the final planning product. Ultimately, they drastically contribute to the upgrading of the planning process per se, via broadening the participatory dimension and therefore delivering an enriched and enhanced final planning outcome (Stratigea 2015; Panagiotopoulou et al., 2018; Panagiotopoulou & Stratigea, 2021).

Literature review unveils a significant range of mature and state-of-the-art technologies and tools that are already available for fulfilling the objectives of participatory e-Planning and e-Participation in the contemporary smart city context. However, an important and noteworthy disproportion between theoretical contributions of tools and technologies to the realms of e-Planning and e-Participation, and the number of their empirical applications, is observed (Geertman, 2002; Campagna & Deplano, 2004). This asymmetry constitutes a major issue for discussion and debate; while its ramifications on expanding public e-Participation remain a matter of sociological investigation.

Some initial attempts to interpret the above discrepancy came to the conclusion that the technological evolution is a necessary but not a sufficient condition for the implementation of successful e-participatory spatial planning exercises. As Viitanen and Kingston (2014) aptly point out, although technology can be a substantially effective means for engaging the public in various debates "smart technologies offer no guarantee about the quality of decisions made in cities" (p. 804). Moreover, experience reveals that the adoption / use of contemporary technologies still requires dealing with numerous intriguing issues that arise and are associated with technical, political, cultural, and social aspects, such as (Kubicek & Westholm, 2005; Macintosh & Whyte, 2006):

- The need for extending ICT applications to spatial planning, in order to achieve the transition from mostly currently implemented, pilot applications to their widespread use, emphasizing in this way their adding value in planning.
- The contribution of technology to the area of public participation should be further stressed, so as to boost, promote and spread the notion of participatory e-Planning; and develop efficacious, user-friendly interfaces for interaction and collaboration.
- The requirement for reliable, discrete, and easily communicated information representation and effective management of participants' contribution.
- The necessity for integrating the technological potential and their applications in political processes and decision makers' organizational structures.

- The assessment of e-participatory processes' outcomes, which can drastically conduce to the improvement of their technological, organizational, political, social, etc. dimensions.

Finally, an important disadvantage observed regards the assessment of the results of e-Participation and e-Planning, in the sense that evaluation criteria and relevant indicators – on the basis of which the effectiveness of their implementation is assessed – should be defined. Having these elements (criteria and indicators) as a reference point, someone can easily delineate the value added by that type of planning exercises.

Effectively coping with the above aspects is quite critical in an information-intensive era, as the concept of smart cities, apart from a new digitally-enabled urban management paradigm for bringing competitive and sustainable urban visions into life, is mainly an evolving *collaborative paradigm*. This new way of doing things is highly characterized by sophisticated ICT infrastructure and relevant applications that can considerably broaden communities' engagement; strengthen interaction and synergies' creation among various actors (policy and decision makers, planners, stakeholders, citizens, scientists, etc.); and promote a cooperative approach, an absolutely necessary prerequisite for coping with great challenges that arise in contemporary city contexts. Such a paradigm may support a user-driven and human-centric tackling of smart cities' planning in the evolving 'urban age', rendering thus spatial planning a powerful discipline for increasing awareness, as well as building consensus and responsibility. Public participation as "the involvement in knowledge production and/or decision-making of those involved in, affected by, knowledgeable of, or having relevant expertise or experience on the issue at stake" (Van Asselt Marjolein & Rijkens-Klomp, 2002, p. 168), but also the digitally-enabled tools and technologies that can open up communities' potential for active engagement, is of crucial importance in this respect.

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CHAPTER 4: Smart, Sustainable, Resilient, And Inclusive (S2RIC) City Examples – A Sneak Peek of The International And Greek Scene

Synopsis: *Unprecedented urbanization rates, extreme climate change pressures, scarce natural resources, unemployment, housing crisis, degradation of environmental quality, health hazards and so on. These are not figments of someone's imagination for a post-apocalyptic movie script, but the true and relentless challenges that most urban environments around the world are already confronted with. In light of this dystopian scenery, several critical questions – relating, among others, to urban planning – arise. Is the smart city paradigm capable and ready to deal with these challenges? Is technology the answer to all problems? Is there a 'recipe for success' when it comes to crafting smart city strategies and adopting innovative solutions? How are the dimensions of sustainability, resilience and inclusiveness embedded – if embedded – in smart city masterplans? What is the citizens' role in a smart city, are they just the recipients of exemplary technological advancements that make their individual lives better or should they be collectively empowered to build a stronger and prosperous society? Taking the above considerations into account, the present chapter focuses on exploring the contribution of the smart city concept to the management of contemporary urban problems by capitalizing on the experience drawn from the international and Greek reality.*

4.1. Getting a Taste of the International Smart City Realm

The present section studies successful smart city examples, deriving from the international scene, and attempts to gain a deep insight into the developmental approach they have been following in their endeavor to jump into the promising high-tech age. In this context, the digital strategies of Singapore, New York and Barcelona are delineated first. These cities are considered to be amongst the most prominent lighthouse paradigms of the smart city concept, since they constantly occupy top positions in numerous relevant lists and benchmarks; and implement a broad spectrum of initiatives that cover all structural dimensions of the smart city model. Next, the section delves into the going smart efforts of Stavanger, Montpellier, Reykjavík, and Cagliari, which, although newcomers in the smart city arena, exhibit remarkable progress and potential.

4.1.1. Singapore

The Republic of Singapore is a small, insular city-state (land area of just 728 Km^2), located in the Southeast Asia, south of the Malay peninsula. The island's distinctive geographic location has rendered it a pivotal commercial node, a fact that led to the establishment of a British trading post in the area in 1819. Today it has the second largest port in the world after Shanghai (World Shipping Council, 2019), offering thus to its territories a decisive comparative advantage over its neighbors. Singapore was an important military base for the United Kingdom (UK) during the first half of the 20th century. The country declared its independence in 1965 and was directly confronted with massive problems, mainly related to scarce natural resources, high unemployment rates, and intense inter-ethnic tensions.

Today, Singapore does not resemble in any way the ghost of the past. On the contrary, it is a contemporary, international, vibrant, economic and financial node; it accommodates 5.5 million inhabitants; and is considered to be one of the pioneers in the use of Information and Communication Technologies (ICTs) in city services (Johnston, 2019).

Singaporean economy is heavily dependent on *manufacturing* and *service provision*, with manufacturing of raw materials, machinery export and oil refining being the most important and profitable sectors (Lim, 2013). In 2021, manufacturing industries contribute 22.3% to Singapore's nominal GDP, while the respective share of the service industry is almost 70% (Department of Statistics Singapore, 2022).

The limited space for growth – due to its small size – and the dearth of natural resources, have forced Singapore to pursue an alternative path to economic prosperity, escaping the norms and the traditional ways of development and shifting towards *technology*. As a result, a series of national plans, aiming at reforming governance, industry, and social life, have been launched (Hoe, 2016). The *"National Computerization Plan"*, initiated in the 1980s, intended to introduce computing technologies to the public sector and was focused on developing new technologies for automating data processing and modelling, and promoting the development of local industry in the field of Information Technology (IT), 'building' at the same time the appropriately trained workforce (Tan et al., 2013). Later on, in 1986, the *"National IT Plan"*, that drastically contributed to the further blossoming of the local IT industry and laid the foundations of the national broadband infrastructure (Hoe, 2016), was implemented. In 1991, the *"IT 2000"* plan, which capitalized on the success of the previous national strategies, was put into action and targeted the rapid expansion of information technologies to sectors other than the public. In the context of "IT 2000", a combination of multiple, diverse technologies is promoted in various sectors, such as traffic management, public libraries, exchange of medical information, etc. All the above are followed by strategies such as *"Infocom 21"*, *"Connected Singapore"* together with the *"e-GAPI"* (2000-2003) and *"e-GAPII"* (2003-2006) projects. Moreover, in 2006, the *"Intelligent Nation 2015"* strategy, together with the *"iGov2010"* project (2006-2015) are launched.

Today, ICTs contribute 5.6% to Singapore's economy, with the majority of private enterprises operating in the programming sector (Department of Statistics Singapore, 2022).

Smart Nation Singapore

Singapore has been planning its smooth and effective transition from the smart city paradigm towards the *'smart nation'* model since 2014. Its vision for the future is imbued with the idealistic notion of a 'smart nation' and wishes to effectively respond to the extremely pressing urban challenges the country is facing, such as ageing population, constantly escalating urban density and major energy sustainability threats (Lee et al., 2016). Its relatively limited geographic size and its 40-year focus on developing new technologies, upgrading its human resources, and incentivizing the technology industry are conducive to the implementation of such a plan, but under no circumstances does that entail that the 'smart nation' goal can be attained immediately or effortlessly. So far, Singapore has managed to transform itself into a leading example in the application of ICTs in specific sectors through a series of smart initiatives.

The pillars that comprise the cornerstones of Singapore's Smart Nation strategy are:

- *Digital economy*.
- *Digital government*.
- *Digital society*.

Digital economy

According to the World Economic Forum (WEF) and the G20, the term *'digital economy'* is defined as a broad range of economic activities that include all jobs in the digital sector, as well as digital jobs in non-digital sectors (Infocomm Media Development Authority [IMDA], 2018). Pursuant to Pratt (2017), "the digital economy is the worldwide network of economic activities, commercial transactions and professional interactions that are enabled by Information and Communications Technologies. It can be succinctly summed up as the economy based on digital technologies".

The reason behind placing great emphasis on digital economy is mainly associated with the effort to perceive and monitor global financial developments that are deeply affected by the *digital transformation*. Digital economy undermines conventional notions about how businesses are structured and operate; how firms interact; and how consumers obtain data, information, services, and goods in the contemporary high-tech era. Today, a tremendous growth in the annual turnover of multinational companies, operating in e-commerce, is marked; whereas, at the same time, traditional retail is suffering from severe pressures, with large retailers experiencing humongous declines in turnover.

Huge multinationals, such as Amazon.com, Inc. and China's Alibaba Group Holding Limited have made strategic capital investments in Singapore during the last years. Moreover, big data management, new applications in robotics and 3D printing, cloud computing, and advances in Machine Learning (ML) and Artificial Intelligence

(AI) offer new opportunities to all economic sectors. Thus, it becomes evident that digitalization constitutes an international imperative that ensures a more sustainable, prosperous, and secure future.

Singaporean economy's journey towards the digital reality guarantees business growth and better jobs that are expected to assist the country in developing new competitive advantages and continuously attracting significant investments and high-skilled, talented workforce. The transformation plan is facilitated by the implementation of the *"Digital Economy Framework for Action"*, which is founded on three strategic priorities as these are illustrated in Figure 4-1:

- The first priority regards the *acceleration* of the digitalization of the industrial production processes, with the simultaneous intensification of technology's penetration in every workplace, so as to increase productivity and achieve economic growth in the medium term.
- The second priority concerns the creation of a *high-tech enabling environment* to boost businesses' economic *competitiveness* in the global market.
- The third priority refers to the *transformation* of the infocommunications industry into a key economic growth engine and a digitalization driver across all industries.

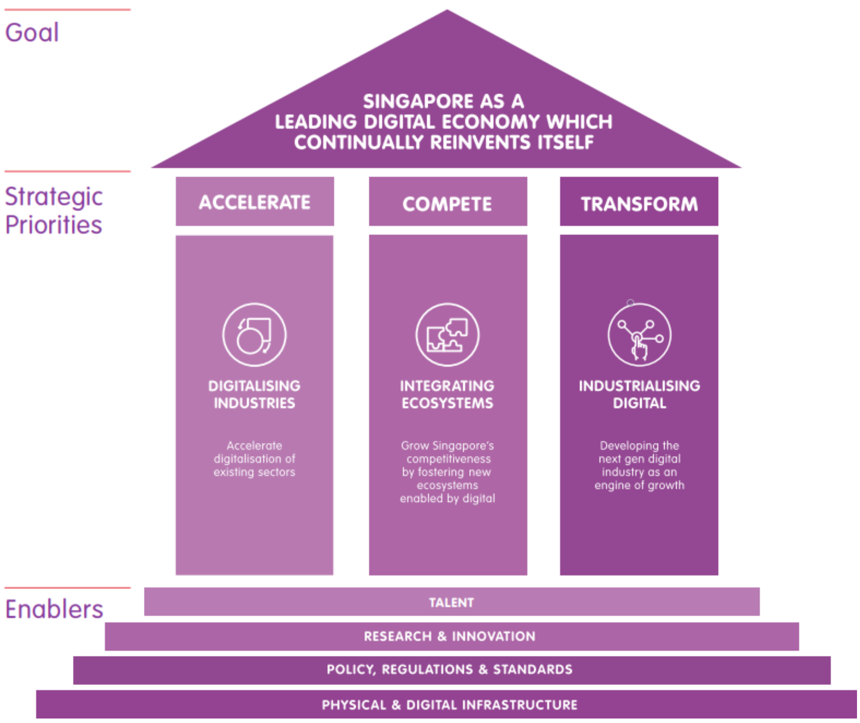

Figure 4-1: Singapore's Digital Economy Framework for Action (Source: IMDA, 2018)

The factors that underpin the success of these strategic priorities are related to the population's digital skills, research and innovation, the policies and regulations that should be followed and finally the physical and digital infrastructure (Figure 4-1).

Digital government

Digital government aims at defining the relationship among three key stakeholders – *citizens, businesses, governmental agencies* – in the digital era (Figure 4-2). The digital government strategy adheres to two fundamental principles that demarcate the way of governance, as outlined in the *"Digital Government Blueprint"* (Government Technology Agency of Singapore, 2018). The first focuses on *fully digitizing* the abovementioned relationship, so that the government can decisively transform its services, production processes and technological infrastructure to better serve citizens, businesses, and civil servants, through data, connectivity, and the use of computing systems. The second revolves around a holistic, *citizen-oriented rationale*, inextricably linked to people's needs and aspirations.

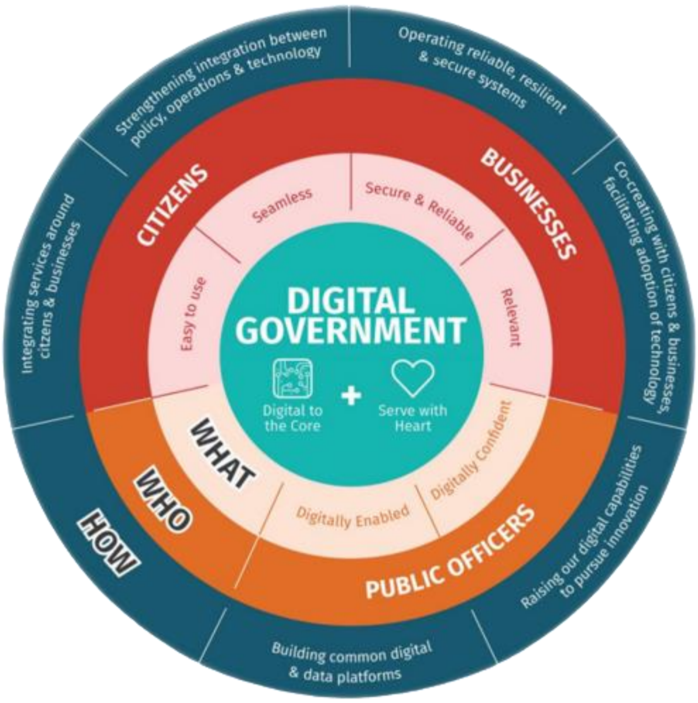

Figure 4-2: Singapore's Digital Government Blueprint (Source: Government Technology Agency of Singapore, 2018)

Digital government's ultimate goal is to provide high-standard services that are: *user-friendly* and *easily accessible* by everyone at any time and from any device; *secure* and *reliable*, making thus people feel protected regarding their data and confident about the infrastructure they use; *relevant*, i.e., designed to meet citizens and businesses' needs by providing seamless services.

At the same time, civil servants should be given the opportunity to work in a technologically advanced environment that allows access to digital applications and data and makes collaboration with other services possible. Moreover, all public services ought to be staffed by properly trained people with sufficient knowledge of the use and operation of digital systems, so that they can capitalize on their potentials and skills.

Seeking to attain digital government's objectives, the following six strategies are crafted (Figure 4-2):

- *Integrating citizens and businesses' needs into the service development philosophy*. In other words, new applications and services should adopt a city- and citizen-focused approach.
- Strengthening the *embedment of technology* into proposed policies and their respective actions.
- Building *shared data platforms*, thereby drastically reducing the time and effort needed to render new digital services fully operational.
- Developing *reliable, resilient, and secure operating systems* that protect citizens, businesses, and government agencies' data.
- Cultivating the workforce's *digital skills* to boost innovation.
- *Collaborating with citizens and businesses* in exploring and providing solutions, as well as in encouraging the adoption of novel technologies.

Digital society

Digital readiness is deemed to be the key driver of Singapore's digital society strategy and is defined as the state in which all Singaporeans have the capacity to fully leverage the opportunities and possibilities arising from the continuous increase in the use of digital systems in all aspects of the city. To do so, citizens should (see also Figure 4-3): (i) have *direct and uninterrupted access* to affordable, reliable digital infrastructure for all; (ii) possess the necessary *digital skills* to use available technology with confidence; and (iii) harness the power of *online participation*, thereby achieving a better quality of life.

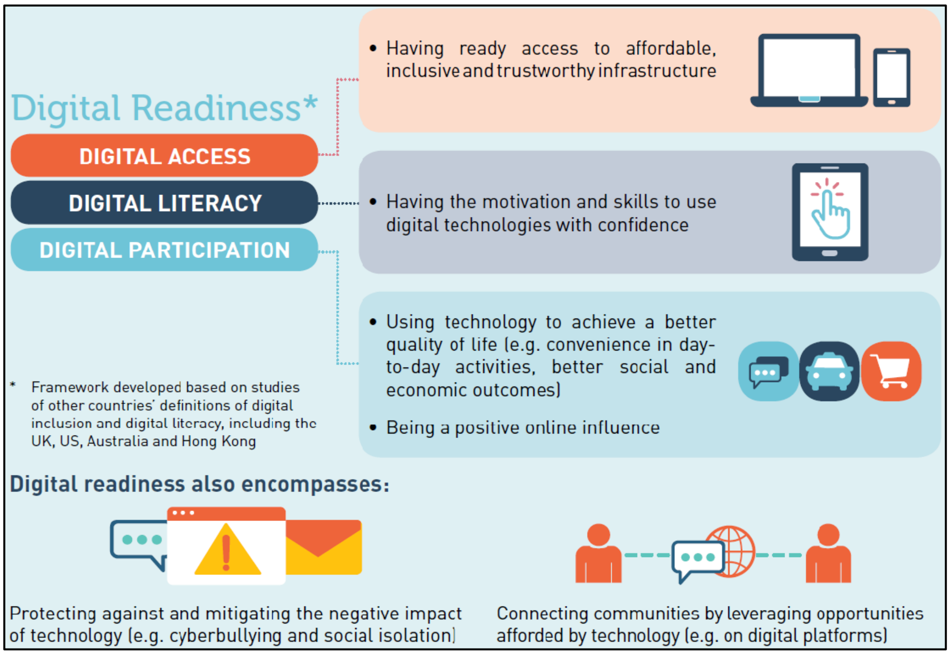

Figure 4-3: The Pillars of Singapore's Digital Society Strategy (Source: Ministry of Communications and Information, 2017)

In this context, four strategic initiatives, that target the attainment of digital readiness, are proposed (Figure 4-4) (Ministry of Communications and Information, 2017):

- *Digital access for all*. Besides focusing on the possession of computing devices and the number of Internet subscriptions, this initiative also implements two extremely vital proposals: (i) the enforcement of a National Digital Identity plan, which ensures access to public, financial and health services; and (ii) the adaptation of access to digital services for people with disabilities.
- *Integration of digital knowledge into national consciousness* by upgrading citizens' digital skills; deepening the knowledge of information and its means of dissemination; and educating the youth about the rational and socially responsible use of technology.
- *Empowerment and motivation of communities and businesses to adopt cross-cutting technologies* by encouraging public and private organizations to step up efforts towards assisting employees and service users in familiarizing with technological changes; supporting projects that promote community involvement; providing help to any citizen who is trying to adopt new technologies, with particular focus on vulnerable social groups (e.g., older people).

- *Promotion of the "digital inclusion" rationale*. Regardless of the form and the content, any digital initiative ought to be designed in such a way that it is easy for everyone to participate in it. Therefore, digital inclusion in Singapore is expected to be attained by urging organizations to develop applications, programmes, initiatives, etc. that can be used by all; and by ensuring that relevant services are available in different languages so that they are accessible to all.

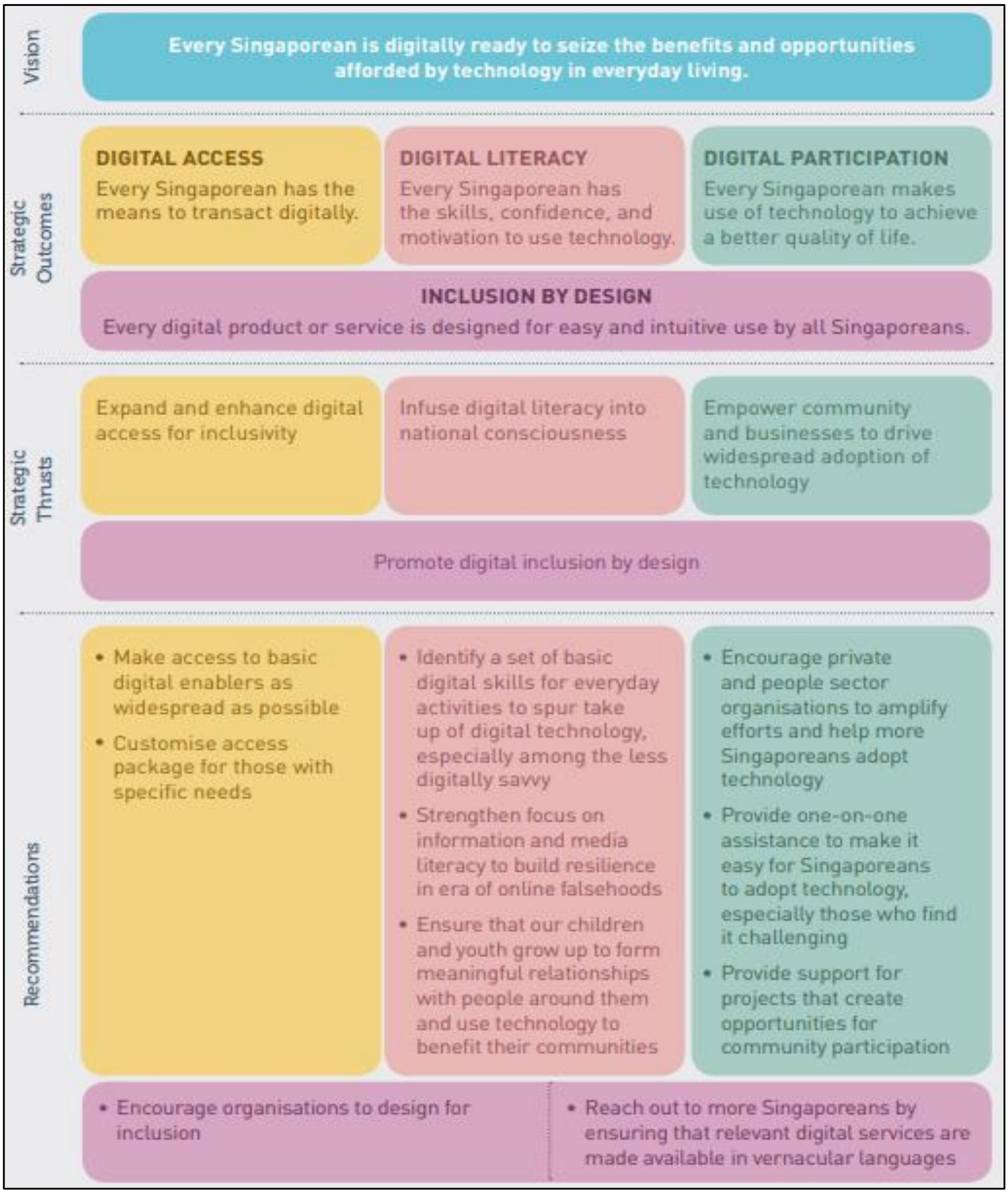

Figure 4-4: Singapore's Digital Readiness Blueprint (Source: Ministry of Communications and Information, 2017)

Singapore's smart initiatives

As already stated, the strategic planning approach that Singapore has been following during the last decades targets the transition from the 'smart city' paradigm to the 'smart nation' rationale. The particular section analyses national strategic programmes and sectoral smart city applications launched in Singapore, and the way they have affected the lives of residents.

The applications and programmes proposed and implemented in the context of the *'Singapore Smart Nation'* strategy are classified into six categories of initiatives:

- *Strategic national projects.*
- *Urban living.*
- *Transport.*
- *Health.*
- *Digital government services.*
- *Business and finance.*

Strategic national projects

The first package of initiatives includes the programmes considered essential for Singapore's endeavor to become a smart nation. These are (see also Figure 4-5) (Smart Nation Singapore, 2023f):

- *GoBusiness*: digital platform that facilitates businesses' access to governmental e-services and resources, rendering that way relevant transactions easier, quicker and friendlier.
- *CODEX*: shared digital platform that allows public authorities to provide improved, faster and more cost-effective digital services to citizens.
- *E-Payments*: open, accessible, and interoperable national electronic payments infrastructure. This effort has been under way since 2014, with the creation of several systems and applications that enable electronic transactions among different stakeholders (FAST, PayNowCorporate, NETS, PayNow, SGQR).
- *LifeSG* or *Moments of life*: attempt to deliver integrated information and services to citizens, focused on the needs of every single user, but also on providing proactive support (e.g., families with newborn or young children, elderly people).

- *National Digital Identity (Singpass)*: programme specially designed to allow Singaporeans to interact electronically with government and other private service providers in a secure and convenient manner. Such applications have been tested and implemented since 2003 (SingPass, MyInfo).
- *Smart Nation Sensor Platform*: integrated, nationwide network of wireless sensors that has been established since 2018 and aims at collecting essential data for improving urban planning, public transportation, and public safety.
- *Punggol Smart Town*: integrated masterplan that focuses on the development of a digital innovation district in the north part of the city, where academia, industries and community are brought together to promote innovation and creative ideas.

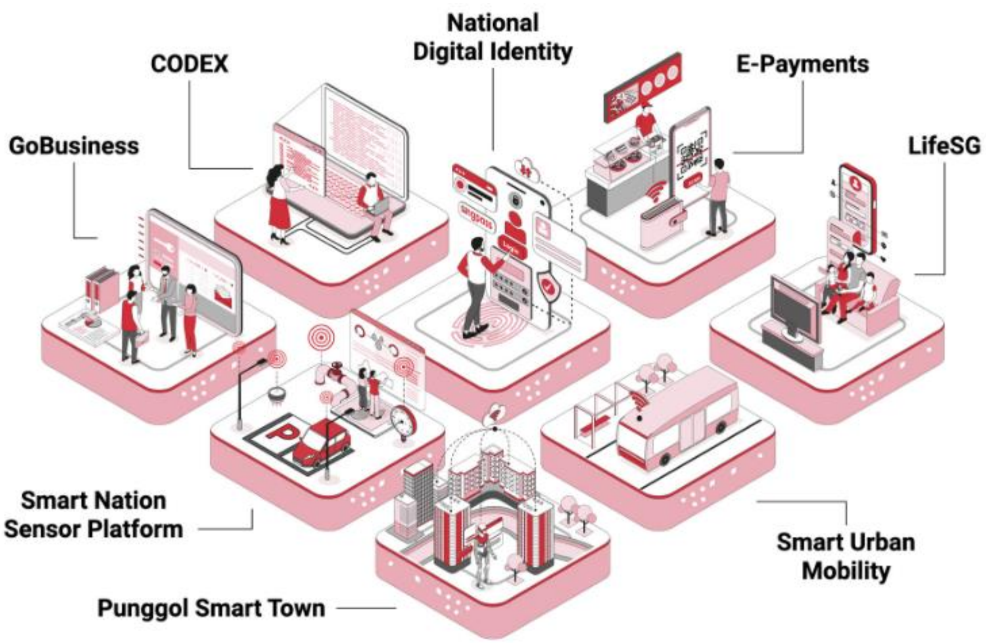

Figure 4-5: Singapore's Strategic National Projects (Source: Smart Nation Singapore, 2023f)

Urban living initiatives

Given that Singapore's urban development is largely constrained by its limited available land, the *urban living initiative* comprises innovative applications that seek to upgrade the urban environment and housing, thereby rendering them safer, more sustainable, and livable. The initiative includes the following applications (Smart Nation Singapore, 2023e):

- *Automated meter reading*: smart water meters for monitoring water consumption and gathering relevant data that are accessible via a mobile app. In this way, users have an overview of the consumed water and are immediately alerted in case of possible network failure. According to Singapore's targets, 300,000 smart water meters will have been installed in households, businesses and industries by 2023.
- *Dengue hotspots survey drones*: use of drones to monitor roof gutters –typical spots where stagnant water is gathered that is conducive to the 'flourishing' of mosquito breeding grounds – easily. Drones are also equipped with insecticides to extinguish mosquito habitats, since they are responsible for dengue virus outbursts.
- *myENV app*: digital tool that informs the public about the latest environmental updates (weather and air quality conditions, drain water levels and floods, water service disruptions, dengue virus outbreaks, etc.).
- *OneService app*: one-stop platform that enables citizens to report problems related to municipal issues, without having to figure out which governmental agency they should reach out to. Therefore, communication between public authorities and citizens is direct and easy, a fact that substantially contributes to the overall improvement of everyday life in the city.
- *Smart urban planning*: Singapore's Urban Redevelopment Authority (URA) strives to achieve urban and economic development in a sustainable manner, by integrating state-of-the-art digital innovations and open data into planning and decision making. URA has developed several digital tools for reducing commuting time; improving public healthcare accessibility for the elderly citizens; helping the public to make informed choices on when to head out without compromising safety due to the COVID-19 pandemic; and enabling planners and other relevant agencies to access advanced spatial visualizations, analytics as well as various land use planning data and information.
- *Elderly monitoring system*: digital system that learns elderly people's daily habits with the help of motion sensors, that are installed in their residencies, and alert their caregivers in time of need or when unexpected behavioral patterns are observed.

- *Smart Towns*: Singapore's approach to urban development and smart housing is founded upon its *"Smart Town Framework"*, which identifies – inter alia – five key dimensions for developing smart towns and shaping improved and sustainable living conditions through the deployment of advanced technological solutions (Priya, 2019): (i) *smart planning*; (ii) *smart environment*; (iii) *smart estate*; (iv) *smart living*; and (v) *smart community*. In order for the "Smart Town Framework" to be efficiently implemented, Singapore has established the *HDB Smart Hub*, which collects and integrates real-time data and information, stemming from multiple sources. Gathered information provides indispensable insights that may help municipal authorities to improve urban planning, building design and city management (Kan, 2018).
- *Virtual Singapore*: dynamic 3D digital replica of Singapore that permits citizens, businesses, governmental agencies and research organizations to conduct simulations and virtual tests of new solutions to urban planning problems (National Research Foundation [NRF], 2021).

Transport

Singapore's transport infrastructure occupies up to 12% of its available land. As the city's population continues to grow without having the ability to sprawl, urban mobility gathers the most radical smart services implemented in the city (Lee et al., 2016). The most important of them are (Smart Nation Singapore, 2023d):

- *Autonomous vehicles*: Singapore intends to reap the benefits of self-driving technology so as to drastically alter the transportation system and substantially upgrade the urban living environment. The widespread use of autonomous vehicles is expected to remarkably contribute to safer travels, reduce traffic congestion, improve travel options for the elderly people, etc. Tests have already been carried out by both private companies and research centers and universities for various types of vehicles.
- *Center of Excellence for Testing and Research of Autonomous Vehicles (CETRAN)*: established in 2017 by the Land Transport Authority (LTA) and Jurong Town Corporation (JTC) in partnership with Nanyang Technological University (NTU), CENTRAN is a test-bed for self-driving technologies,

where researchers work on developing international standards for autonomous vehicles as they test, certify, trial and deploy these vehicles on a large scale.

- *Contactless fare payment*: public transport users have the option, through the SimplyGo app (account-based ticketing system), to pay for their commuting fares via contactless bank cards, mobile phones or smartwatches.
- *On-demand shuttle*: real-time, demand-driven, smart application based on self-driving technology and communication with users, that allows on-demand booking of autonomous vehicles via a mobile application. Testing of autonomous shuttles has begun since 2018.
- *Open data and analytics for urban transportation*: gathering and provision of real-time data and information on urban mobility aspects. In this way municipal authorities can improve their transport planning and inform citizens about transport-related issues (real-time bus arrival timing, taxi and parking availability, traffic conditions, etc.).

Health

Considering the steadily growing share of elderly people and the low birth rates, it becomes evident that the healthcare sector takes precedence in Singapore's policy agenda. Several projects and applications focusing on delivering advanced technological solutions to proactively manage the abovementioned issues and equipping Singaporeans with the necessary tools, information and data to better take control of their healthcare needs, have been introduced. The most significant smart initiatives to improve healthcare are listed below (Smart Nation Singapore, 2023c):

- *Assistive technology and robotics in healthcare*: introduction of revolutionary technologies in the healthcare sector with the ultimate goal of delivering practical applications that will efficiently aid those in need and will offer them a better quality of life, increasing at the same time the overall productivity of healthcare services and facilities.
- *HealthHub*: often characterized as Singaporeans' *'digital healthcare companion'*, HealthHub is a digital tool designed to provide access to information on healthcare services. It allows users to obtain an overview of their healthcare history, medical appointments, prescriptions, medical fees, etc., at any time.

- *National Steps Challenge™ & 365 app*: nationwide, fitness tracker-based physical activity initiative that motivates Singaporeans to move more, promoting thus a healthier and more active lifestyle. By use of the 365 mobile application, users can track their daily steps, monitor their nutrition and get rewarded when they reach certain physical activity milestones.
- *TeleHealth*: launched in 2017, the programme allows users to contact medical staff remotely via video conferencing. Therefore, available resources are managed much more rationally, healthcare's productivity is noticeably increased; patients' need to visit a healthcare institution is drastically reduced; and problems relating to limited medical staff are properly addressed.

Digital government services

Digital government services initiative is associated with major projects and applications intended to improve the interaction of governmental services with citizens through the following contemporary, tech-enabled solutions (Smart Nation Singapore, 2023b):

- *CentEx*: center of excellence for ICT and smart systems, where specialist engineering expertise will be developed to support the government.
- *CrowdTaskSG*: Web portal for engaging citizens and gathering useful insights through crowdsourcing tasks (surveys, opinion polls, choice questions and translation requests).
- *Digital birth and death certificates*: fully digitalized birth and death certificate generation, issue and publication services.
- *HDB Resale Portal*: Web portal for buying and selling flats.
- *Multilingual digital services*: accessible to all inclusive governmental services, translated into Singapore's four national languages.
- *OpenCerts*: blockchain-based platform, whereby educational institutions can, in an easy and reliable manner, issue and validate digital academic certificates.
- *Parents Gateway*: online platform that makes digital communication between parents and schools on administrative issues possible, skipping thus the need for physical presence.
- *SG Translate Together*: Web portal that allows users to generate localized translations.

- *SG Government Developer Portal*: Web portal that assists developers and other technology professionals in exploring the latest government technological solutions and integrating them into their own applications.

Businesses and finance

Business and finance initiative package seeks to shape a stable, secure, prosperous and fully digitalized economic environment that helps existing businesses to thrive while attracting new ones, and includes the following applications (Smart Nation Singapore, 2023a):

- *Corppass*: single authentication and authorization system that enables businesses to transact with governmental electronic services in a secure, reliable and user-friendly way.
- *Data Innovation Program Office (DIPO)*: specialized in innovation, DIPO has a two-pronged goal to encourage and facilitate data-driven innovation projects on one hand; and to ensure the smooth development of data ecosystems in Singapore on the other.
- *FinTech Sandbox*: in a bid to promote and maintain Singapore's image as one of the very few leading financial hubs worldwide, governmental authorities have established the *"Smart Financial Center"* that is expected to provide local financial institutions the required facilities and infrastructure to experiment with new, innovative, financial technologies in a secure environment.
- *Networked Trade Platform*: information management platform that renders the way of managing trade documents digitally pretty convenient, seamless, and secure.
- *Singapore Financial Data Exchange (SGFinDex)*: centralized digital infrastructure that assists citizens in retrieving their personal financial information (e.g., deposits, loans, credit cards, investments) – that derive from different agencies – by using their national digital identity (Singpass).
- *Singapore Trade Data Exchange (SGTraDex)*: digital platform that makes businesses' online connection and communication possible. Apart from the trading enterprises, those operating in the accounting sector and related industries are also supported.

4.1.2. New York – United States of America

Home to Broadway, Central Park, Times Square, Wall Street and the United Nations' headquarters, New York city (henceforth NYC) is deemed to be the most influential metropolis on a global scale in terms of economy, entertainment, media, arts, education, technology, and scientific research (Lai, 2022). With almost 9 million inhabitants, it is the most populous city across the US and one of the most crowded cities worldwide; while relevant projections reveal that its population will climb considerably in the future (World Population Review, 2022a).

In the light of the extreme urbanization pressures and the emerging climate change challenges NYC is confronted with, accompanied by increased energy consumption, massive ecological footprint, environmental degradation, depletion of natural resources, excessive needs for urban infrastructure, etc., city authorities have adopted a well-articulated *demand-driven* strategy (Angelidou, 2015); and have deployed disruptive technologies that will lead NYC to a more smart and sustainable future, marked by new market opportunities for economic prosperity and substantially improved quality of life.

New York's first digital strategic plans are crafted in 2010-2013 and since then the city has been a prominent frontrunner in developing and implementing game-changing smart solutions and innovative technologies. Its current integrated masterplan – OneNYC – includes city initiatives, mainly oriented towards boosting diversity, inclusion, equity, growth, resilience, and sustainability and is founded upon six essential principles (Access Cities, 2022):

- *Welcome all New Yorkers*: empowerment of all citizens regardless of their language, ethnicity, cultural and socioeconomic background, etc.
- *Make Government Simple*: provision of well-designed and user-friendly municipal services.
- *Build Collaboration*: development and sharing of digital platforms and data to upgrade all city services.
- *Reach People Where They Are*: promotion of inclusion and cohesion by delivering services and information to all New Yorkers through various channels.

- *Protect New Yorkers' Trust*: delivery of reliable, accountable, secure, and transparent city services.
- *Listen and Respond*: development of accurate responsive services.

In order to attain the abovementioned goals and objectives, NYC has launched several smart city projects – listed below – in collaboration with residents and companies.

Smart buildings and infrastructure initiatives

- *Smart Street Lighting*: NYC launches the Accelerated Conservation and Efficiency (ACE) program in 2013 to help reduce imprudent energy consumption and greenhouse gas emissions, by identifying and funding cost-effective energy saving initiatives. The project encourages the replacement of city lights with LED retrofits and the extended capitalization on smart technologies for advanced lighting controls (lighting intensity, operating hours, etc.) (Mayor's Office of Tech and Innovation, 2015; Access Cities, 2022).
- *Smart Water Metering*: automated meters for monitoring water usage. New devices also inform users of rainwater harvesting and greywater recycling levels (Access Cities, 2022).
- *Smart Waste Management*: innovative waste and recycling systems equipped with real-time sensors for monitoring refuse levels and notifying sanitation agency to empty the bins when needed, averting thus garbage overflow and streamlining pickup schedules; and solar-powered compaction mechanisms for significantly increasing their capacity (Mayor's Office of Tech and Innovation, 2015; Access Cities, 2022).

Smart transport and mobility initiatives

- *New York Citi Bike*: network of hundreds of bike-sharing stations operating 24/7 in Manhattan, Northern Brooklyn, and Western Queens. Citi Bike's connected application assists users in finding the closest available bike in real-time and guide them to the station of their choice (Access Cities, 2022).
- *Midtown in Motion*: technology-enabled traffic controlling system, comprising traffic sensors, cameras and E-ZPass readers, that gathers real-time traffic information and allows responsible agencies to monitor and respond to traffic

conditions immediately (World Highways, 2012; Mayor's Office of Tech and Innovation, 2015; Smart City Press, 2017).

- *Transit Signal Priority (TSP)*: tech-based method (location-based technologies, wireless networks, etc.) capable of enhancing municipal transit services by coordinating buses and traffic signals to reduce the time transport vehicles are stopped at traffic lights along a corridor and therefore, improve attractiveness and reliability of the public transportation system (Mayor's Office of Tech and Innovation, 2015; New York City Department of Transportation, 2018).
- *Connected Vehicle (CV) Technology*: novel technology deployed to render NYC's streets safer and smarter; and assist the city in attaining its *vision zero* goals to eliminate traffic related deaths and limit crash related injuries (Cities, 2022).

Smart energy and environment initiatives

- *Green Energy Legislation*: law framework developed to support the strategic vision on the *net-zero economy*. Laws and regulations focus on setting standards for efficient buildings, energy and water consumption and conservation; and ensuring that 70% of electricity comes from renewable sources until 2030 (Access Cities, 2022).
- *Water Quality Monitoring*: remote water quality monitoring system, consisting of numerous sensors, placed throughout the city and watershed, that provide responsible authorities real-time data on water quality and supply (Mayor's Office of Tech and Innovation, 2015).

Smart public health and safety initiatives

- *Air Quality Monitoring*: conduct of annual air quality surveys to estimate the levels of air pollutants in NYC (Mayor's Office of Tech and Innovation, 2015).
- *HunchLab*: crime-forecast software tool that uses historical crime data, socioeconomic indicators, temporal patterns, weather conditions, terrain modelling, etc., to predict crime occurrence and identify crime hotspots, thereby guiding the responsible municipal authorities towards increasing safety measures in these areas. During its two-year trial period, violent crime rates had considerably decreased (Nahmias & Neubauer, 2015; Access Cities, 2022).

- *Real-Time Gunshot Detection*: gunshot detection system, comprised of hundreds of rooftop mounted sensors for identifying the acoustic fingerprint and the location of a gunshot and immediately alerting police authorities to any possible incident (Mayor's Office of Tech and Innovation, 2015).

Smart government and community initiatives

- *NYC Open Data*: online platform that renders New York State's assets data accessible to everyone. Its primary goals focus on boosting innovation, broaden economic opportunities, empower public participation, strengthen municipality's democratic spirit and inform decision-making (Access Cities, 2022).
- *311 Service*: user-oriented service that facilitates the effective communication between the municipal government and the resident on non-emergency issues. New Yorkers can submit requests or complaints to the city authorities via phone, text, Internet, social media, etc., and receive relevant information (Mayor's Office of Tech and Innovation, 2015).
- *NYC Connected Communities*: governmental program designed to establish computer hubs in places with high rates of poverty, thereby reducing the gap of digital divide and improving quality of life by creating new employment opportunities (Smart City Press, 2017).
- *LinkNYC*: communications network aiming at replacing payphones with a kiosk (link). Each LinkNYC installation provides free and encrypted Wi-Fi coverage, USB ports for device charging, a tablet for browsing and video calling, a keypad for free national calls and an emergency call button (LinkNYC, n.d.).
- *PlowNYC*: Web application designed to enable residents to monitor snow removal progress in real time by taking advantage of GPS and GIS technologies (Mayor's Office of Tech and Innovation, 2015).
- *Brownsville Innovation Lab*: urban innovation lab (in Brooklyn) where public programs and workshops take place all year round. All New Yorkers can participate in numerous actions by testing and giving feedback on technologies intended to improve quality of life and city services (Smart Cities Connect, 2017).

- *Quantified Community (QC)*: long-term informatics research initiative that motivates neighborhoods to gather, measure, and analyse data on physical and environmental conditions and human behavioral patterns so as to better grasp how built environment affects individual and social well-being. The project is intended to shape a data-oriented environment that will serve as a hotbed, where urban neighborhoods' complex interactions can be effectively studied (Kontokosta, 2016).
- *Women Entrepreneurs NYC*: project focusing on promoting female entrepreneurial spirit by linking 5,000 women – who do not have sufficient access – to free training and business services (Smart City Press, 2017).

4.1.3. Barcelona – Spain

Barcelona is the capital of the autonomous community of Catalonia and the second largest and most populous city in Spain after Madrid. With a population of 1.7 million, the city's urban fabric extends to several neighboring municipalities; and altogether constitute a vast metropolitan area, where more than 5.6 million people reside.

In consideration of the fact that Barcelona is one of the most important cities in Spain, both in economic and political terms, innumerable opportunities for the implementation of contemporary, innovative, digital strategies are emerging within its boundaries; while at the same time plentiful political and societal conflicts – instigated either by the new dominant global conditions or the historical continuity of the Spanish political life per se – are taking place.

The city exhibits one of the highest employment rates compared to both the respective average of Spain and the European Union (EU) (Barcelona Activa, 2017). Moreover, it is deemed to be one of the most prominent, world-class tourist destinations and an extremely cosmopolitan and multicultural city, considering that 16.6% of its population consists of foreigners, the majority of whom come from Italy, Pakistan, China, and France (Barcelona Activa, 2017). It constantly invests in digital transformation and embeds revolutionary technological solutions in every urban aspect, while a great share (34%) of Spain's start-ups is located and operate in it (Barcelona Activa, 2017). The financial crisis of 2008 had a significant impact on the Spanish economy, especially in terms of unemployment, reduction of labor force's size, income, social, and spatial inequalities. However, from 2012, the country had already started to undergo a slow but steady recovery process (Moreno, 2021).

Today, Barcelona is recognized as one of the most *pioneering cities* in Europe regarding its efforts towards implementing extraordinary, innovative projects and ICT solutions in public life; and a *lighthouse example* in the field of smart cities. Multiple networks of optic fibers, sensors and activators, novel 'smart' networks for energy, heating, water, and waste management have been deployed (Yaqoob et al., 2017). Additionally, camera networks disseminate information on the state of the mountain ranges surrounding the city, weather conditions, seafront, traffic conditions and particular cultural heritage sites in the city; while 85% of its inhabitants use the Internet on a daily basis (Mobile World Capital Barcelona, 2016).

Barcelona's 'going smart journey' dates back to the early 1990s and is closely linked to the city's developmental trajectory, its distinctive character and its central administrative planning. It has changed its orientation over the years, based on the global, European, national, and local, economic, political, social, and cultural scenery every time and it is still being adapted to the radical technological advancements and international practices.

Barcelona's peculiarities, as delineated above, combined with the dominant trends of urban evolution constitute its biggest challenges today. The city's social and economic cohesion, as well as the digital divide constitute a major threat against the welfare of the population and the city's democratic foundations (Mobile World Capital Barcelona, 2016). At the same time, mobility, and housing issues (Turró et al., 2019) are reappearing in everyday life, especially due to the changing patterns of mass tourism.

Neighbor-sized projects

It is pretty common to implement pilot smart city projects to particular districts before fully extending them to the city's scale (*neighbor-sized* or *neighbor-scale* projects). These districts act as *testbeds* for experimentation, research and development, and application of specific technologies and innovations. Before diving into Barcelona's smart strategy, two very significant and influential neighbor-scale initiatives – considered to be as distinctive and independent smart city-oriented case studies – are briefly delineated.

22@District

The 22@District programme, launched by city authorities in 2000, aims at regenerating 200 hectares of the Poblenou industrial area and creating a vibrant space, where knowledge and innovation-based activities are concentrated. It places particular emphasis on the establishment of activities and businesses operating in the fields of knowledge, ICT and data management (Ajuntament de Barcelona, 2020). The 22@ project constitutes one of the city's first endeavors to shift towards the knowledge economy by appropriately leveraging technology and human capital (Angelidou, 2015).

This emblematic initiative has induced some very positive impacts, such as Barcelona's top ranking in the fields of innovation, business attraction, efficient land-use planning, gentrification techniques and methodologies, etc. Moreover, 22@ has been a major economic driver, which has allowed the city to continuously build new workforce in the technology-based sectors and the creative industries (Ajuntament de Barcelona, 2020).

However, many people dispute the efficacy and significance of the project's outcomes, as several firms relocated to Poblenou due to the lower rents the area offers, although they had already been operating in Barcelona. Moreover, the project has been intensely criticized for favouring mostly large enterprises and marginalizing the small and medium ones (Chia, 2018).

Sant Cugat del Vallés smart initiatives

The municipality of Sant Cugat del Vallés, located in the metropolitan area of Barcelona, has created the first *'smart street'* (Carrer de César Martinell) in Catalonia. This suburb of Barcelona belongs to a special category of cases, where testbed micro infrastructure and cross-cutting technologies are met along a particular route, which is broadly known as *'smart'* or *'climate street'* (Manville et al., 2014). Relevant examples also appear in other European countries, such as the Netherlands, Italy, England, Germany, etc. Smart streets act as facilitators for the implementation and assessment of pilot projects that focus predominantly on the dimensions of smart environment, smart mobility, and smart economy (Manville et al., 2014).

Since 2011, six *sensor monitoring systems* – concisely described below – in the areas of traffic management, street lighting and recycling have been developed and operate along a specific street (Sopeña, 2012). Sensors enable the transfer and dissemination of continuous data streams to competent municipal authorities. These data can be effectively embedded in urban management and may significantly contribute to citizens' information and awareness.

- *Parkhelp* system uses sensors in every parking space and provide real-time information about parking vacancy, thereby saving drivers' time, substantially reducing traffic congestion, fuel consumption, gas emissions, etc. (Sopeña, 2012). It can also remind drivers of their vehicle's location and is interconnected with smart lighting applications.
- *Sinapse* system properly adjusts street lighting according to the time of the day and pedestrian traffic, through the implementation of smart lighting technologies. It ensures efficient illumination, reduced energy consumption and decreased light pollution during night hours (Sopeña, 2012).
- *CitySolver* system monitors and manages the road traffic by collecting real-time data, identifying congestion conditions and accident cases, with the aim of analysing them and trying to optimize the traffic patterns within urban systems (Sopeña, 2012). Barcelona is awarded for the launch of the CitySolver initiative by the Living Labs Global Awards (Presswire, 2011).
- *Urbiotica and Moba* is an environmental control and waste management system. It consists of ground sensors that provide measurements of humidity levels for more efficient irrigation; and sensors placed on waste bins for streamlining garbage collection schedules (Sopeña, 2012; SmartEcoCity, 2014).
- *FastPrk* is a parking control system, created by the partnership between the World Sensing start-up, founded in Barcelona in 2008, and two research institutes, the Autonomous University of Barcelona (UAB), located in Sant Cugat del Vallés, and the Catalan Telecommunications Technology Centre (CTTC). The pilot project was implemented initially in the UAB and then in Sant Cugat del Vallés (European Commission, 2015); and was awarded by the Living Labs Global Awards in 2011 in the category of urban mobility. The scheme, co-funded by the European Union, led to the development of the XALOC application and has been implemented in several cities, such as Moscow, Montreal, and Dubai.
- *Bigbelly's smart bins* is a network of solar-powered garbage cans. They have the ability to compact refuse by leveraging solar energy, storing thus up to five

times more garbage compared to other containers of their size. Their use can significantly contribute to major cost savings, reduction of energy consumption and gas emissions. The bins are designed by the North American company BigBelly and their production is carried out by SolidWorks, a company located in Sant Cugat del Vallés (Sopeña, 2012; La Vanguardia, 2012).

Moreover, Sant Cugat del Vallés hosts an impressive, open, participatory, experimental living lab. The lab is situated in Volpelleres, a relatively new suburb of Sant Cugat del Vallés, whose development started in 2005. Although it was initially planned to accommodate 8,000 apartments, the financial crisis of 2008 had destructive ramifications on the suburb's developmental trajectory. In 2008, with only half of the apartments having been constructed, the first residents started to move in. By 2012, public services were still inadequate, while at the same time, the level of commercial activity and available businesses did not cover the residents' needs (Santonen et al., 2016). City authorities have set as a major priority the establishment of a living lab in Volpelleres, with culture – the main driving force for economic development and social cohesion – being placed at its core.

The local library is selected as the reference point of the living lab, as it is accessible to all citizens, while it also serves as a culture facilitator and promoter. The lab focuses on the ways technological evolution and the solutions it provides, can actually be of substantial help, in the light of culture (Santonen et al., 2016).

Several living labs can be found in Barcelona, such as LIVE, BDigital Cluster TIC Living Lab, Hangar, Citilab-Cornellà, Fab Lab Barcelona, BCN LAB, Guifi.net, etc. (Capdevila & Zarlenga, 2015). The most significant ones are iCat Catalonia Digital Living Lab and Barcelona Laboratori. The iCat Catalonia Digital Living Lab is one of the first living labs to appear in the European area. It is established in 2006 and focuses on promoting research and innovation in the digital sector (Santonen et al., 2016). Barcelona Laboratori aims at encouraging innovation in the fields of art, science and technology through public-private collaboration (Capdevila & Zarlenga, 2015).

Lastly, since the early months of 2019, the municipal authorities of Sant Cugat del Vallés have proceeded with specializing the UN 2030 agenda so as to identify the most effective path that the city should follow for meeting UN's proposed goals; and to craft a suitable strategic plan that will serve as a roadmap and a guide for the local ecosystem (municipal authorities, businesses and communities). The whole process began with a series of workshops that mainly focused on:

- *Goal 5*: Achieve gender equality and empower all women and girls.
- *Goal 7*: Ensure access to affordable, reliable, sustainable and modern energy for all.
- *Goal 12*: Ensure sustainable consumption and production patterns.
- *Goal 13*: Take urgent action to combat climate change and its impacts.

Barcelona and Cisco – An integrated approach

On March 1st, 2012, the mayor of Barcelona, Xavier Trias, and Cisco's chairman and CEO, John Chambers, announce the strategic partnership between the city and the multinational for the development and implementation of innovative, tailor-made initiatives that seek to further integrate ICTs into the urban life and create radical, smart solutions (Cisco, 2012). It is about a well-coordinated effort to pursue a totally ICT-oriented urban development that adopts the philosophy of the 22@ district project, although its scope is significantly broader (Gascó et al., 2016). Moreover, this partnership has led – inter alia – to the establishment and promotion of the Institute of Technology for the Urban Environment with the intention of boosting innovation in urban services through public-private collaborations (Gascó et al., 2016). It should be noted that the cooperation between the two parties commences in 2011, when the "Smart + Connected Communities" platform – powered by Cisco – begins to operate (Cisco, 2011).

This agreement is an attempt to change Barcelona's strategic approach to the smart city model, as municipal authorities recognized a lack of coordination, a shared vision and a unified strategy (Mora & Bolici, 2016).

European capital of innovation 2014

On March 11, 2014, Barcelona is announced to be the European capital of innovation (*iCapital*) for that year, as a reward for the smart initiatives the city had implemented (European Commission, 2014). These initiatives were launched in the context of the 'umbrella' project *"Barcelona as a People City"*, that encourages the use and development of new technologies to boost economic prosperity and upgrade quality of life (Capdevila & Zarlenga, 2015). The program is founded upon five pillars (European Commission, 2014):

- *Open data* and information initiatives.
- Development of *smart applications* in the field of lighting, mobility and energy.
- *Social innovation*.
- Promotion of *cooperation* among public and private agencies, research centers and universities.
- Delivery of ICT-based *smart services*.

Barcelona's smart city strategy

In 2011, Barcelona's municipal authorities map out a new digital strategy, intended to introduce the adoption and use of advanced technologies in an innovative way, so as to upgrade the city's overall operation and management, boost economic growth and improve quality of life. The rationale of the strategy is in alignment with the goals of Horizon 2020 and EU's 2010-2020 growth model strategy to create a smart and sustainable developmental path for all (Ferrer, 2017).

Barcelona's smart city strategy is built upon three axes (Gascó, 2016): (i) *international positioning*; (ii) *international cooperation*; and (iii) *smart local projects*; and defines 12 areas of interventions (environment, ICT, mobility, water, energy, waste, nature, built domain, public space, open government, information flows, services) (Cisco, 2014). Regarding the smart local projects, the city currently implements 22 flagship programmes (see Figure 4-6), under which more than 240 individual projects are launched (Cisco, 2014a; Ferrer, 2017).

It should be noted that the first three programmes illustrated in Figure 4-6 (telecommunications networks, urban platform and smart data) have a *transversal* impact on the successful application of all the rest, which target specific sectors.

According to Mila Gascó (2016), although Barcelona's emblematic smart city projects are developed to treat different sectoral inefficiencies, they share the following six common characteristics:

- They aim at developing the smart city in a *coherent* way.
- They are implemented through public-private *partnerships*, together with research centers and academia.
- They fuel *urban innovation*.
- They offer *new opportunities* to citizens and enhance their *active participation*.

- They promote *experimentation*, particularly with SMEs.
- They strengthen *international links*.

Figure 4-6: Barcelona's Flagship Smart City Programmes (Source: Ferrer, 2017)

Barcelona's city digital plan

In 2016, during the Smart City Expo World Congress, one of the most prominent smart city exhibitions taking place in Barcelona, the municipal authorities presented the city's future image for the period 2017-2020. Their vision is founded upon a bottom-up approach and envisages Barcelona as a *city in common*, as well as a *democratic*, *circular* and *creative* urban environment (Kuyper, 2016) (Figure 4-7). The term 'city in common' is related to social transformation and innovation – via technology – for a more participative and efficacious environment; 'democratic city' perceives technology as a facilitator for more inclusive, collaborative and transparent urban ecosystems; 'circular city' regards aspects of sustainability; and 'creative city' focuses on the way arts, science and technology can be effectively embedded into productive co-creation processes (Parteka & Rezende, 2018).

According to the above, it becomes apparent that the new city strategy is imbued with more community-based and citizen-oriented concepts, such as governmental transparency, public participation, citizen's empowerment, cooperation, co-decision, etc., thereby abandoning the barren, technology-pushed rationale of the past; while it intends to fully leverage open data and social innovation (Kuyper, 2016).

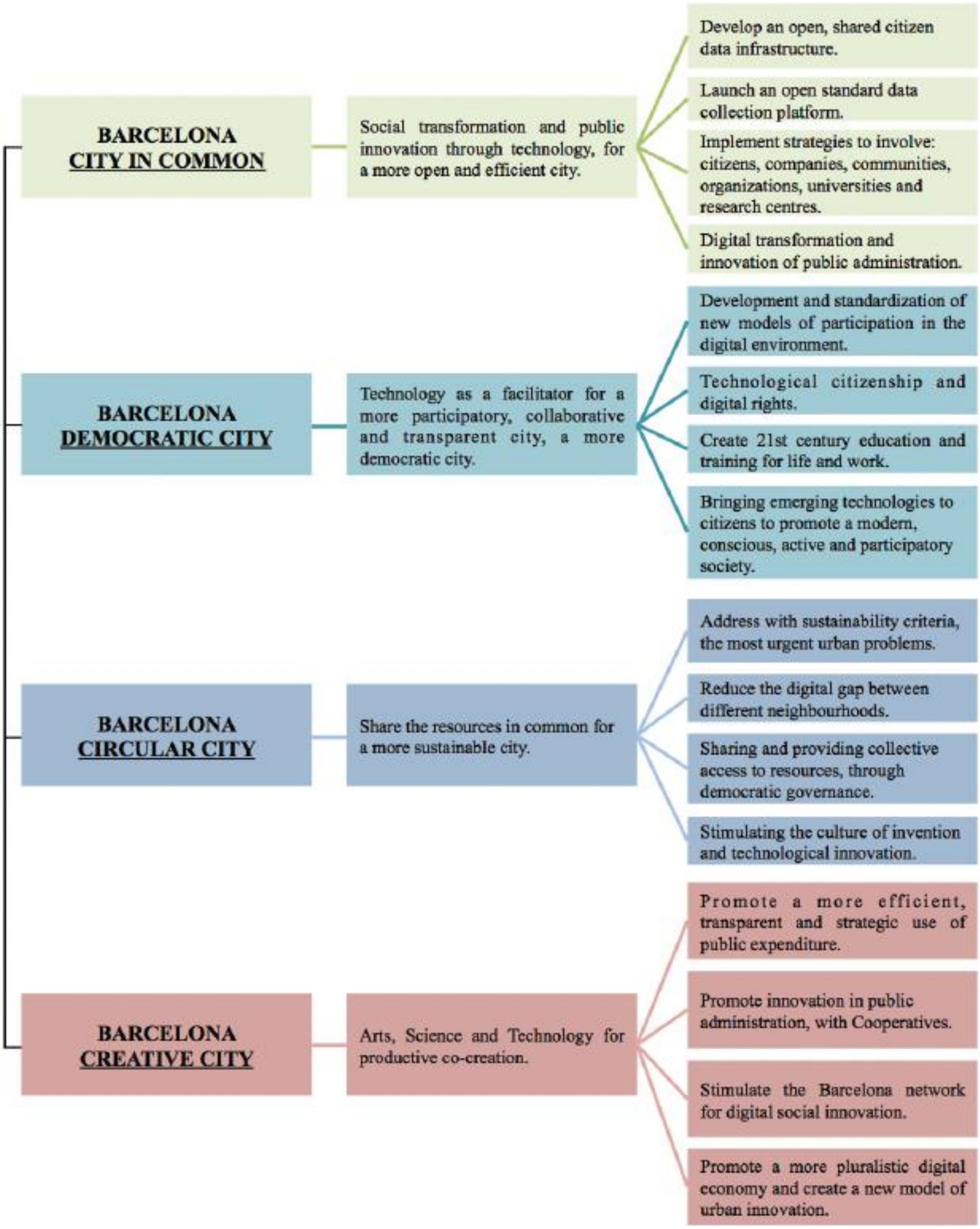

Figure 4-7: Barcelona's City Digital Plan (Source: Parteka & Rezende, 2018)

Based on these four principles, city authorities proceeded with the implementation of numerous programmes and projects, which are classified into three generic categories, as listed below (Ajuntament de Barcelona, n.d.-b).

❖ ***Digital transformation***

The first category of Barcelona's smart city projects concerns its digital transformation through technology and data to deliver economic services to citizens and assist the city in shifting towards a transparent, inclusive and efficient governance model. Digital transformation projects and applications are divided into three sub-categories:

- *Technology for a better government*
    - *Open-Source Software*: Barcelona supports the adoption of open code technology and the development of free open-source software and applications with the ultimate goal of achieving full *technological sovereignty*. Citizens, councils and businesses can access publicly published (e.g., Github) open-source programs and relevant coding, which they can use, expand or improve (Ajuntament de Barcelona, n.d.-ak).
    - *Open Budget*: from 2016 onwards, municipal authorities offer the possibility of direct information on the city's budget at any time and graphical representation of relevant data, making thus city budgets easier to grasp (Ajuntament de Barcelona, n.d.-ah).
    - *Digital Market*: digital environment for interaction between businesses and municipal authorities to develop more transparent relationships and processes in the field of public procurement (Ajuntament de Barcelona, n.d.-p).
    - *Digital Identity*: digital identification mechanisms for providing personalized digital services, based on the needs of each citizen (Ajuntament de Barcelona, n.d.-o).
    - *Ethical Mailbox*: digital service that allows citizens to communicate with responsible authorities and report anonymously cases of unfair practices and corruption in public institutions and services (Ajuntament de Barcelona, n.d.-u).

- *Progressive Web Apps*: regards the city's commitment to the adoption of open standards, open-source software, and cross-platform technologies (Ajuntament de Barcelona, n.d.-al).
- *Open and Agile Digital Transformation Toolkit*: includes all the necessary tools (open-source software, development standards, coding, practices, etc.) that will assist Barcelona in changing the way it provides its services to the public in the years to come (Ajuntament de Barcelona, n.d.-ag).

- *Urban technology*
  - *5G Barcelona*: initiative launched by city authorities together with businesses, living labs and universities, that aims at implementing experimental network technologies, turning thus Barcelona into a metropolitan laboratory of 5G technology (Ajuntament de Barcelona, n.d.-a).
  - *KIC Urban Mobility*: since 2018, Barcelona has been a member of the Knowledge and Innovation Communities (KIC) in urban mobility initiative. To implement this large-scale project, the MOBILus consortium – composed of cities, countries, businesses, and universities – is launched and focuses on proposing innovative ways to upgrade urban mobility (Ajuntament de Barcelona, n.d.-aa).
  - *Technology and Innovation Events*: refers to Barcelona's effort to continue hosting events and conferences linked to smart cities, disruptive technologies and digital innovation (Ajuntament de Barcelona, n.d.-ar).
  - *CityOS*: organizing infrastructure, relying on open-code big data technology, that guarantees more efficient data management, quality controls, higher privacy and security; and allows city authorities to make better, data-driven and knowledge-based decisions (Ajuntament de Barcelona, n.d.-i).
  - *Internet 4all*: addresses inequalities and connectivity issues observed among neighborhoods and endeavors to bridge the digital divide by implementing digital inclusion programmes (Ajuntament de Barcelona, n.d.-z).
  - *Bicing*: public bicycle network, which has been operating successfully since 2007 and offers an alternative and sustainable mode of transport within the urban fabric. With the radical development of ICTs, city authorities are now able to collect data through the service application; and utilize them to

upgrade the service per se, inform the users (list of stations, bike availability, best routes, etc.), streamline bike sharing and optimize vehicle transit (Ajuntament de Barcelona, n.d.-d).

- *Superblocks*: urban regeneration effort, according to which the use of particular groups of streets (superblocks) is radically redefined, by giving priority to pedestrians and public transport. Superblocks are designed to address the lack of green spaces and lower pollution and noise levels (Ajuntament de Barcelona, n.d.-ap).
- *T-Mobilitat*: new transport tickets that allow the collection of data regarding citizens' journeys when using public transportation means. These pieces of data are essential for the overall city management and for crafting more efficient, informed-based transport policies (Ajuntament de Barcelona, n.d.-as).
- *Sentilo*: open-source software that makes data, stemming from several sensor networks of the city, readily available. It allows municipal authorities to obtain real-time data and information on the flow of pedestrians, bicycles and vehicles along the streets; noise levels; temperature and air quality conditions of each neighborhood (Ajuntament de Barcelona, n.d.-an).

- *City Data Commons*

    - *Open Data Challenge*: Barcelona encourages, through relevant initiatives, the identification of city challenges, whose proper address requires social collaboration "by means of approaching data as a common asset" (Ajuntament de Barcelona, n.d.-ai). These initiatives aim at fostering small and medium scale economy, entrepreneurship and digital knowledge.
    - *Municipal Data Office*: office responsible for the unified management, quality, and use of data, controlled and/or stored by Barcelona City Council (Ajuntament de Barcelona, n.d.-ae).
    - *Municipal Management Dashboard*: data visualization tool that diffuses indispensable, real-time information on the city's current state in an easier, simpler, and more understandable form. Visualized data are pertinent to housing, employment, healthcare facilities, etc. Moreover, the dashboard provides indicators that offer a deep insight into the implementation

progress of public policies, and the way citizens deal with them (Ajuntament de Barcelona, n.d.-af).

- *Open Data Portal (Open Data BCN)*: citizens' rights to access public information have been established since 2014 in Barcelona. Through the open data portal, every resident can have access to more than 450 datasets related to financial, demographic, environmental, social, etc., city aspects (Ajuntament de Barcelona, n.d.-aj).
- *Blockchain for Data Sovereignty – DECODE*: European project, that aims at offering citizens the opportunity to decide the privacy terms of their data. Decentralized technologies, such as cryptography and blockchain, are deployed to achieve this goal (Ajuntament de Barcelona, n.d.-f).
- *Big Data for Public Policies*: extensive use of big data in order to have a clear view of the city's aspects, such as housing, mobility, pollution, citizens' participation, etc. (Ajuntament de Barcelona, n.d.-e).

❖ ***Digital innovation***

Digital innovation includes programmes, projects and applications designed to support entrepreneurship and strengthen inclusion in the digital economy. Its initiatives are classified under three sub-categories:

- *Digital Economy*

  - *Bringing the Innovation Ecosystem to Life*: initiatives designed to strengthen the urban innovation system. Barcelona has established itself as a digital hub, where innovation and entrepreneurship are promoted through strategic partnerships between public and private actors. These 'alliances' (e.g., Mobile World Capital, Barcelona Tech City, Barcelona SuperComputing Center, i2Cat and BigDataCoE) immensely contribute to the development of the digital economy and attract a highly skilled workforce to the city (Ajuntament de Barcelona, n.d.-g).
  - *MediaTIC Incubator*: innovation incubator, serving as a meeting point for ICT-related companies, research centers and institutes. Currently, it houses 20 companies operating in the fields of robotics, IoT, artificial intelligence, nanotechnology, and space technology (Ajuntament de Barcelona, n.d.-ad).

- *Digital Technology Entrepreneurship*: a great share of Barcelona's labor force is employed in a medium to high tech-intensive environment. Moreover, an increasing trend in the number of technology companies, operating within the city, is pretty evident during the last years. Taking the above into consideration, Barcelona City Council has launched several programmes to support digital entrepreneurship, upgrade the local technological economy and the digital ecosystem, attract highly qualified workforce, etc. (Ajuntament de Barcelona, n.d.-r).

- *Make in BCN*: focuses on circular economy and comprises pilot applications and projects regarding production modes within the city, with a particular emphasis on citizen networks and democracy.

  - *DSIPLAY*: aims at presenting the most emblematic digital social innovation (DSI) projects, their social ramifications, benefits, and feasibility; and at conveying the philosophy thereof to communities and citizens. Moreover, it encourages synergies among urban actors, with the ultimate goal to achieve mutual learning in fields, such as technology-oriented entrepreneurship, participation, collaborative and circular economy, proper use of data, etc. (Ajuntament de Barcelona, n.d.-s).
  - *Impulsem el que Fas (We Promote What You Do) – Digital Social Innovation Method*: handles grants for proposals and projects that promote the recycling, digital inclusion, bridging of the digital gap, social and economic innovation, etc., thereby providing solutions to Barcelona's social needs (Ajuntament de Barcelona, n.d.-x).
  - *Maker Mornings*: quarterly meetings among local producers who add value to digital social innovation projects and those interested in the city's production culture (Ajuntament de Barcelona, n.d.-ac).
  - *BCN Industry 4.0 Hub*: Barcelona's authorities are promoting the development of platforms and collaboration among companies operating in key sectors of industry 4.0. The aim is to accelerate industry digitalization and foster cooperation among engineers, manufacturers, technology providers, research centers, universities, and municipal authorities, in order to identify, develop and disseminate best practices in the areas associated with industry 4.0 (Ajuntament de Barcelona, n.d.-c).

- *Fab Lab in the Technology Park*: intends to become Barcelona's advanced industry hub, focusing on local small and medium-sized companies and particularly on those that produce their own technological and industrial products (Ajuntament de Barcelona, n.d.-v).
- *Maker Faire Barcelona*: annual event for invention and digital creation that attracts engineers, artists, designers, hackers, creators, programmers, scientists, etc. and offers them the opportunity to present their work (Ajuntament de Barcelona, n.d.-ab).
- *Poblenou Market District*: already analysed in previous section.
- *Digital Social Innovation Programme (DSI4BCN)*: local project that encourages the conduct of conferences, round tables and events, so as to connect the local community with European opportunities (Ajuntament de Barcelona, n.d.-q).

- *BIT Habitat-i.lab*: refers to Barcelona's endeavor to become a platform for social and urban innovation and a laboratory for its creative talent, local communities, and knowledge centers.
  - *Urban Innovation Platform*: digital platform where citizens, academia, businesses, and public administration (quadruple helix) can interact and communicate to strengthen innovation in the city (Ajuntament de Barcelona, n.d.-at).
  - *Innovation in Public Procurement*: Barcelona City Council has decided, following the European Union's strategy, to change the criteria that define public procurement. Thus, instead of evaluating procurements on the basis of market criteria, the authorities now assess procurements according to criteria of sustainability and innovation, promoting thus sustainable public procurement, circular local economy, and SMEs (Ajuntament de Barcelona, n.d.-y).

❖ ***Digital empowerment***

The digital empowerment dimension consists of three groups of initiatives that are mainly oriented towards utilizing cross-cutting technologies to promote citizens' well-being, broaden the spectrum of their potential and protect their rights. All the above can be attained through the creation of high-jobs and fight against inequality. At the same time, it should be ensured that the development of new technologies secures citizens' digital justice and gender equality and promotes social inclusion. The most significant digital empowerment projects, which fall under these three discrete categories, are delineated below:

- *Digital education and training (talent factory)* category aims at familiarizing the general public with state-of-the-art technologies, creating thus active, well-aware and better prepared citizens.
    - *STEAM BCN*: focuses on familiarizing students with new technologies and promoting technology vocations from the preschool level through secondary education, by providing resources to both teachers and families. It also tries to demystify the link between professions and socioeconomic background and fights against gender inequality in the ICT sector (Ajuntament de Barcelona, n.d.-ao).
    - *Educational Events*: educational events, conferences and workshops that deal with the role of technology in education, collaborative participation, recycling, science, etc. (Ajuntament de Barcelona, n.d.-t).
    - *Cibernàrium*: enables people to be trained in technological fields and acquire digital skills (Barcelona Activa, n.d.).
    - *FabLabs*: places for learning, collaborating in various projects and participating in the city's social development. These labs constitute a technology- and digital production-oriented public service (Ajuntament de Barcelona, n.d.-w).
- *Digital inclusion* category focuses on bridging the digital divide that appears due to the emerging technologies. Digital divide is deeply affected by the access to new technologies and is correlated with economic and educational imbalances.
    - *Connecting Barcelona*: pilot project aiming to provide high-quality Internet access to 400 vulnerable households, combating in this way digital inequalities (Ajuntament de Barcelona, n.d.-j).
    - *Rec*: Barcelona's digital social currency, designed to be complementary to the national currency and allows transactions between individuals,

businesses and institutions that accept it. Today, Rec is introduced in 10 neighborhoods of the city (Ajuntament de Barcelona, n.d.-am).

- *Vincles BCN*: social innovation project for strengthening the social bonds of elderly people and improving their welfare, with the assistance of advanced technologies (Ajuntament de Barcelona, n.d.-au).
- *Digital Education* and *Digital Social Inclusion*: training and educational programmes to combat the digital divide, upgrade citizens' technological skills and encourage the flourishing of new professions (Ajuntament de Barcelona, n.d.-n).
- *Technology and Gender*: series of events to promote gender equality and strengthen women's role in the technology sector (Ajuntament de Barcelona, n.d.-aq).
- *Digital Commons for Social Inclusion*: project that intends to bridge the digital gap and alleviate digital inequalities, through the implementation of several educational, informative and infrastructure modules (Ajuntament de Barcelona, n.d.-m).
- *Declaration of Barcelona for Digital Social Inclusion*: partnership among the City Council, institutions and companies that operate in the field of digital technologies and telecommunications, intended to reduce the digital gap in the city (Ajuntament de Barcelona, n.d.-l).

• *Democracy and digital rights* category includes initiatives that leverage new technologies to highlight citizens' crucial and central role, by increasing their digital sovereignty and allowing them to exercise their digital rights; while, at the same time, their data, information and privacy are secured.

- *Cities Coalition for Digital Rights*: alliance, initiated by Barcelona, Amsterdam, and New York, to support and protect people's digital rights on a global scale (Ajuntament de Barcelona, n.d.-h).
- *Decidim Barcelona*: digital participatory and democratic platform, focused on encouraging citizens to participate in co-designing and co-deciding processes. The platform has the capacity to receive and respond to proposals, but also to support dialogue (Ajuntament de Barcelona, n.d.-k).

4.1.4. Stavanger – Norway

Stavanger is Norway's 4th most populous city, whose history dates back to 1125 CE, the year of its foundation. Its population and size grew rapidly during the late 20th century, owing to the development of the offshore oil industry in the North Sea. Today, it is estimated that the city has about 144,700 inhabitants (City Population, 2022b). Stavanger's economy is mainly relying on oil refining, shipbuilding, and shipping (Britannica, 2012); while it appears in several lists as one of the cities with the *highest cost of living*.

Stavanger has been trying to become smart city both by implementing initiatives within its boundaries and by being a member of the *Nordic Smart City Network*, in which 20 Nordic cities from Norway, Sweden, Finland, Denmark and Iceland participate, with a shared vision to *"explore the Nordic way to create livable and sustainable cities … The cities can benefit from closer collaboration by sharing experiences and the network provides innovative solution providers with a wider market"* (Nordic Smart City Network, n.d.-a, About the Network section, para. 1).

Roadmap for the smart city Stavanger

In December 2016, the municipal authorities published the *"Roadmap for the Smart City Stavanger"*, which delineates the steps to be followed towards Stavanger's transformation into a smart city. The roadmap is the outcome of broad and rigorous participatory procedures that involve both the public and the private sector (public agencies, enterprises, industries, commerce, organizations, institutions, academia, etc.), and focuses on (Stavanger City Council, 2016): citizens' needs; openness and transparency; creativity and involvement; equality and mutual adjustment; sharing of information and data; testing and innovation. Moreover, the roadmap is not deemed to be just another municipal plan; conversely, it transcends the city's geographic boundaries and perceives the broader region of Stavanger (neighboring municipalities as well as industry and commerce throughout southern Rogaland) as an organic whole (Stavanger City Council, 2016).

The backbone of the roadmap consists of three fundamental dimensions / key drivers (Stavanger City Council, 2016) (Figure 4-8):

- *Technology* for boosting economic, social, and environmental well-being (e.g., ICTs, nanotechnology, IoT, big and open data, materials technology).
- *Cooperation* among different parties (public and private), highly characterized by openness and trust (ad hoc or long-term forms of interaction, networks and partnerships, different degrees of formalization, living labs, etc.).
- *Citizen involvement* (e.g., users of services or their families, groups of citizens or users, persons who reside and/or work in the region) for developing citizen-oriented smart solutions.

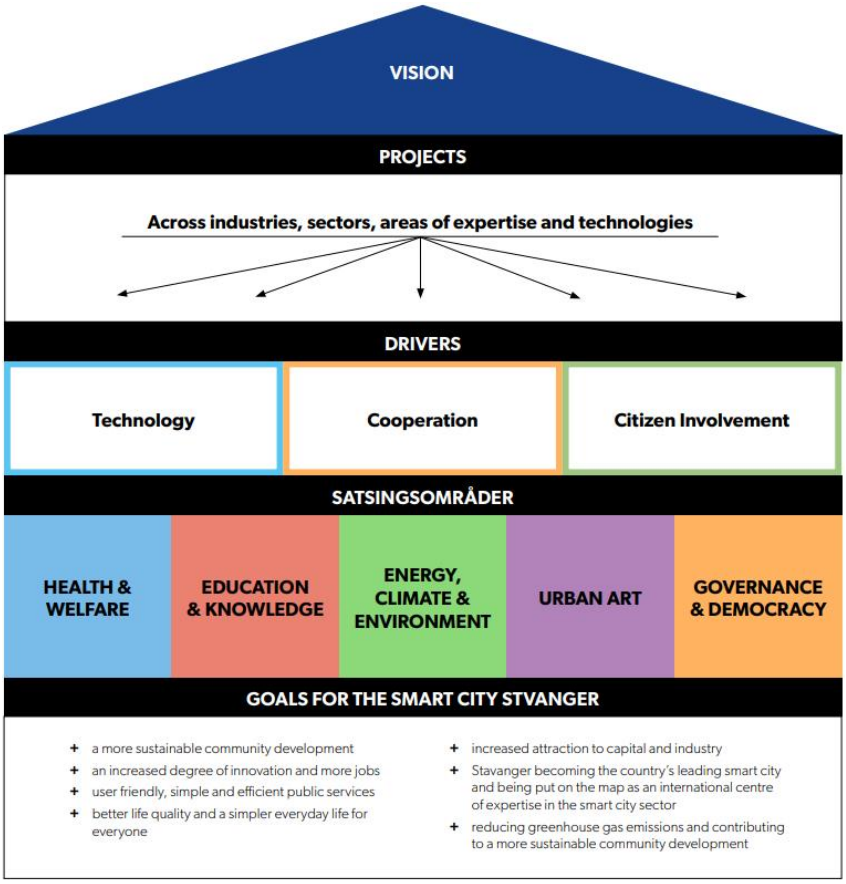

Figure 4-8: Stavanger's Smart City Vision and Priority Areas (Source: Stavanger City Council, 2016)

Stavanger's roadmap places emphasis on five priority areas, where the city has significant potential to develop smart technological solutions for the benefit of its citizens (Stavanger City Council, 2016) (Figure 4-8):

- *Health and welfare*. As the city's share of elderly residents is expected to escalate in the forthcoming years, municipal authorities are called to design and apply the necessary technological solutions so as to meet citizens' needs in an efficacious way, thereby offering them an upgraded quality of life.

- *Education and knowledge*. Investment in education and knowledge development are perceived essential directions towards forming a highly skilled and diverse workforce that will drastically contribute to the city's innovative and competitive spirit.
- *Energy, climate, and environment*. Technological solutions, that target substantial emissions' cut will be developed and implemented.
- *Urban art*. Stavanger wishes to become a leader in the development of urban art as part of its infrastructure and public spaces.
- *Governance and democracy*. The city focuses on: (i) improving its services by rendering them more accessible and user-friendly, achieving thus a high level of efficient governance; (ii) facilitating interaction across various sectors; and (iii) stimulating citizens' active engagement.

Stavanger's smart city projects and applications

Stavanger's most important smart city initiatives, launched by the municipal authorities, are presented in the following sub-sections.

❖ ***Smart environment and energy initiatives***

- *Triangulum*: EU's lighthouse, five-year-long (2015-2020), joint project with the cities of Stavanger, Eindhoven and Manchester and their collaborators (22 partners in total). Triangulum is a *triple helix* cooperation among public agencies (Municipality of Stavanger and Rogaland County Municipality), industries and commerce (Lyse AS and Greater Stavanger) and academia (University of Stavanger). The project aims at integrating energy, mobility and ICTs in novel solutions that will assist in confronting societal challenges; and is expected to decisively boost sustainability through a more environmentally friendly urban development, reduction of CO_2, greener and cleaner energy as well as increased energy efficiency improvement (Stavanger City Council, 2016).
- *Smart Waste Management*: deployment of state-of-the-art technologies and launch of innovative initiatives (solar-powered bins equipped with sensors,

underground refuse containers and monitoring systems for recycling points) for waste management in private households (City of Stavanger, n.d.-n).

❖ ***Smart governance and community initiatives***

- *GeoViz*: public-private pilot project for the development of a 3D viewer for drawing up and assessing urban plans, especially designed to be connected to Virtual Reality (VR) technology (Stavanger City Council, 2016).
- *LoRaWAN – Sensor Network*: extended network of sensors for monitoring temperature, sound, water, and CO_2 levels, vacant parking spaces, etc. To guarantee its proper function, (continuous data streams and low maintenance costs) the municipality uses the Long Range Wide Area Network (LoRaWAN). The collected data are combined with other data sets and are used in novel and useful services (City of Stavanger, n.d.-g).
- *Real-time dashboards*: centralized system that provides, through a single screen, real-time data of the city, which derive from several municipal departments (City of Stavanger, n.d.-j).
- *My Neighborhood*: citizen-oriented programme that uses Decidim – a participatory platform for promoting cooperation between municipal authorities and local community – to empower participatory democracy (City of Stavanger, n.d.-i).
- *Smart Art*: initiative for linking art – an indispensable source of knowledge and competence – to new technologies, infrastructure and services and integrating it into urban planning practices (City of Stavanger, n.d.-m).

❖ ***Smart mobility initiatives***

- *EV Charging in Lampposts*: pilot project that intends to increase the number of electric vehicles by developing the necessary infrastructure and improve the air quality of the city (City of Stavanger, n.d.-d).
- *Mobility Hub*: place where citizens have access to parking spaces and different modes of transport (public transport, cars, city bicycles, car-sharing, scooters, walking, etc.) and can select whatever mode suits their journey best (City of Stavanger, n.d.-h).

❖ ***Smart people and community initiatives***

- *TechnologySMART*: project intended to involve pupils in discovering new solutions to problems that are detected in the local community (City of Stavanger, n.d.-p).
- *Youth Citizen Panel*: panels of students, specially formed to engage them in important matters of the city and cultivate their skills that relate to resolving real case urban problems (City of Stavanger, n.d.-q).
- *Living Lab*: participatory method for involving the local community in the development of new and upgraded services. It is also a field for testing and piloting (City of Stavanger, n.d.-f).
- *Everyday Innovators*: research project, targeting the promotion and diffusion of innovation to the public via the interface it offers for linking talented people to interested businesses or municipalities (City of Stavanger, n.d.-k).
- *School of Co-creation*: project ran by the municipal authorities for developing appropriate internal courses that combine co-creation and design principles through practical projects (City of Stavanger, n.d.-l).
- *Design Studies*: The municipality of Stavanger, in collaboration with the design industry and the University of Stavanger, have taken the initiative to organize a design curriculum that currently offers courses in service management. This way, students can gain useful knowledge in innovation and service design (City of Stavanger, n.d.-c).

❖ ***Smart economy initiatives***

- *Sustainable Tourism in Nordic Harbor Towns*: three-year-long project that aims at identifying common challenges and problems created by the increase in the number of cruise ships and tourists. Afterwards, it is necessary to collaborate with stakeholders from the cruise ship and tourism industry to develop innovative methods, products and services for the benefit of the local ecosystem (City of Stavanger, n.d.-o).
- *Kvikktest*: experimental project, in the context of which selected suppliers are committed to testing their solutions in a real environment, with the overriding goal of learning for the municipality but also for the participant businesses per se (City of Stavanger, n.d.-e).

- ***Smart living initiatives***
    - *AiRMOUR*: three-year-long EU project, focusing on the use of drones in the city and its suburban districts for emergency medical uses (City of Stavanger, n.d.-a).
    - *AV1 Robots – The Eyes, Ears and Voice of Chronically Ill Children*: robots, especially designed to operate as the eyes, ears and voice of students who suffer from chronic health issues and are incapable of attending classes. Entrants are given the opportunity to participate in the educational process and socialize with their friends via a tablet (City of Stavanger, n.d.-b).

4.1.5. Montpellier – France

The city of Montpellier is located in southern France, near its borders with Spain, 12 Km from the Mediterranean coast and constitutes the 7th most populous city in the country with around 295,000 inhabitants (City Population, 2022a). Montpellier accommodates a considerable number of students, due to the academic institutes and research centers based in it. The share of students is estimated to be 29% of the city's overall population (Giband, 2016). Knowledge and research play a critical role in the local economy, as since the 1960s – with the establishment of private and public research centers by the electronics, pharmaceutical and agri-food industries – a large proportion of the local workforce has been absorbed by these sectors (Giband, 2016).

Montpellier's 'going smart' journey starts in 2011, when city authorities together with businesses, universities and research organizations begin to develop digital solutions intended to deliver new and effective services, create economic and social value, and stimulate economy through innovation and advanced technologies. Interventions are associated with 12 priority areas: habitat, health, energy, waste, mobility, urban logistics, tourism, culture, water, risk management, citizen engagement and social cohesion (Invest in Montpellier, n.d.).

In a bid to implement its horizontal smart city strategy that activates all the local creative forces, Montpellier has launched *nine flagship projects* (Invest in Montpelier, n.d.):

- *EcoCité*: urban testbed for smart city experiments.

- *City on Alert*: alert system that combines data from meteorological forecasts, risk prediction maps, flood monitoring systems, etc., and serves as a collaboration tool among crisis and risk management actors.
- *TaM Application*: mobile application that offers users parking and mobility solutions.
- *Emma*: multimodal mobility solution that uses a single subscription card to access various transportation services (parking spaces, buses, bicycles, car sharing, etc.) and provides real-time information to people.
- *HUT (HUman at home projecT) Project*: research project that focuses on the opportunities and risks that will arise in the apartments of the future from the use of modern technologies, with a particular focus on the control and management of personal data, and human-machine interaction. The project is carried out through the collaboration of scientific laboratories, industry, and city institutions.
- *Mantilla City Block*: building complex of 33,000 m^2 area, where a smart digital data exchange system, that enables residents to monitor and control their water and energy consumption, has been installed. The system also makes it easier to manage the block's energy supply, provided by an environmentally friendly wood-based power plant that produces heat, cooling, and electricity.
- *Eurêka District* and *My Eurêka platform*: 0.39 Km^2 urban area where services, dedicated to the elderly people and the issue of 'aging well', are provided. My Eurêka platform, which is developed in Eurêka district, is a digital tool that supports seniors or people with reduced mobility to remain independent at their homes under the best possible conditions.
- *Independent Living Cluster*: center of excellence for research on personal autonomy.
- *Fabre and the City*: application that aims at promoting the permanent collection of the Fabre Museum of Montpellier, while boosting at the same time the museum's traffic.

4.1.6. Reykjavík – Iceland

Reykjavík is Iceland's capital and largest city, with a population of approximately 135,000 inhabitants. In the greater metropolitan area (Great Reykjavík) – consisting of seven municipalities in total – the number of inhabitants is estimated at about 216,940 (World Population Review, 2022b). Reykjavík was founded in 1786 as a trade town and has been growing slowly but steadily since then. Today it holds the role of the national center of trade and a hub for governmental activity, while it is considered to be one of the greenest, cleanest and safest cities worldwide (World Population Review, 2022b).

Iceland's economy, after the financial meltdown of 2008 that severely dented its banking sector (Teather, 2008), has been attempting to recover by relying on clean energy production, marine resources, infrastructure, and a highly educated workforce. Nowadays, national economy is based primarily on service provision, manufacturing, construction, utilities, and fisheries (Forbes, 2017).

Reykjavík's smart city vision and goal

Reykjavík's municipal authorities perceive smart city as

> a city that uses information, communications and telecommunications technology to improve the quality of life in a sustainable way. Smart city gathers and combines data from different databases related to the infrastructure of the city and uses it to improve services, quality of life and environment. (Nordic Smart City Network, n.d.-b, para. 1)

The smart projects implemented in the city – which are briefly listed below – are designed to offer more efficient transportation, increase environmental awareness, promote more sustainable energy uses and improve the overall functioning and quality of services.

❖ ***Smart governance and community initiatives***

- *Better Reykjavík*: online advisory forum where citizens can present their ideas and propose solutions to issues relating to urban challenges (identification of weaknesses and opportunities, generation of new ideas, design of solutions, development of proposals, assessment, etc.). It has multiple transparent functions / modules, namely agenda setting, participatory budgeting and policy making (Observatory of Public Sector Innovation, n.d.). Every month the city council debates on the most popular ideas and by 2015 1.9 million euros had been allocated for the development of 200 projects proposed by citizens (Saunders & Baeck, 2015).

- *LUKR*: Reykjavík's GIS that has been developed by the municipal authorities in cooperation with the state telecommunication company since 1988. The system currently covers the entire administrative area of Reykjavik and provides important geographic information about streets, buildings, landscapes, parking systems, etc. (Center of Remote Sensing [CRS], n.d.; City of Reykjavík, n.d.-b).

❖ ***Smart mobility initiatives***

- *Straetó.is*: mobile application, provided by the transport authority of the Grater Reykjavík area, for better planning and easier use of Iceland's public transport. Users can plan their journeys, access real-time and travel information and conduct payments via their mobile phone (Google Play, 2022b).

❖ ***Smart environment initiatives***

- *ON Power*: the largest clean energy company in Iceland. It provides electricity and hot water for heating by harnessing the power of renewable resources, with a special focus on geothermal energy (EVBox, n.d.). In Iceland, renewable energy sources account for over 80% of total primary energy consumption, the highest percentage in the world; while it is the first country ever to propose to run on 100% renewable energy (Michelson, 2022).

Reykjavík a carbon-neutral city by 2040

Reykjavík's envisages becoming carbon-neutral by 2040 and adapting to climate change in a human-centric and environmentally friendly manner. In a bid to attain this ambitious vision, the municipal authorities have developed an appropriate *action plan*, that is subject to assessment every five years – starting from 2020 – in accordance with the Paris Agreement (City of Reykjavík, 2016; City of Reykjavík, n.d.-a).

The backbone of the city's climate policy consists of four key areas, where specific interventions are planned to be implemented (City of Reykjavík, 2016):

- *Transport and energy use.*

- *Land use.*
- *Public awakening.*
- *Matters of waste.*

4.1.7. Cagliari – Italy

Cagliari is the capital of the island of Sardinia, located in the Mediterranean Sea and belongs to Italy. The city has 154,019 inhabitants, while in the wider metropolitan area, which consists of 16 municipalities, 439,100 people reside (Garau et al., 2016).

The metropolitan city of Cagliari has been closely cooperating with Huawei and the Center for Advanced Research and Development Studies of Sardinia (CRS4) since 2018, when all interested parties (municipality of Cagliari, local stakeholders, universities, and local SMEs) signed a memorandum of understanding, aimed at structuring a tailor-made action plan for the creation and implementation of ICT solutions and services in the fields of health, transport, waste management, security, and Industry 4.0 (Huawei, 2018). This collaboration follows the Joint Innovation Center (JIC) initiative, a specialized research center dedicated to the development of novel smart city-related technologies (Perla, 2019).

The city of Cagliari has launched several smart city initiatives, with the most important of them being briefly described below:

- *Wi-Fi Connectivity*: wireless telematic network, consisting of more than 250 access points distributed throughout the city, particularly in outdoor areas and cultural centers, that provides free Internet access to citizens and visitors (Municipality of Cagliari, 2021a).
- *Open Data*: data and information – mainly related to traffic and road accidents, demographics, and environmental conditions – collected or produced by municipal authorities, anonymized, organized and exported in standard formats, suitable for being accessible to anyone (Municipality of Cagliari, 2020b).
- *Energy Desk*: virtual counter, created to raise citizens' awareness of issues related to energy saving, adoption of environmentally responsible behaviors and sustainable patterns (Municipality of Cagliari, 2022b).

- *Online Appointment Booking*: Web service that allows citizens, businesses, and professionals to schedule an appointment with municipal operators online (Municipality of Cagliari, 2022a).
- *Digital Civil Service*: municipal initiative intended to bridge the digital divide by establishing a network of young volunteers, who provide people at risk of digital exclusion with the necessary training for the development and improvement of digital skills (Municipality of Cagliari, 2022d).
- *Territorial Information System (Sit)*: digital tool that allows the acquisition, recording, analysis, display and presentation of information deriving from georeferenced data (Municipality of Cagliari, 2020a).
- *Digital Services Desk*: support desk, dedicated to assisting citizens, businesses, and other urban actors in effectively using the digital services offered by the city of Cagliari and other public administrations (Municipality of Cagliari, 2022c).
- *Connectivity Vouchers*: funding for tablet acquisition with emphasis on vulnerable social groups (Municipality of Cagliari, 2021b).

4.2. Comparing International Smart Strategies

Based on the analysis of the seven smart city examples drawn from the international scene, as these are presented in the previous sections, it becomes crystal clear that cities around the world adopt quite diversified approaches when it comes to mapping out smart strategies and the implementation thereof. More particularly, it is observed that the smart initiatives undertaken by different cities vary considerably in terms of volume / number, scale, and time horizon.

Singapore, Barcelona, and New York constitute prominent examples and are deemed to be beacons of smart city developments on an international scale. They perceive, design, and implement their going smart paths in a more holistic / integrated way, through appropriate and diligent planning, as well as via the launch of a multitude of initiatives that touch all smart city dimensions.

These three cities share several commonalities. For example, they have shaped a very specific vision on the way they desire to become smart; they adhere to the necessary planning principles for fulfilling this vision and set specific objectives for that reason; while they have also crafted long-term strategic plans – obviously different in each case – which seek to bring particular outcomes.

Nonetheless, these cities differ significantly from each other. The fact that Singapore is an island, where the urban fabric is spread over a physically limited area, and the fact that its national borders coincide with the city's borders, have led to the launch of smart projects of both national and urban / municipal nature. New York and Barcelona have been taking a series of highly advanced initiatives that have established them as urban innovation frontrunners at the international level. However, in the case of Barcelona, many projects have a specific spatial scope, i.e., particular areas of application, as evidenced by the examples of the Poblenou district or the Sant Cugat del Vallés suburb. Moreover, Barcelona has been entering into multiple partnerships with public and private bodies to implement specific flagship European smart city programmes; while it has fully leveraged all the actors of its local ecosystem (decision-makers, businesses, academic and research institutions, citizens, etc.), which seems to be the case for Singapore and NYC as well.

The going smart journeys of Stavanger, Montpellier, Reykjavík, and Cagliari are still at a relatively premature stage – compared to those of Singapore, New York, and Barcelona – and are characterized by fragmentary planning and implementation of pertinent initiatives. This becomes apparent from the limited number of projects, applications, and services these cities offer; the recency of their attempts to transform into smart urban environments; and their scarce partnerships with local, European, and international bodies.

According to all the above, it can be safely inferred that there are much different speeds of adaptation to the new conditions and implementation of smart initiatives. Although the cities of Stavanger, Montpellier, Reykjavík, and Cagliari cannot by any means be compared with examples such as Singapore, New York or Barcelona, the world is witnessing an ongoing trend for more and more cities to adopt smart applications. At the same time, the European and international smart city frameworks are being strengthened through the allocation of resources from various channels and the support of broader partnerships. As regards the European territories, this framework is expected to be further reinforced in the forthcoming years through the EU's initiative *"Mission for Climate-Neutral and Smart Cities"*, which treats the concept of smart cities as a powerful tool for managing contemporary problems.

4.3. Delving Into the Greek Smart City Experience

This section attempts to shed light on the smart city scenery in Greece by elaborating on the smart strategies (initiatives, projects and applications) of three cities (Thessaloniki, Trikala and Heraklion) that represent completely different urban profiles of the Greek state.

4.3.1. Thessaloniki – Region of Central Macedonia

Thessaloniki is the second largest city in Greece after Athens, with the population of its metropolitan area exceeding 1.1 million inhabitants. It is the most significant administrative, financial, cultural, entrepreneurial, and commercial center in Northern Greece, and a major transportation hub for the Southeastern Europe. It also houses the second largest export and transit port in the country (Intelligent Cities Challenge, n.d.).

Although Thessaloniki's post-war economy is heavily industrialized, its base has dramatically changed since the beginning of the 21st century, as the number of firms, employees and products' added value have started to decline (Komninos & Tsarchopoulos, 2013). Today, the manufacturing sector is dominated by medium to low technology-intensive industries, with the majority of them being classified as SMEs and operating in the service and administration sectors (Alexander Innovation Zone, n.d.).

Thessaloniki's going smart journey

Thessaloniki's efforts towards becoming a smart city are based on a very high level of education, public research and development (Komninos & Tsarchopoulos, 2013).

The first attempt to formulate a coherent digital strategy coincides with the *"Intelligent Thessaloniki"* project, developed by the URENIO research team of the Aristotle University of Thessaloniki (Komninos, 2011b). The plan focuses on developing broadband networks and digital services in six main districts of Thessaloniki: i) the port; ii) the commercial center; iii) the Aristotle University campus; iv) the technopolis business park; v) the museum of science and technology; and vi) the Macedonia airport.

Regarding the first five innovation and entrepreneurship districts, certain emphasis is placed on (Komninos, 2011b):

- the deployment of local networks – wireless and fixed – to ensure broadband connectivity and access to services;
- free Internet access for businesses and citizens;
- the development of smart applications;
- the provision of digital services to businesses and organizations;
- proper training of businesses' staff in the management of digital services;
- the interconnection of districts; and
- the establishment of a central unit that will be in charge of the project's coordination and support.

Eventually, the strategy has not been implemented since – as Komninos et al. (2019) claim – the adverse effects of the economic meltdown and political upheaval in Greece have led to its complete abandonment.

IBM's smarter cities challenge

Smarter Cities Challenge is a competitive grant programme in the context of which cities from all over the world suggest developmental ideas and IBM "provides its problem-solving capabilities in the areas of cloud, cognitive, analytics and more to the cities with the most compelling proposals" (Wilson, 2017) in order to disseminate information based on real world data, thereby drastically contributing to evidence-oriented policy development and decision making. The selected cities receive the support of IBM expert teams that cooperate closely with city leaders for three weeks and deliver valuable recommendations on how to make the city smarter and more efficient (IBM, n.d.).

Thessaloniki is chosen to participate in the Smarter Cities Challenge 2015-2016 in a bid to deal with issues relating to limited municipal resources and efficacious service delivery (European Commission, 2016). The programme mainly focuses on identifying the most effective routes for transforming Thessaloniki into a leading city in the collection, processing, and use of open data in several fields (governance, mobility, education, environment, economy) (Komninos et al., 2019). The outcomes of the open data initiative are intended to support decision-making processes, stimulate entrepreneurship, encourage the development of novel digital applications, boost local development and citizens' involvement, and promote use of data by the academic and research community (European Commission, 2016). In February 2017, IBM's expert team present their strategic recommendations to promote open data, with the most significant of them being listed below (Komninos et al., 2019):

- Restructuring of IT-related departments to facilitate open data overall management, policies, practices, and applications.
- Establishment of a steering committee to oversee the city's open data initiatives.
- Development of a comprehensive open data strategy that will secure consistent understanding across municipal departments.
- Shaping of an environment that encourages cooperation.
- Hosting of events and activities to promote the initiative, increasing thus the number of open data users.
- Addressing resource availability barriers via investments, strategic coalitions, and shift of management's orientation.
- Collaboration with Aristotle University and University of Macedonia to support the open data initiative through the provision of human resources and the development of the necessary technological infrastructure.

The above directions are structured in such a way as to support cities to confront all those threats that are currently being identified as the key obstructions to their digital transformation. The first five recommendations focus on the complete absence of a national strategic framework on how cities approach the open data philosophy, by addressing the problem of municipal departments' vertical organizational structures (silos), which prevent effective data transfer. The last two deal with the 'riddle' of limited city resources, by proposing strategic investments and collaborations that can guarantee access to capital, skilled workforce, and technological expertise.

Finally, it should be noted that although the Smarter Cities Challenge is touted as IBM's largest philanthropic initiative, it has been acutely criticized as to whether it is indeed a true charitable contribution or a tactic whereby IBM can engage with local governments and promote its services (Alizadeh, 2017).

Resilient Thessaloniki – A strategy for 2030

In 2017, the *"Resilient Thessaloniki – A Strategy for 2030"* policy document, the fruit of the city's participation in the "100 Resilient Cities Pioneered by the Rockefeller Foundation" program in 2016, is published. The strategy is founded upon eight key principles (social cohesion, local identity and heritage, environmental management, health and well-being, youth empowerment, multi-stakeholder engagement, technology adaptation and economic prosperity); and crosscut four main goals that form its basis (Resilient Thessaloniki, 2017):

- *Shape a thriving and sustainable city* by designing and delivering urban mobility systems that serve citizens with efficacy, environmental integrity, and strategic utilization of resources.
- *Co-create an inclusive city* by investing in human talent and entrepreneurship, by empowering citizens and community programmes, and by offering opportunities for co-creation in open and public spaces.
- *Build a dynamic urban economy and responsive city* through the development of an urban economic policy that recognizes and supports current and potential local economic cluster activities and zones. At the same time, new cross-sectoral partnerships and modern ways of approaching governance will enable the city to respond effectively to changes and satisfy the citizens' needs.
- *Re-discover the city's relationship with the sea* via the integrated economic and urban development of Thermaikos bay. The city can restore the local ecosystem and drastically improve quality of life by capitalizing on the cultural and natural capital of its marine environment.

These four goals are broken down into 30 objectives, which – in turn – comprise more than 100 actions (policies, projects, and initiatives), that associate the strategy's goals and objectives (Resilient Thessaloniki, 2017).

Thessaloniki's digital strategy 2017-2030

Thessaloniki's *"Digital Strategy 2017-2030"* aims at providing a reference framework for the digital development of the municipality and guiding the selection of specific actions, projects, and policies towards this end. At the same time, it is inextricably linked to the city's long-term planning and more particularly to the *"Resilient Thessaloniki – A Strategy for 2030"* masterplan (Municipality of Thessaloniki, 2017).

The digital strategy defines five *key features* that the city ought to acquire to start shaping a strong, contemporary, digital character. Therefore, Thessaloniki should become (Municipality of Thessaloniki, 2017):

- *Interconnected*: a city that can offer fast, low-cost, and stable Internet connectivity, thereby improving the residents' lives and also supporting smart devices and sensors that collect and disseminate data to all.
- *Inclusive*: a city that does not exclude citizens from Internet access and technology and works hard towards bridging the digital divide.
- *A city that harnesses data*: policies are implemented and decisions are made on the basis of available solid data and information, a fact that results in more effective and transparent governance.
- *Participatory*: a city that promotes active public involvement, boosting thus the democratic spirit and accountability of city authorities; and delivering more efficient services, as these are designed in accordance with citizens' needs and aspirations.
- *Reliant on digital innovation*: a city that fully leverages digital innovation to develop new, but also improve existing, services and products, particularly in sectors where it has comparative advantages (culture, tourism).

The benefits expected to be reaped, the priorities on which digital developmental efforts should be focused, specific and measurable objectives to be achieved, and the actions deemed necessary to fulfil the intended objectives, are also described for each one of the above-listed features.

Thessaloniki and the digital cities challenge

"Digital Cities Challenge" is a European initiative that seeks to develop and implement digital policies by fully exploiting the potential and dynamics of the 4th industrial revolution, helping thus the participant cities to pave their way towards digital transformation (European Commission, 2019). From a total of 41 cities that finally took part in the initiative, 15 were selected to receive funding (9.2 billion euros overall budget), including the Greek cities of Thessaloniki, Patras, and Kavala; 21 cities were involved but used their own resources (Greek cities of Athens and Trikala are among them); and the last five served as beacons in order to convey successful practices and act as sources of inspiration for the rest (European Commission, 2019).

As far as the city of Thessaloniki is concerned, the "Digital Cities Challenge" project is linked to the "Digital Strategy 2017-2030", the "Research and Innovation Strategy for Smart Specialization (RIS3) for the Region of Central Macedonia", the

"Resilient Thessaloniki – A Strategy for 2030" and the "Regional Operational Programme of Central Macedonia 2014-2020" (Maroulis et al., 2019).

The programme recognizes that the existence of a vibrant digital community, the experienced and high-skilled human capital as well as the digital competences of local businesses, operating in the ICT sector, are considered to be the strengths of Thessaloniki. Conversely, the dearth of financial resources, the digital illiteracy of the workforce that is employed in non-digital sectors, and the lack of proper ICT-related training, constitute the main weaknesses of the city. At the same time, only 67% of households have Internet access with moderate connection speeds, while there are no Wi-Fi hotspots in the city's public spaces. All these characteristics, together with the abovementioned policy-making documents, define the strategy adopted by the "Digital Cities Challenge" programme for the digital transformation of Thessaloniki. Therefore, for instance, it is assumed that the development of the necessary telecommunication infrastructure will be carried out by private companies, since the city exhibits very limited economic potential for investments in this sector (Maroulis et al., 2019).

Moreover, the initiative aims at turning Thessaloniki "into a resilient city, which relies on digital transformation, its human capital and institutions to boost economic growth and improve quality of life" (Maroulis et al., 2019, p. 4). To achieve this mission, four *ambitions* are defined (foster companies' digitalization, render Thessaloniki a living lab for innovative products and services, promote extensive use of data by all, leverage the city's talents), which in turn are linked to eight *operational objectives*. Operational objectives are perceived as the way whereby the ambitions will be attained; and are the outcome of a consultation process with various stakeholders. Lastly, the operational objectives are associated with 22 tangible and concrete actions, with a clearly defined timeframe (Maroulis et al., 2019).

CUTLER project

The *"Coastal Urban developmenT through the LEnses of Resiliency"* (CUTLER) is a 36-month-long European initiative, funded under Horizon 2020, that places emphasis on the resilient urban development of coastal cities. It intends to take full advantage of the data stemming from existing infrastructure (relevant to environment, society, and economy) and create data mining and visualization tools for knowledge extraction. These tools will support a platform exclusively focused on policy making, as well as on its implementation and assessment through the filter of resilience (Coastal Urban

Development through the Lenses of Resiliency [CUTLER], n.d.). The project's four pilots are running in Thessaloniki (Greece), Antalya (Turkey), Antwerp (Belgium) and Cork (Ireland). The municipality of Thessaloniki has chosen, as an experimental application, the use of the CUTLER platform for the design, implementation, monitoring and evaluation of a new controlled parking system that operates in three specific districts (Papastergios et al., 2019).

Thessaloniki's participation in the EU Mission for 100 climate-neutral and smart cities by 2030

Since April 2022, Thessaloniki – together with five more Greek cities – has been a member of the *"EU Mission for 100 Climate-Neutral and Smart Cities by 2030"* initiative. The aim of this flagship project is to support European cities in precipitating their green and digital metamorphosis by implementing concrete solutions (integrated urban planning, smart technologies, agile energy management systems, innovative and eco-friendly modes of transport, etc.) to the massive contemporary challenges of climate change and digital transformation. The 100 selected cities will act as experimentation and innovation hubs to become climate-neutral and smart by 2030, 20 years earlier than the goal of climate neutrality set by the European Green Deal, thereby paving the way to the rest of the European cities (Ministry of the Environment and Energy, 2022).

Thessaloniki's smart city projects and applications

Thessaloniki's most significant smart city initiatives are briefly delineated below.

❖ ***Smart governance initiatives*** (City of Thessaloniki, n.d.-c)

- *Open Budget*: offers citizens the opportunity to have direct overview of the city's budget from 2011 till present, both in terms of revenues and expenditures, either in detail or in the form of charts.
- *Open Data Portal*: open platform where 136 datasets – classified into 12 themes and available in various formats – are provided. It should be noted that the first datasets were made public in 2013 (Komninos et al., 2019).
- *E-Services*: numerous mainstream municipal services, provided electronically to residents and businesses.

- *Improve my City*: Web-based platform where citizens can submit and comment on non-emergency urban problems (Komninos et al., 2019). The platform facilitates the direct communication between citizens and responsible municipal authorities. It was launched in 2015 in Thessaloniki and has been successfully implemented in other cities (Karatzouli, 2016).
- *City Dashboard*: online platform, where part of the city's open data (related to municipal budget, financial indicators, environment, municipal police, "Improve my City" service, etc.) are gathered, visualized and presented in an intuitive way to the public.
- *Apps4Thessaloniki*: crowdsourcing platform, where citizens can upload their ideas about the development of Web and mobile applications that improve city functioning by providing residents, visitors, and businesses with new, innovative services.
- *Hackathess*: application development marathon (hackathon), intended to upgrade city's operation (economy, networks, utilities, governance, and quality of life), by taking advantage of the tremendous possibilities offered by ICTs.
- *GIS Portal*: spatial data infrastructure (SDI) that incorporates a plethora of spatial datasets.
- *Storm Clouds*: European funded project (2014-2017), designed to explore the way municipalities can accelerate the process of migrating their e-services from their own infrastructure to the cloud; and the impact this process would induce from the users' perspective (European Commission, 2017).

❖ ***Smart environment initiatives** (*City of Thessaloniki, n.d.-b)

- *Covenant of Mayors for Climate and Energy*: In 2017, the municipal council of Thessaloniki decides to participate in the *"Covenant of Mayors for Climate and Energy"* initiative and commits to reduce CO_2 emissions by 40% until 2030 (City of Thessaloniki, 2017).
- *Energy Vision 2020 for South East European Cities*: European project, launched in 2012, focusing on crafting and implementing policies in South-east European countries, to reduce energy consumption, with particular emphasis on the building sector.

- *PEPESEC (Partnership Energy Planning as a tool for realizing European Sustainable Energy Communities) Project*: European project, initiated in 2008 and lasted 30 months, oriented towards supporting the development of sustainable energy communities and setting out *"Sustainable Energy Action Plans"* for every participant city.

❖ ***Smart mobility initiatives*** (City of Thessaloniki, n.d.-e)

- *EasyTrip*: project financed by the European Territorial Cooperation Programme "Greece – Bulgaria 2007-2013", with the main goal to improve cross-border accessibility through the development of a digital tool that offers online mobility services accessible to all (Chalkiadakis, 2017). The project was completed in 2014 and the resulting Web platform has the potential to provide multimodal route planning and travel information for smartphones (Iordanopoulos et al., 2018). The application offers a wide spectrum of features including trip planning, points of interest based on the location and categories selected by the user; information on available public transport; dispersion of shops near the user's defined location; information in relation to events, traffic conditions, parking spaces, taxi stands; and levels of pollutant emissions. At the same time, it is possible to review the provided services (Chalkiadakis, 2017).
- *Smart Urban Mobility Management System of Thessaloniki*: Web platform designed to offer optimal mobility services. It provides information and increases citizens' awareness of contemporary urban mobility challenges and their environmental impacts. The system is divided into two sub-systems: (i) the *urban mobility center* that allows users to plan their travel route according to the means or any combination thereof they wish to use; and informs the public about traffic and environmental conditions, public transportation, and sustainable urban mobility aspects; and (ii) the *traffic control center*, which is mainly focused on processing real-time, mobility-related data (traffic flows, travel times, etc.).
- *THESi*: controlled parking system, focusing on assisting users in searching and finding a parking space, preventing illegal parking and alleviating the heavy

traffic congestion problems of city center. The system operates at specific time periods and provides parking spaces to residents and visitors (THESi, n.d.).

- ***Smart economy initiatives*** (City of Thessaloniki, n.d.-a)
  - *Virtual City Market*: application developed in the context of STORM CLOUDS project that allows every business, located in the city, to create its own virtual shop; and enables customers to access several retailers through a single platform (Kakderi, et al., 2016).
  - *OK!Thess*: initiative launched in 2016 by the municipality of Thessaloniki in collaboration with the city's universities and business associations, to create an innovation incubator for start-up enterprises. OK!Thess offers workspaces, proper training, consulting, networking opportunities, help to identify funding options, etc., so as to assist entrepreneurs in introducing their innovative ideas to the market (Komninos et al., 2019).

- ***Smart living initiatives*** (City of Thessaloniki, n.d.-d)
  - *Thesswiki*: crowdsourcing project that intends to digitize the history and culture of Thessaloniki by the citizens themselves through Wikipedia. It interconnects the physical and digital environment, and at the same time contributes to users' education and promotion of tourism and culture.
  - *Digitization – Documentation of Cultural Artifacts*: digitization of Thessaloniki's cultural capital, in order to promote and disseminate its cultural heritage and make it available to all through the Internet.
  - *City Branding*: application created in the context of STORM CLOUDS project, that promotes the city's identity via the deployment of interactive maps, 360^{o} panoramic images, videos, and photos (Kakderi, et al., 2016).

- ***Smart people initiatives*** (City of Thessaloniki, n.d.-f)
  - *Integrated Green Cities*: places emphasis on the integrated management of urban green spaces with parallel education, awareness, and mobilization of citizens (Keep.eu, 2021). The final deliverables include – among others – an interactive online game for educating children about rainwater management methods in the city of Thessaloniki.

- *synTHESSI*: Web platform that encourages citizens, citizens' groups and organizations to present their actions on an interactive map and communicate with each other.

4.3.2. Trikala – Region of West Thessaly

Trikala is a small-sized, peripheral, urban settlement, located in the Region of Thessaly (West Greek mainland). According to the 2011 Greek census, the municipality's permanent population is 81,355 inhabitants, with 61,653 of them residing in the city of Trikala. Local economy is characterized by the dominance of the tertiary sector (tourism and catering services mostly), as it gathers 75.65% of the economically active population. The secondary sector follows with a share of 17.31%, while the primary sector accounts for only 12.04% of the workforce (Municipality of Trikala, 2015).

During the last decades, many areas of the Region of Thessaly – including the municipality of Trikala – have been suffering from *isolation*, *population decline*, *economic stagnation,* and high rates of *unemployment* due to insufficient transport accessibility; rough morphology that obstructs productivity and economic gains; limited access to communication and knowledge infrastructure; and low-skilled labor force (Stratigea & Panagiotopoulou, 2015).

e-Trikala

Striving to deal with the abovementioned issues, Trikala commences its going smart effort in 2004 – with the establishment of the e-Trikala office, which had the overall supervision and development of ICT applications – and things have evolved quite impressively since then. The whole endeavor reflects the city's desire to pave new developmental paths by use of ICT-enabled applications for removing isolation, revitalizing economy, boosting governmental efficiency and transparency, and improving quality of life.

It should be noted that Trikala is recognized as the first Greek city to have approached the smart city concept holistically and successfully (Angelidou et al., 2020); and has been following a top-down philosophy for transitioning to the new digital era, with municipal authorities being the key agent in promoting this rationale (Anthopoulos & Tsoukalas, 2006). In 2008, the e-Trikala office is transformed into e-Trikala S.A., a joint development company (99% of its share capital belongs to the municipality of Trikala and 1% to the Chamber of Commerce of Trikala) (e-Trikala, n.d.-e). The office has been tremendously assisting Trikala in participating in European projects and developing applications and pilot projects that are tested in the city, as well as projects that are still in effect.

Trikala's huge, constant, and diligent effort towards implementing its integrated smart city strategy has been recompensed by the Intelligent Community Forum (ICF) as the city was included in the 21 smartest communities in the world for three consecutive years (2009, 2010, 2011); and was the first Greek city to gain international recognition in the field of smart cities by the ICF (Stratigea & Panagiotopoulou, 2015).

The following sub-sections concisely describe the most significant smart, sustainable, resilient, and inclusive initiatives the city of Trikala has participated in or has launched so far.

CitiesNet network

In 2008, 11 municipalities of Central Greece – with the city of Trikala holding the reins – adopt a citizen-specific and local-oriented strategy, founded on communications, information and infotainment; and intended to ensure direct and effective telecommunication interconnection among citizens, visitors and companies, improving thus quality of life and fostering local development. Bearing in mind that the economic engine for the implementation of this strategy are several local, regional, national and European projects, the participant municipalities establish the Digital Cities of Central Greece enterprise in 2009 (DCCG-CitiesNet), that constitutes the first Greek digital community. In a bid to realize its vision, DCCG-CitiesNet has dynamically entered the technological arena by utilizing applied and state-of-the-art technologies in order to meet the local needs and offer integrated solutions and services to municipalities and citizens, adapted to the peculiarities of each area (CitiesNet, n.d.).

Covenant of Mayors

Since 2008, the municipality of Trikala has been participating in the *"Covenant of Mayors"* initiative and in 2010 it finalized its first *"Sustainable Energy Action Plan 2010-2020"*, focusing on an overall CO_2 emissions reduction target of 25% by 2020. Pursuant to the plan, the proposed actions are related to interventions in municipal buildings, lighting infrastructure, energy production through renewable sources, urban transport system upgrade, social awareness-raising, information, and public involvement (Municipality of Trikala, 2010).

European projects

Through e-Trikala and CitiesNet network, the city of Trikala has actively taken part in various European initiatives, which aim at developing and/or implementing smart projects and applications to resolve urban problems and inefficiencies. The most significant thereof are listed below.

❖ ***Projects related to education***

- *Comenius Regio "Schools Without Borders"* (2013-2015): effectively addresses school problems related to social exclusion of migrants and other vulnerable groups (e-Trikala, n.d.-u).
- *PRISSM* (2012-2014): promotion of the coordination among municipal services, provision of professional training to the municipal staff and delivery of integrated social services (e-Trikala, n.d.-r).
- *DEN-CuPID – Digital Educational Network for CUltural Projects Implementation and Direction*: strategic partnership among local authorities, academia, and SMEs, intended to improve managerial skills and boost entrepreneurial spirit and knowledge in the field of cultural management (e-Trikala, n.d.-f).

❖ ***Projects related to health***

- *INDEPENDENT*: three-year-long telecare pilot project, completed in 2013. The initiative's goal was to upgrade the health services provided to vulnerable social groups and help them maintain their independence by leveraging novel technologies (e-Trikala, n.d.-m,).
- *ISISEMD* (*Intelligent System for Independent living and SElfcare of seniors with cognitive problems or Mild Dementia*): development of e-health applications to support patients with dementia (e-Trikala, n.d.-n).
- *Momentum*: thorough analysis of telecare applications in order to create a guide / roadmap for their proper development and certification (e-Trikala, n.d.-o).

- *Renewing Health*: integration and identification of well-recognized and acceptable standards for the provision of proper and effective telemedicine services to patients who suffer from chronic diseases (e-Trikala, n.d.-s).
- *SUSTAINS (Support Users To Access Information and Services)* (2012-2015): development of the necessary applications that allow users to access their medical records and remotely communicate with their doctors without having to visit a health facility (e-Trikala, n.d.-x).
- *SmartCare*: development of integrated care services for elderly residents that assist them in retaining their independence and ensuring a better quality of life for them by use of innovative technological solutions (e-Trikala, n.d.-v).
- *CarePath*: development of a proper mechanism to help children in need of psychological and social support, based on trauma-informed interventions (e-Trikala, n.d.-b).
- *ACTIVAGE*: launched in 2017, aims at developing IoT-based applications to create smart environments and support the independent living of older citizens (ACTIVAGE Project, n.d.).

❖ ***Projects related to mobility***

- *TEAM* (*Tomorrow's Elastic Adaptive Mobility*) (2012-2016): development and testing of new collaborative transport applications by utilizing cross-cutting technologies, telecommunications and telematics (e-Trikala, n.d.-y).
- *CityMobil2*: promotion of automated mobility by creating demonstrations with autonomous (or self-driving or driver-less) vehicles that move in specific routes within the urban fabric (e-Trikala, n.d.-d).
- *AVINT*: similar to the CityMobil2 initiative, the aim of this pilot project is to implement a bus line, fully integrated into the city's transport network and supported by self-driving buses, that will be covering citizens' daily transportation needs for six months. The results of the trial period will be thoroughly analysed both in terms of the impact on Trikala's traffic conditions and, more importantly, in terms of the possibility of extending the project to a larger scale (e-Trikala, n.d.-a).
- *MyWay – European Smart Mobility Resource Manager* (2013-2016): designed to develop an integrated smart mobility platform that encourages the use of all

means of transport. It promotes sustainable movement and exercise by suggesting the respective optimal ecological routes and combination of mobility media (e-Trikala, n.d.-p).

- *Elviten*: launched in 2017, it aims at rendering the use of Electric Light Vehicles (EL-Vs) in cities a more attractive option, compared to conventionally-fuelled alternatives (e-Trikala, n.d.-i).
- *Cities-4-People*: brings together various groups of people to propose and co-create sustainable urban and peri-urban mobility solutions. The project's main objectives are: (i) mobility enhancement via the deployment of appropriate, innovative, collaborative tools; (ii) design of sustainable, demand-based, urban mobility solutions; and (iii) fostering of civic-oriented mobility. Focusing on the city of Trikala, the initiative seeks to redesign the current public transportation system, while introducing new mobility solutions, with a particular emphasis on the urban market (e-Trikala, n.d.-c).
- *iHeERO*: supports the development of the necessary infrastructure to harmonize the European area with the eCall service (service associated with the European emergency number 112 and targets the creation of an integrated system for dealing with road accidents). Since 2018, vehicles sold within the EU have been equipped with the eCall service, which allows the authorities to be immediately notified in cases of emergency road incidents (e-Trikala, n.d.-l).
- *Harmony*: launched in 2019, the project focuses on supporting authorities to lead a sustainable transition towards a low-carbon mobility era. In the case of Trikala, the initiative endeavors to activate all stakeholders on urban and peri-urban mobility issues; encourage the use of drones for transferring medicines from the city to peri-urban and rural areas; collect data to explore the impact of new mobility technologies and services; and to help municipal authorities to create Sustainable Urban Mobility Plans (SUMPs) (e-Trikala, n.d.-k).
- *SMARTA 2*: complements the *"SMARTA"* European initiative and aims at implementing shared mobility services interconnected with public transport in four European rural areas (Mehmet, 2019). The municipality of Trikala is expected to develop an online application that will feed citizens with real-time information about public transport, and will assist them in coordinating car-

pooling efforts, having access to taxi and bus services but also to storage lockers for scooters, wheelchairs or bicycles, offered at the city's central square (e-Trikala, n.d.-w).

❖ ***Projects related to governance and citizens***

- *Elder-Spaces*: the project attempts to create a platform whereby people over 55 years old can communicate, get familiar with the use of technology, organize and participate in events, etc. (e-Trikala, n.d.-h).
- *NET-EUCEN*: intends to create and manage a network of organizations from different countries, that cover the supply chain of the service for users to share experience and develop guidelines to enhance governmental ICT initiatives and services (e-Trikala, n.d.-q).
- *SABER* (2012-2014): designed to provide basic broadband to all Europeans, thereby eliminating the digital divide (e-Trikala, n.d.-t).
- *DESMOS*: digital participatory platform that aspires to provide a framework for citizens and visitors' protection and security through: i) immediately notifying the public in cases of emergency; ii) enabling citizens to report anonymously dangerous incidents; and iii) appropriate adaptation and preparation of infrastructure in order to respond effectively to emerging needs (e-Trikala, n.d.-g).

Trikala 2025 strategic plan

In 2014, the municipality of Trikala proceeds with the adoption of *"Trikala 2025 Strategic Plan: A Smart, Sufficient and Resilient City"*, which is expected to be implemented through two operational programmes (Sustainability Observatory, n.d.). The city's vision comprises five key features – *smart, resilient, agile, sustainable*, and *efficient* city – and is articulated as follows: *"The need to form an environment that is smart in its operation, efficient against crises (political, economic, nutritional), resilient, agile, and sustainable for its citizens and businesses. A municipality that is attractive to investments, visitors, and new citizens"* (Municipality of Trikala, 2015, p. 261).

Pursuant to Trikala's strategic plan fundamentals, smart municipality is recognized and perceived along the six smart dimensions proposed by Giffinger et al. (2007). A sufficient city is the one that possesses the resources to successfully confront any risks that may emerge during social, political, financial and food crises; while resilient cities have the capacity to quickly recover from the shocks these crises provoke. The concept of the agile municipality regards the preparation of the organizational structures and citizens to respond effectively to changes. Finally, sustainable municipality is related to the planning and implementation of proper strategies to ensure the smooth operation and development of the municipality, without compromising its ability to meet the needs of future generations.

Trikala's participation in EU Mission for 100 climate-neutral and smart cities by 2030

Starting from April 2022, the city of Trikala is participating in the *"EU Mission for 100 Climate-Neutral and Smart Cites by 2030"* initiative with the ultimate goal to achieve zero emissions of air pollutants by 2030 through appropriate interventions in the domains of energy, transportation and urban planning (Ministry of the Environment and Energy, 2022).

Smart city solutions launched by the municipality of Trikala

The municipality of Trikala offers a broad range of services and applications, that give flesh and bones to the notion of the *smart, resilient, agile, sustainable*, and *efficient* city, adopted by the local ecosystem. The initiatives are classified under the smart city dimensions, as these articulated by Giffinger et al. (2007), and are listed below.

❖ ***Smart governance initiatives***

- *Free Access Wi-Fi Network*: the city of Trikala implements the first, open and free wireless network in Greece in 2008, ensuring in this way free of charge, wireless access to municipal services and the Internet for all. The infrastructure has been constantly expanding and adopting technological advancements for greater coverage, speed and security since then. Today, the network comprises more than 40 Wi-Fi nodes that allow free Internet access to approximately 15,000 citizens (e-Trikala, n.d.-j).
- *Fiber Optics Network (MAN)*: network of more than 50 Km of fiber optics that interconnect 50 municipal bodies and public schools throughout the city.
- *Open Data*: given the significant value of free access to data, the municipality of Trikala has made publicly available several datasets (in various file formats

and classified under ten general categories) through its open data portal, boosting thus transparency, strengthening trust and supporting local prosperity (Municipality of Trikala, 2018).

- *E-KEP (Automated Citizens Service Center)*: ATM-style machines that offer residents the opportunity to request and print out – at any time – municipal certificates and other related documents, rapidly, simply and easily (Municipality of Trikala, n.d.-f).
- *Comprehensive Geographic Information System (GIS)*: the municipal geoportal provides users with spatial information, so that they can make well-informed decisions and have a complete picture of the urban systems under the municipality's jurisdiction. The thematic layers allow the cartographic representation of urban planning data, technical projects, land use, the fiber optic network, traffic lights, street lighting, points of interest, etc. (Municipality of Trikala, n.d.-a).
- *Citizens' Request Line 20000*: integrated platform where citizens can submit requests to the municipality's services electronically and report non-emergent operational problems (Municipality of Trikala, n.d.-c).
- *Trikala Mobile CheckAPP*: mobile application – linked to the integrated citizen service platform "20000" – whereby citizens send requests to the municipality and monitor their progress. Additionally, the app covers basic information needs, and provides guidance to tourists by highlighting the points of interest within the city (Municipality of Trikala, n.d.-j).
- *Smart+Connected Digital Platform*: comprehensive IT system that reaps the benefits of IoT and manages the city's various surveillance and information applications by collecting, storing, processing and visualizing data generated by them and rendering them available to third parties interested in developing value adding products for residents and local businesses (Municipality of Trikala, n.d.-f).
- *Smart City Control Center*: monitoring and control center for all smart city services that run in the municipality (Municipality of Trikala, n.d.-d).
- *Data collection and analysis*: the city of Trikala utilizes the data that emerge from users' connection to the wireless municipal network to inform citizens and stakeholders of various events in the city, to promote their services and

products, etc., upgrading thus quality of life and strengthening local entrepreneurship (Municipality of Trikala, n.d.-f).

❖ ***Smart environment initiatives***

- *Smart Lighting System*: pilot project, implemented along a representative street of the city that consists of two phases, the installation of new LED lamps in the existing infrastructure; and the deployment of a wireless management system to better monitor, control and operate street lighting (Municipality of Trikala, n.d.-e).
- *Smart Waste Management*: network of sensors that sends real-time alerts to the waste collection center about the level of refuse in trash cans, streamlining thus the collection process (Municipality of Trikala, n.d.-g).
- *Environmental Conditions Monitoring System*: provides real-time data on environmental quality that facilitate the performance of relative evaluations, the assessment of any potential negative ramifications on public health, real-time alerts, the identification of trends that should lead to specific measures, etc. (Municipality of Trikala, n.d.-f).

❖ ***Smart mobility initiatives***

- *Controlled Parking*: monitoring and analysis of parking conditions (parking availability, detection of parking violation incidents, etc.), in the city by utilizing advanced video analytics technologies (Municipality of Trikala, n.d.-b).
- *Traffic Conditions Analysis through CCTV*: installation of CCTV cameras (used for the controlled parking system as well) to monitor and analyse traffic conditions, thereby enabling the competent authorities to better manage emergency incidents, which impede traffic within the urban fabric (Municipality of Trikala, n.d.-i).
- *Smart Parking System*: enables the identification, visualization and monitoring of designated parking spaces – with the assistance of installed sensors – along two main streets of the city center. Users are informed in real time of available parking spots either via a mobile application or through signs deployed in central points within the city (Municipality of Trikala, n.d.-f).

- *Traffic Lights Operation Monitoring System*: monitors traffic lights' operation and continuously checks for technical faults in the infrastructure. In case of failure, the system informs the control center of the location, direction and signage of the traffic light; while at the same time it notifies the authorized municipal employees for its restoration (Municipality of Trikala, n.d.-f).

❖ ***Smart living initiatives***

- *Tele-Care*: online platform that provides health and welfare services, using contemporary technologies (Municipality of Trikala, n.d.-h).

❖ ***Smart economy initiatives***

- *Innovation and Entrepreneurship Hub "GiSeMi"*: joint effort of municipality of Trikala and e-Trikala, launched in 2019, intended to shape a creative environment where innovative business ideas can, with the appropriate support, be transformed into start-ups. The hub provides young entrepreneurs with space to start setting up and developing their businesses, as well as the opportunity to test their implementation within the city of Trikala. Moreover, GiSeMi greatly contributes to the dissemination of the know-how produced by academia, research centers / institutes, etc., thereby rendering itself a new developmental pole of interregional scope. The benefits for the local community are of immense importance, considering that the businesses are obliged to provide and implement their products / services for free, assisting thus in solving real problems through smart approaches; and contributing to the economic development and sustainability of the city (GiSeMi Innovation & Entrepreneurship Hub, n.d.).

4.3.3. Heraklion – Region of Crete

Heraklion is the administrative capital of the Region of Crete, the largest city of the island and the 4th largest city in Greece after Athens, Thessaloniki, and Patras. According to the 2011 census, the municipality of Heraklion houses 173,993 inhabitants, while the city per se is estimated to accommodate 140,730 residents (Britannica, 2017). Heraklion is also a major transportation hub (it hosts the third largest Greek port in terms of passenger and transport load and the fourth busiest airport) as well as the most prominent commercial, educational and technological center of Crete. It possesses a strategic geopolitical location in the southeastern Mediterranean Sea, at the crossroads of three continents, where multiple, diverse cultures come together.

The city's economy relies heavily on tourism; however, the agricultural and commercial sectors play a substantial role in the local economy. Despite the economic significance of agriculture – due to the intense export of agri-food products – this absorbs only a very limited share of the workforce (4.2%), while the vast majority of the active working population is employed in the tertiary sector (80%) (Coccossis et al., 2017).

IKAROS network

In 2009, 15 municipalities – including Heraklion – sign the *"Memorandum for the Creation of an Inter-Municipal Cooperation Network between the Municipalities of Crete and the Aegean Islands in the Field of Information and Communication"*. The memorandum intends to establish a solid cooperation framework for the development and exchange of innovative solutions in the field of informatics and communication, with particular emphasis on the promotion of initiatives for the implementation of metropolitan area networks (MAN) and broadband infrastructure in local communities (Mochianakis, 2009).

Covenant of Mayors

In 2011 the municipality of Heraklion participates in the *"Covenant of Mayors"* initiative and sets an ambitious goal to reduce CO_2 emissions by 40% until 2030. The city's overall energy strategy is articulated in the *"Sustainable Energy and Climate Action Plan for the Municipality of Heraklion"*. The plan focuses predominantly on saving energy and reducing CO_2 emissions through appropriate interventions in the city's buildings, with actions concerning the way these are electrified, heated and insulated. At the same time, as far as green areas are concerned, the continuation of tree planting actions for regenerating public spaces and the seafront, is proposed. Regarding the residential 'rebirth', the replacement of light bulbs with new LED ones is intensely promoted; while in the mobility domain, emphasis is placed on the renewal and replacement of the municipal vehicle fleet, as well as on improving the operation of public transport in order to attract citizens and discourage them from using cars (Municipality of Heraklion, 2020).

Strategic plan of the municipality of Heraklion for the 'smart city'

In 2016, municipal authorities issue their strategic plan to transform Heraklion into a smart city. The plan perceives smart city as an urban environment that has adopted at least one initiative in the context of the six dimensions (smart economy, smart environment, smart mobility, smart living, smart people, smart governance) proposed by Giffinger et al. (2007) in their seminal work *"Smart Cities: Ranking of European Medium-Sized Cities"* (Municipality of Heraklion, 2016).

The principal goal of the smart city strategic plan revolves around establishing and promoting five critical developmental identities for Heraklion (Municipality of Heraklion, 2016):

- A *resilient city*, which provides a safe living environment to its citizens and visitors.
- A city that adopts and implements *people-oriented social policies*, thereby ensuring broad participation in policy making and protection of citizens' rights.
- A *safe city* through the development and maintenance of structures and services that can guarantee safety and security.
- A city with prominent *cultural and tourist identity*, which fosters the local economy.
- A hub of *innovation* and *entrepreneurship*, a place with *upgraded quality of life* and *extended participation in democratic processes*, an environment that adheres to *sustainable mobility* and *energy principles* and ensures *environmental protection*.

All the above reveal a modern vision that successfully associates the smart city paradigm with the concepts of resilience, sustainability, safety, security and inclusiveness.

In a nutshell, the scope behind Heraklion's smart journey reflects its effort to *re-gain competitiveness* and improve *quality and range of services* offered to citizens. The *strategy* set in this respect is twofold and aims at: i) promoting *place identity* by investing in preservation and e-marketing of local assets; and upgrading *competencies* of local labor force by taking advantage of the proximity to R&D institutions and universities; and ii) supporting local stakeholders' *digital inclusion* in order to improve the provided services and strengthen participation in local affairs (Stratigea & Panagiotopoulou, 2015).

Heraklion's smart city strategy is being unfolded over a ten-year-long period, with 2020 and 2025 set as milestones for its attainment. In a bid to support the plan's smooth application, municipal authorities have formed the *"Heraklion: Smart City"* Committee, in which several local institutions, organizations and other stakeholders participate. The aim of the Committee is to ensure harmonized cooperation among involved actors, averting in this way the launch of multiple initiatives in overlapping fields. At the same time, the Committee together with municipal authorities guide and assess actions' implementation and shape the conditions for the revision of the plan, which has an advisory rather than a restrictive character (Municipality of Heraklion, 2016).

Smart city initiatives launched by the municipality of Heraklion

Before diving into Heraklion's smart city initiatives, it should be mentioned that the city is ranked by the Intelligent Community Forum (ICF) among the 21 smartest cities in the world for three consecutive years (2009, 2010 and 2011), a fact that actually reflects the hard work and persistence of municipal authorities and the local community in structuring and realizing their shared smart city vision.

The city of Heraklion has deployed several smart projects, applications, and services, which are falling under six broad categories, namely: digital transformation, smart living, mobility and transport, citizens, economy, energy, and environment. To facilitate the analysis and comparison with the already described Greek cities, Heraklion's initiatives are classified according to the six fundamental smart city dimensions of Giffinger et al. (2007).

❖ ***Smart people***

- *citizens4heraklion.gr*: online platform where citizens can be informed of the municipality and the independent citizen groups' voluntary work, while they are also given the opportunity to submit their own proposals and ideas. Moreover, users can, through specific filters, get a full picture of the time, place and content of the city's activities. The aim of the platform is to become a vivid meeting place and a creative space for promoting active citizens / volunteers (Heraklion Smart City, n.d.-b).
- *Electronic navigation system in the old town of Heraklion*: tourism-oriented project, which started in 2007. The digital system guides the visitors and provides them with multilevel and diverse information, through the use of

audiovisual material, about the history of the city and its cultural heritage (Heraklion Smart City, n.d.-c).

❖ ***Smart governance***

- *Metropolitan Fiber Optic Network (MAN)*: the first milestone in the city's endeavor to become smart (URBACT, 2017). Today, it serves 55 schools with more than 16,000 students (Heraklion Smart City, n.d.-l) and it is the largest municipal network, providing Internet access in the country. It is worth mentioning that the implementation of Heraklion's smart city strategy has resulted in – among others – 100% broadband infrastructure coverage (the entire urban fabric is being served by broadband connectivity) (URBACT, 2017).
- *Wi-Fi Network*: Heraklion offers free Internet access in most of municipal buildings, but also in outdoor public spaces (e.g., squares and streets) to everyone. Citizens can find out where the service is available through the municipality's official Website (Heraklion Smart City, 2018).
- *Open Data Portal*: Heraklion provides a broad range of open data (pertinent to mobility and transportation, tourism, governance, smart living, citizens, energy and environment) to its citizens and stakeholders, thereby enhancing transparency and accountability in the public sector and strengthening local economy Heraklion Smart City, n.d.-h).
- *Urban Dashboard*: online platform that collects and displays all the open data of the city (Heraklion Smart City, n.d.-g).
- *Geographic Information System (GIS)*: contemporary, data-rich and user-friendly GIS portal that assists every citizen in enjoying upgraded and faster service and information on urban planning issues (Municipality of Heraklion, n.d.-a).
- *Citizen of Heraklion*: mobile application, whereby citizens can have access to a range of electronic municipal services. More specifically, users can be informed of the municipality's latest news, watch live broadcasts of the municipal council's meetings, make online requests for certificates and attestations, report any problems they have identified accompanied by

photographic material, description and location of the problem, etc. (Google Play, 2022a).

- *Citizenapp Schools*: application for the proper management and immediate communication of the problems that are detected in school structures to the responsible services of the municipality. School directors can submit their requests electronically via the application, drastically reducing in this way the resources consumed for recording and managing the relevant requests (Heraklion Smart City, n.d.-a).
- *IP telephony in all the main buildings of the municipality*: IP telephony refers to a set of technologies that allow voice transmission over the Internet Protocol (IP). In this way, communication among municipal services takes place via the Metropolitan Optical Fiber Network, instead of the public telephone network; greatly boosting thus the municipality's digital transition (Heraklion Smart City, n.d.-e).
- *Online services and online request platform*: Heraklion is one of the pioneers regarding municipal e-services provision in Greece. Several services are available online, while the platform is continuously being enriched with new ones (Heraklion Smart City, n.d.-f).

❖ ***Smart mobility***

- *RERUM* (2013-2016): IoT-based European program in the context of which four applications are implemented in the city of Heraklion in two phases. Initially, a system for measuring the city's traffic through the installation of smart devices in 25 bus stations is developed. At the same time, the RERUM traffic application, which allows users to provide data on traffic in the city is also launched. It the second phase, sensors are installed in municipal buildings to measure environmental conditions and energy; as well as at outdoor spaces to measure air pollutants. The sensor data is available through the municipal open data portal (Heraklion Smart City, n.d.-i).
- *Controlled parking system*: it introduces into everyday life an advanced technological solution, with online interconnection of functions, services, control, and information of the public. The system displays the availability of free parking spots in real time through alternative communication channels,

such as mobile devices; contributes to the quick and efficient control by the responsible authority; reduces traffic congestion problems and the consequent pollution; and prevents illegal parking (Heraklion Smart City, n.d.-j).

❖ ***Smart economy***

- *Science and Technology Park of Crete (STEP-C)*: founded in 1993, it constitutes one of the most prominent research organizations in Greece. It offers incubation services to start-up companies active in new and innovative technologies, as well as specialized business development services; while it also participates in several regional, national and international Research, Technology Development and Innovation (RTDI) projects (Science and Technology Park of Crete [STEP-C], n.d.).

❖ ***Smart living***

- *Municipal e-gallery*: smart initiative directly linked to culture and its promotion. Through the electronic gallery, users have access to over 900 artworks owned by the municipality of Heraklion (Heraklion Art Gallery, n.d.).
- *Vikelaia Municipal Digital Library*: leveraging the benefits of new technologies, Vikelaia municipal library has put into operation its electronic branch by digitizing part of its cultural material and making it available to the public. Users can have remote access to books, newspapers, magazines, Turkish archives, photos, videos and sounds of the city of Heraklion (Vikelaia Municipal Library, n.d.).
- *Steps into Culture and Tradition*: innovative online service provided by the Vikelaia municipal library, which enables users to search historical documents, books and newspapers, dating back from the 16^{th} up until the 19^{th} century (Heraklion Smart City, n.d.-k).

❖ ***Smart environment***

- *IMPULSE* (2016-2019): European project that deploys a set of actions for mapping the energy profile of numerous public buildings in six Mediterranean cities (including Heraklion), with the ultimate goal of introducing a supportive management system for the integrated design of energy efficiency interventions in public buildings (Municipality of Heraklion, n.d.-b).The project’s outcomes offer significant benefits to the city of Heraklion, as the pilot application has led to remarkable energy savings of approximately 30-35% (Sympraxis, n.d.).

- *Environmental monitoring*: online municipal dashboard, which provides citizens with environmental information pertinent to the location of IoT infrastructure, as well as to historical but also real-time environmental data (temperature, humidity, rain, wind, particles, etc.) (Heraklion Smart City, n.d.-d).

4.4. Juxtaposing Greek Smart City Initiatives

The Greek smart city examples analysed in the preceding section originate from a stiff, top-down approach, which is further shaped and enriched by the pursuit of diverse objectives and the development of different partnerships / coalitions to achieve them. Therefore, in the case of Thessaloniki, the city’s smart strategy results from the cooperation between the municipality and the URENIO research group. Trikala’s smart vision is driven by the municipality – through e-Trikala S.A. – and the local Chamber of Commerce. Finally, as far as Heraklion is concerned, smart applications are also initiated by the municipal authorities.

It becomes apparent that, despite the fundamental dissimilarities observed among these cities, as well as their completely different starting points and duration of their going smart journeys, they all follow a centralized ‘top-down’ approach, expressed by the leading role of the municipal authorities. This facilitates the comparison among the various initiatives in terms of their focus areas, peculiarities and outcomes.

By delving into the smart strategies of the three Greek cities and attempting to align their initiatives with the smart city dimensions of Giffinger et al., (2007), Table 4-1, that summarizes the key directions and priorities of the explored endeavors, is constructed. It should be noted that *strategic planning* for attaining a sustainable and smart future is added as an extra dimension, since it greatly determines the realization of successful and coherent smart city visions; it promotes long-term, integrated policies; it boosts plans’ resilience against political changes; and provides the basis upon which smart initiatives, fulfillment of relevant objectives and efficacy of smart strategies are evaluated.

According to Table 4-1, all three Greek cities appear to be pioneering examples, as they have developed and implemented applications and programmes across the six smart city characteristics. Moreover, all of them seem to place emphasis on *smart governance* and particularly on the provision of e-services, by taking advantage of the emerging technological benefits. This entails that Greek cities are still in the very early stages of materializing the concept of governance, and they have a long way to go before reaching more advanced ones that involve the use of ICTs for integrating information, processes, institutions and physical infrastructure; and strengthening cooperation and interaction among all urban actors.

Table 4-1: Comparison among Smart City Strategies of Thessaloniki, Trikala, and Heraklion

	Smart City Characteristics	**Smart Initiatives**	**Cities**		
			Thessaloniki	**Trikala**	**Heraklion**
Smart City Strategy	**Strategic Planning**		✓	✓	✓
	Smart Governance	e-Services	✓	✓	✓
		Open Budget	✓	✓	
		Open Data	✓	✓	✓
		GIS Portals	✓	✓	✓
		Public Wi-Fi	✓	✓	✓
		Online Problem Reporting	✓	✓	
	Smart Mobility	Parking	✓	✓	
		Traffic Monitoring	✓	✓	✓
		Free Bicycles		✓	✓
	Smart Environment	Environmental Data	✓	✓	✓
		Lighting		✓	
		Traffic Lights	✓	✓	
		Waste Management		✓	
	Smart Economy	Innovation Incubators	✓		✓
	Smart People	Training of Digital Skills	✓	✓	✓
		Volunteering	✓		✓
		Visitors' Information	✓	✓	✓
	Smart Living	Healthcare		✓	
		Culture	✓		✓

Another crucial issue regards the *spatial dimension* of smart initiatives and more specifically whether these cover the whole city or part of it. In this respect, cities may follow different paths, which are probably proportional to the intensity of the problem they are called upon to manage in each case. For example, in the case of parking applications, the municipality of Thessaloniki has implemented a city-wide system, since parking availability constitutes one of the most severe problems to be addressed.

Conversely, Trikala has launched pilot applications in specific streets, which not only aim at better managing parking slots in places where the problem is acute, but also at leveraging new innovative technologies and fostering experimentation. It is therefore evident that cities choose different paths to solve problems of the same nature, depending on their inherent characteristics; their capacity; and the intensity and extent of the issues they are confronted with.

The pilot projects launched in the context of European programmes and memoranda of understanding with private companies, play a significant role in the successful transition to the smart city paradigm, for they contribute to the development of vital infrastructure; as well as to the extraversion of the involved cities by promoting their image and opening up new opportunities for discovering resources and partnerships. For instance, although Trikala had already started its smart journey in 2003, it was broadly recognized as a prominent smart city after the implementation of autonomous vehicles through the CityMobil2 program in 2015. Despite the project's short time horizon, it 'endowed' the municipality with a highly developed network infrastructure and rendered it an attraction for businesses operating in this sector.

Reputation / visibility is another key factor, as it ensures cities' participation in several European programmes and attracts private capital and businesses. Leading examples are already moving rapidly towards promoting their cities as highly innovative urban environments with specific pioneering applications, such as Trikala in the field of electromobility and autonomous vehicles.

In general lines, the Greek experience on smart cities is directly linked to European funding and guidelines for the implementation of pertinent projects, with the most advanced examples being internationally recognized, but at the same time seriously lagging behind when compared to smart city frontrunners. This is a critical matter of concern, as in the coming years the whole world is expected to place particular focus on combating climate change and its impacts, with cities being the epicenter of this effort. The importance of the changes that need to be made to urban systems, aided by ICTs and their applications, is emphasized in the *"European Green Deal"* promoted by the European Commission in 2019. Despite the difficulties that many Greek cities face (limited financial resources, technological illiteracy of local population in peripheral urban settlements, etc.), they possess enough indigenous talent and a highly educated and skilled workforce, which can be an important asset in promoting innovations; leveraging technological advancements; and taking advantage of the rapid developments in the field of smart cities.

4.5. Discussion and Conclusions

In closing, experience gained from the thorough analysis of the way the smart city concept has been taken shape worldwide, but also from the formerly delineated urban ecosystems, reveals a series of crucial issues that may raise interesting questions or instigate vivid discussions; and therefore, they should be taken into serious consideration.

To begin with, the dominant tendency – at national, European, and international level – for small and medium-sized urban environments to exhibit poor technological performance should be stressed. Most of them are immensely short on *governance maturity*, *online participation culture* as well as *penetration* and *assimilation of technology* in general, contrasted with larger cities (Panagiotopoulou & Stratigea, 2022). The main reason behind this remark lies at the root of the prevalent contemporary neoliberal notion that perceives large cities as dynamic marketplaces, which can efficaciously serve the interests of particular companies (mostly technological) and states (Kitchin, 2022). For over a decade, colossal industries have been monopolizing the diffusion of technology and the development of smart urban environments. Attention is paid almost exclusively to large cities and metropolises, for these have the capacity to develop economies of scale and constitute much more attractive investing environments, compared to smaller cities and the limited economic benefits these entail (Muro & Whiton, 2017; Panagiotopoulou et al., 2019; Panagiotopoulou & Stratigea 2022). As a consequence, the critical issue of digital divide and the predicament of those who have limited to no access to ICT infrastructure, or are void of the necessary skills (Brabham, 2009; Stratigea, 2011; Panagiotopoulou & Stratigea, 2022) is emerging and is gradually gaining importance among planners and decision makers, as it leads to a certain kind of social inequality and social exclusion (Carver et al., 2001), thereby nurturing discussions on technological (Ortega et al., 2018) and spatial justice (Jones at al., 2019). Sudden adverse circumstances, such as the COVID-19 pandemic outbreak, may severely exacerbate the problem, since access to technology, especially during such turbulent, uncertain and restrictive periods, constitutes the only window to the outer world.

Secondly, successful and sustainable (in terms of feasibility, resilience and endurance) strategies for the development of a smart city ought to be, first and foremost, *realistic* and *'down to earth'*, in the sense that they should be in harmony with the economic, political, social, environmental and cultural context, within which they are meant to operate (Stratigea & Panagiotopoulou, 2015). History has shown that goals and objectives that ignore the reality of their corresponding context, are doomed to fail miserably.

Finally, the last remark – closely related to the previous one – refers to the fact that smart city strategies should be oriented towards *capitalizing on existing resources* (Angelidou, 2015). It is extremely easy to get carried away by utopian visions and fanciful future images of a smart city – often shaped, maintained and advocated by key technological industries – and begin crafting idealistic strategies that are based on rotten foundations; place emphasis on what is missing or required for attaining a paradoxical future state; while, at the same time, they completely defy what is already there, and how existing assets can be identified, updated, improved and finally deployed as a starting point, before moving on towards the next steps.

To sum up, the successful implementation of the smart city paradigm is inextricably linked to *visionary leadership*, *good planning*, as well as *strong commitment*. Moreover, time and effort should be devoted to the identification of community needs and expectations, based on traditions, culture, etc. in order to make decisions on proper infrastructure and relating city- and citizen-specific applications (Stratigea, 2012; Stratigea & Panagiotopoulou, 2015; Panagiotopoulou & Stratigea, 2022). The latter is of crucial importance as customer profiling or, even more, co-designing of services with the citizens may lead to more sustainable and effective e-services, boosting thus public satisfaction and achieving higher rates of 'log-in' potential (Stratigea, 2011; Stratigea & Panagiotopoulou, 2015).

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- **Part 1** Contextual Background
- **Part 2** Bibliographic Review on Smart Cities
- **Part 3** Construction of an Integrated Indicator Framework for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)
- **Part 4** Bibliographic Review on Semantics & Ontologies
- **Part 5** Development of an Ontology for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)
- **Part 6** Conclusions & Future Research

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CHAPTER 5: ASSESSING THE PERFORMANCE OF SMART, SUSTAINABLE, RESILIENT, AND INCLUSIVE CITIES (S2RICS) – DEVELOPMENT OF A MULTIFACETED, INTEGRATED, AND COMPREHENSIVE INDICATOR FRAMEWORK

***Synopsis**: The scope of this chapter is to set up a multidimensional and comprehensive indicator framework, capable of effectively assessing the performance of Smart, Sustainable, Resilient, and Inclusive Cities (S2RICs). Towards this end, several critical aspects regarding the very nature, usability, importance and relevance of indicators, as well as numerous, broadly used indicator typologies are analysed. Moreover, a rigorous and critical review of contemporary international indicator frameworks intended to assess cities' smartness, sustainability, resilience and inclusiveness, is conducted (top-down or expert-led approach); and is coupled with an endeavor to integrate the different perspectives explored into a more enriched and coherent indicator framework. This framework aims at providing assistance to urban planners and policy makers in assessing, monitoring, and managing cities as well as in reaching more informed decisions for serving current multi-purpose (or multi-level) target setting in diverse urban contexts; while they are in alignment with new, emerging concerns in the urban planning realm (e.g., resilience and disaster reduction) and recently endorsed global sustainability goals and frameworks (2030 UN Agenda, Sendai Framework, etc.). Additionally, the rationale behind indicators' selection process is described (bottom-up or citizen-led approach), thereby guiding urban managers on how to navigate in the proposed framework and identify the most appropriate, city- and citizen-specific indicators for implementing relevant assessments and formulating more sound and robust policies.*

5.1. Preamble

The 21st century is highly marked by a tremendous *urbanization wave* that has dramatically escalated over the last years and constitutes an immensely defining and influential trend of our time (Suzuki et al., 2010), hence the characterizations 'Urban Century or Age' or 'Metropolitan Century' often used to describe it (Annez et al. 2008; United Nations Human Settlements Programme [UN-Habitat], 2009; United Nations [UN], 2015a; Organization for Economic Co-operation and Development [OECD], 2015; etc.). Pursuant to United Nations' estimations (UN, 2019b), 55% of the global population is residing in cities in 2018 (contrary to 30% in 1950). Moreover, relevant projections reveal that nearly 68% of the world's inhabitants will be urban dwellers by 2050; while the phenomenon is anticipated to exhibit severe tension in Asia and Africa (especially in India, China and Nigeria).

The radical and ominous impacts that derive from the extremely aggressive and spontaneous urban expansion (e.g., constantly rising energy demand, increasing urban waste generation, land encroachment, poverty, slums, water shortage, pollution, environmental hazards, health risks, congestion, lack of social cohesion, migration and displacement, insecure and inadequate housing) pose great barriers and overwhelming challenges to city administrations (Harrison & Donnelly, 2011) regarding the attainment of 2030 UN Agenda Sustainable Development Goal (SDG) 11 towards inclusive, safe, resilient and sustainable cities and human settlements. These threats also constitute the focal point of policy makers and urban planners' work all around the globe, who desire to deliver widely acceptable, efficacious, innovative, sustainable and resilient solutions to all people in order to mitigate or prevent the risks ahead (Madlener & Sunak, 2011; Uttara et al., 2012; Smith et al., 2017; Patra et al., 2018; Wang et al., 2018).

On the other hand, attractiveness of urban environments, perceived by many as the natural habitat of contemporary societies (Rogers, 1997), the future of the human kind (Harrison & Donnelly, 2011) or a place of change endowed with a considerable reserve of innovative capacity (German Federal Ministry for Economic Cooperation and Development, 2016), is nowadays mainly anchored in their role as powerful engines of growth and prosperity, acting as a real magnet for highly qualified, talented young labor force and significant agents of innovation, creativity and inclusion (Clos, 2016; Marava et al., 2018; De Filippi et al., 2019). Taking into consideration their vital contribution to the world's Gross Domestic Product (GDP) (it is estimated that cities account for 80% of the global GDP), urban areas are also conceived as the backbone of the global economy (Clos, 2016; German Federal Ministry for Economic Cooperation and Development, 2016).

Coping with the strengths and weaknesses of contemporary urban environments is placed at the forefront of policy concern in order *glocal* (global and local) sustainability objectives to be reached, i.e., pursuit of prosperity and innovation; restoration of social cohesion, boosting of inclusion, shaping of proper prerequisites and conditions that ensure health and safety for the citizens; adaptation to climate change impacts; etc. (Stratigea, 2012, 2015; Tao, 2013; Marava et al., 2018); rendering thus cities ardent proponents of sustainable development efforts (Girardet, 1999). Fulfillment of these objectives is taking place within a continuously evolving, incredibly unpredictable and highly complex environment, marked by major alterations observed in four discrete contexts (Marava et al., 2018):

- The *technological context*, where disruptive technological advancements and pertinent applications, permeating all different dimensions of urban reality and broadening perspectives for interaction, collective intelligence and (e-) participation, emerge (Rodríguez Bolívar, 2018).
- The *governmental context*, where evolving collaborative, decentralized and ICT-enabled (Information and Communication Technologies) governmental structures prepare the ground for institutional rearrangements and establishment of wider partnerships and coalitions that crosscut all the domains of the urban realm (Burby, 2003; Stratigea, 2015; Rodríguez Bolívar, 2018).
- The *societal context*, where matters like justice and fairness, poverty alleviation and social equity, empowerment and engagement, awareness raising and responsibility sharing, shift in power and influence structures, consensus building, etc., become key issues in the policy agenda and planning practice towards paving smarter, more sustainable, resilient and inclusive future pathways.
- The *economic context*, where dominant driving forces, such as globalization, economic downturn and scarcity of financial resources stimulate the discovery and implementation of new, innovative, ICT-enabled and more resource-

efficient problem-solving ways for producing urban wealth and providing decent services to citizens (Stratigea et al., 2015; Rodríguez Bolívar, 2018).

In order to deal with the adverse implications, but also strengthen and harness the positive outcomes of the current urbanization pattern, the goal of *sustainable urban development* has been – for several decades now – placed at the core of the policy agenda in numerous urban regions around the globe. The concept of smart cities, treated as an alternative solution to the traditional city planning model during the last twenty years (Li et al., 2019), is lying at the heart of this policy, supported by the aforementioned transitions. Confronting the constantly evolving urban challenges and fulfilling aspirations for creating sustainable urban futures, the smart cities' paradigm seems to be an effective and favourable strategy to many urban locales for steering economic competitiveness, innovation, environmental sustainability, and liveability (Stratigea, 2012; Lövehagen & Bondesson, 2013; Stratigea & Panagiotopoulou, 2014, 2015; Willis & Aurigi, 2017; Zait, 2017); and mitigating the impacts of urbanization trends and the consequent overpopulation pattern (Chourabi et al., 2012).

Despite the fact that the smart city concept is widely perceived as a new and innovative ICT-enabled approach for achieving urban sustainability and a new 'brand' in the urban planning realm, constantly gaining ground among various cities around the globe (Komninos, 2002), the way smart city *performance* can be assessed and monitored with respect to sustainability aspects still remains an unresolved issue. As highlighted at the Symposium on Key Performance Indicators (KPIs) for Smart Cities, organized in 2015 by the Joint Programme on Smart Cities (JPSC) of the European Energy Research Alliance (EERA), in spite of the several satisfactory indicator frameworks that have been proposed, *a broadly-accepted one* that reflects the 'smart city' dimension *does not still exist* (EERA, 2015). This remark is mainly justified by the lack of an unambiguous operational definition of the smart city term, whose conceptual exploration is still in progress (Chourabi et al., 2012; Stratigea et al., 2017; Panagiotopoulou, 2018; Panagiotopoulou et al., 2019). Various indicator frameworks, intending to support urban planners and policy makers in shaping *sustainable urban futures* and evaluating urban sustainability accomplishments (Shen et al., 2011), have been developed by numerous organizations during the last decades. The selection and deployment of the most suitable framework has always been considered an intriguing issue that demands expert knowledge (Huovila et al., 2019). It has provoked utter perplexity and has obstructed planners and decision makers' efforts from properly monitoring urban sustainability projects; while, in many cases, it is characterized by insufficient (or even absent) *performance metrics* and/or *equivocal definitions of such metrics* that could contribute to the replication of best practices (Marsal-Llacuna et al., 2015; Glasmeier & Nebiolo, 2016). Moreover, it has been a source of mistrust, owing to the lack of transparency regarding the preference of particular indicators which doubts their soundness and insinuates deliberate support of foregone policy directions and decisions that are determined behind the scenes. Finally, bearing in mind the plethora of smart technologies that are emerging, as well as their unmapped impacts with regard to urban sustainability achievements, evaluation processes seem to become even trickier since an essential corps of empirical-based evidence is rather missing (Deakin, 2009).

While a clear view of smart city applications on sustainability aspects does not exist, the value and significance assigned to sustainability objectives and concerns in the 3rd Millennium has been greatly endorsed by the United Nations' aspirational sustainability targets that are articulated in the 2030 UN Agenda. Pursuant to this agenda, sustainable urban futures towards 2030 are grasped both directly, by shaping a widely embraced urban vision through the attainment of SDG 11 on "Making cities and human settlements inclusive, safe, resilient and sustainable" (UN, 2015a); and indirectly, through the accomplishment of several SDGs and objectives that are relevant to the urban level as well. Furthermore, new concepts – stemming from emerging challenges which affect cities and consequently the urban planning and policy domain – are highly stressed; whereas they have already been a main subject of the urban planning discourse during the last few years, e.g., *resilience* and the efficient management of new, emergent *risks*. These concepts, that originally derive from the environmental discipline (Davoudi et al., 2012), possess an instrumental role in the 2030 UN Agenda and have become indispensable constituents of the urban sustainability target setting process (UN, 2015a). Nowadays, however, they are further expanded so as to incorporate *resilience* into economic, societal, environmental, cultural, political, individual and infrastructural dimensions; as well as the *dangers / risks* inherent in urban systems, such as globalization, climate change, escalating urbanization, demographic pressures, resource scarcity, lack of social cohesion, and ageing of infrastructure (Caldarice et al., 2019). This expansion reflects an endeavor to realize newly emerging pressures and embed them in the pursuit of urban sustainability. The importance attached to these terms by the scientific and policy community is rapidly growing since they are considered important lens for policy response in an era where disastrous incidents and relevant risks increase in severity and frequency (Hayward, 2013). Even though the meaning they bear is not fully understood or explicitly defined until now on a theoretical level, yet they form the core of global organizations' work and drastically contribute to a constantly mounting number of governmental and non-governmental reports and frameworks (Davoudi et al., 2012). Considerations of these works focus on the development of ready-made, off-the-shelf toolkits for e.g., resilience-building or disaster risk management solutions, in an effort to operationalize these concepts and directly engage them in urban planning theoretical ground and practice (Leach, 2008).

Based on the above discussion, several *research questions* are raised: how can urban sustainability performance be assessed, especially in the smart city context? Should this be treated independently or should it be part of a more integrated approach, evaluating the impact of both smart and sustainable policies, since the first, in many cases, is adding value to the latter? What is the current practice in respect of this intriguing problem at the global scale? How can the newly emerging concerns on resilience of urban environments, inclusiveness and engagement or disaster risk reduction be reflected in this assessment?

Or, stated differently, are there any available sets of indicators that effectively deal with the new challenges confronted by contemporary cities in the information and globalization era? Are existing sets of indicators sufficient enough to assess smart city performance as to sustainability objectives, or should they be further enriched / expanded so as smart city sustainability achievements to be properly incorporated in these sets? Do these, or other complementary sets, efficaciously capture issues of resilience and disaster risk reduction, considered as the new 'headache' and focal points of planners and decision makers' duties? Is a commonly shared list of sustainable urban development indicators even feasible, given the broad variety of urban current conditions / states, as well as the huge dissimilarities observed among different places?

An analysis of several smart city examples – drawn from the global scene – reveals that there is not an explicit definition and clear underlying semantics, specific indicators and measures, as well as standardization of the concept's critical aspects (International Telecommunication Union [ITU], 2014a; Panagiotopoulou, 2018; Panagiotopoulou et al., 2019, 2020). Moreover, cities' smart development does not follow a particular pattern and as Bhattacharya et al. (2015) state, there is not only *"one size that fits all smart city models"* (p. 17). In fact, current smart city examples exhibit substantial variations in terms of technological maturity; level of ICT infrastructure and type of smart applications deployed to satisfy the needs of cities of varying spatial scales; sustainability objectives and current state of achievements; geographical and geopolitical context in which smart applications are developed; and so on. This renders the assessment of sustainability performance even *trickier* and rather *case-specific*, while it implies the need for bridging this gap by: (i) developing a coherent, comprehensive, integrated and well-structured indicator framework / system, based on the international experience – *top-down or expert-led approach*; and (ii) offering valuable guidance on how to navigate in this system and select the most relevant and suitable – to each single city profile – set of indicators for evaluating the impact of ICT-enabled and non ICT-enabled policies on cities' sustainability accomplishments – *bottom-up or citizen-led approach* (Stratigea et al., 2017; Panagiotopoulou et al., 2020). Additionally, such a framework has to: (i) take into consideration the currently ongoing discussion on resilience and public involvement (empowerment and engagement) that have become an inseparable part of the discourse on smart and sustainable cities; (ii) include concerns regarding the mitigation of disaster risks as these are articulated in the *Sendai Framework for Disaster Risk Reduction 2015-2030* (United Nations Office for Disaster Risk Reduction [UNDRR], 2015), steering in this way resilience objectives of contemporary cities; and (iii) incorporate the 2030 UN Agenda (UN, 2015a) aspirational sustainability goals and objectives and related metrics for their monitoring and assessment.

Along these lines, the particular chapter endeavors to elaborate on the above-mentioned issues with a specific focus on *urban sustainability*, which constitutes the overarching planning goal behind smart, resilient and inclusive city developments. Towards this end, in the first step the definitions, nature and importance of indicators are analysed. Several indicator typologies, proposed and used by prominent international organizations and institutions, are also briefly described. In the second step, current global *frameworks of performance indicators* regarding: (i) urban sustainability and SC objectives; (ii) the emerging concepts of resilience, disaster risk reduction and public empowerment and engagement; and (iii) the UN SDGs in general and the SDG 11 in particular, are explored. Based on the rationale of the different indicator frameworks examined, but also on literature review of related concepts, the chapter proceeds with an effort to establish, in a systematic and coherent manner, an integrated and comprehensive indicator framework that is built upon them. Such a framework can serve, in a universal way, urban sustainability assessments, incorporating at the same time contemporary aspects and concerns of smartness, resilience and inclusiveness. Finally, an indicator selection process, capable of providing assistance to urban managers on how to navigate in the proposed framework and identify the most suitable performance indicators for making more informed, knowledge-based and responsible policy decisions, is sketched.

5.2. Grasping the Notion, Nature, Role, and Significance of Indicators

> *Indicators are a necessary part of the stream of information we use to understand the world, make decisions, and plan our actions* (Meadows, 1998, p. 1)

Extensive and painstaking literature review unveils a profusion of definitions that have been proposed from time to time by various organizations, institutions, academics, etc., in an endeavor to capture the meaning of *indicators*. The fact that the term is met in plentiful diverse contexts; and it is embedded in the core of work or research of an extremely broad variety of different scientific disciplines, leads to conclude that there is still no mutually shared interpretation thereof.

According to OECD (1993), an indicator can be defined as "a parameter or a value derived from parameters, which provides information about a phenomenon. The indicator has significance that extends beyond the properties directly associated with the parameter value. Indicators possess a synthetic meaning and are developed for a specific purpose" (p. 5).

Adriaanse (1993) attributes to indicators two key distinguishing features: their ability to *quantify* information, so as to render their importance more obvious and hence more easily grasped; and their capacity to *simplify* information regarding complex phenomena, in order to boost / improve communication.

Hammond et al. (1995), who focused on effectively informing decision makers and the public (public policy issues) in their work entitled "Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development", claim that:

> Indicators provide information in more quantitative form than words or pictures alone; they imply a metric against which some aspects of public policy issues, such as policy performance, can be measured. Indicators also provide information in a simpler, more readily understood form than

> complex statistics or other kinds of economic or scientific data; they imply a model or set of assumptions that relates the indicator to more complex phenomena. (p. 1)

Meadows (1998) suggests that indicators delineate the *perceived state* of a system (although it might not be calculated accurately most of the times). This assertion attributes pivotal importance to them, considering that every human decision focuses on the transition of a system from a current condition to a desired one. This shift is attained through proper actions / interventions / decisions, depending on the *discrepancy* detected between these two different states; and thus, indicators' role in describing the current state appears to be really crucial.

Briggs and Wills (1999) perceive indicators as "a means of providing information on a condition or quality which cannot easily be directly measured or assessed. As such, an indicator can be defined simply as a variable plus a relationship. We measure the variable, and through the known relationship can infer something about the condition of interest" (p. 188).

Briggs (2003) provides a clear-cut and plain interpretation of indicators' meaning by characterizing them as "signals for things that cannot be directly seen. They are based on data, but ideally add value to data by expressing them in a way which is more understandable and more relevant to the user" (p. 2).

The World Health Organization (World Health Organization [WHO], 2011) states that an indicator:

> is a variable that can be measured repeatedly (directly or indirectly) over time to reveal change in a system. It can be qualitative or quantitative, allowing the objective measurement of the progress of a programme or event. The quantitative measurements need to be interpreted in the broader context, taking other sources of information (e.g., supervisory reports and special studies) into consideration and they should be supplemented with qualitative information. (p. 8)

Pursuant to Delorme and Chatelain (2011, p. 8):

> An indicator is a (generally statistical, but also potentially logical) order of magnitude linked naturally or arbitrarily to the measurement of policy activities (in the broadest sense of governance). Indicators are characterized primarily by the fact that they provide information in summary form, are communicable and are subject to relative consensus. An indicator is generally defined by its function (what it measures), the means of obtaining it (formula and necessary data), its quality (the extent to which it can be interpreted and monitored over time) and the limits on its use (what it does not measure or measures poorly).

Parsons et al. (2013, p. 6) describe an indicator as “a quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect the changes connected to an intervention, or to help assess the performance of a development actor”.

The aforementioned indicative definitions and explanations imply – in one way or another – that indicators facilitate the exploration of a system’s current state, or the determination of any change occurred, by providing valuable details about the functioning of this system for a particular purpose. Moreover, indicators possess a substantial role in the transformation of data into relevant pieces of information, intended to be consumed by decision makers and the public; and therefore, they constitute integral parts of management, policy- and decision-making processes (Nuttall, 1990; Von Schirnding, 2002). They offer a useful insight into systems’ performance or behavior, by simplifying convoluted relationships (or phenomena) and offering a “synthesized view of existing conditions and trends” (Von Schirnding, 2002, p. 20), which can be utilized to improve, update and enrich decision-making procedures (Nuttall, 1990; Von Schirnding, 2002).

Furthermore, indicators’ significance is considered greater than solely the values these represent and extends beyond what is actually measured / determined, to a more generic or broader topic / phenomenon / trend of concern. In other words, indicators shed light on aspects / dimensions regarding matters of higher importance or unveil a phenomenon or tendency that is not immediately or directly perceptible (Hammond et al., 1995).

Taking into account all the above discussion, the magnitude of deploying appropriate indicators, at the context of *policy* and *decision-making*, is clearly evident since they can drastically contribute to the (Von Schirnding, 2002): (i) detection and delineation of existing problems and weaknesses; (ii) explicit and efficient prioritization; (iii) formulation and assessment of policies and plans; (iv) guidance / orientation of Research and Development (R&D); (v) standardization and development of guidelines and roadmaps; (vi) progress monitoring and proper actions for informing the public.

It is noteworthy that indicators are often misunderstood and treated as ordinary statistics or primary (raw) data, a fact that urgently calls for the establishment of a clear and explicit distinction between them (Bakkes et al., 1994; Hammond et al., 1995). In broad terms, statistics are purely descriptive, whereas indicators have a reference point with which they can be contrasted and, in this sense, they contribute to the implementation of various relevant comparisons (Van den Berghe, 1997; West, 1999). Additionally, indicators are composed of two or more variables of the system under study (or a combination of a variable with reference values or standards) (Van den Berghe, 1997). Thus, the total number of workers of a factory is perceived as a statistical measure, while the average number of workers per shift constitutes an indicator.

Figure 5-1 provides a clear and easy to understand picture on the various levels of scientific information, and graphically depicts the differences among primary data, statistics and indicators, in the shape of a pyramid.

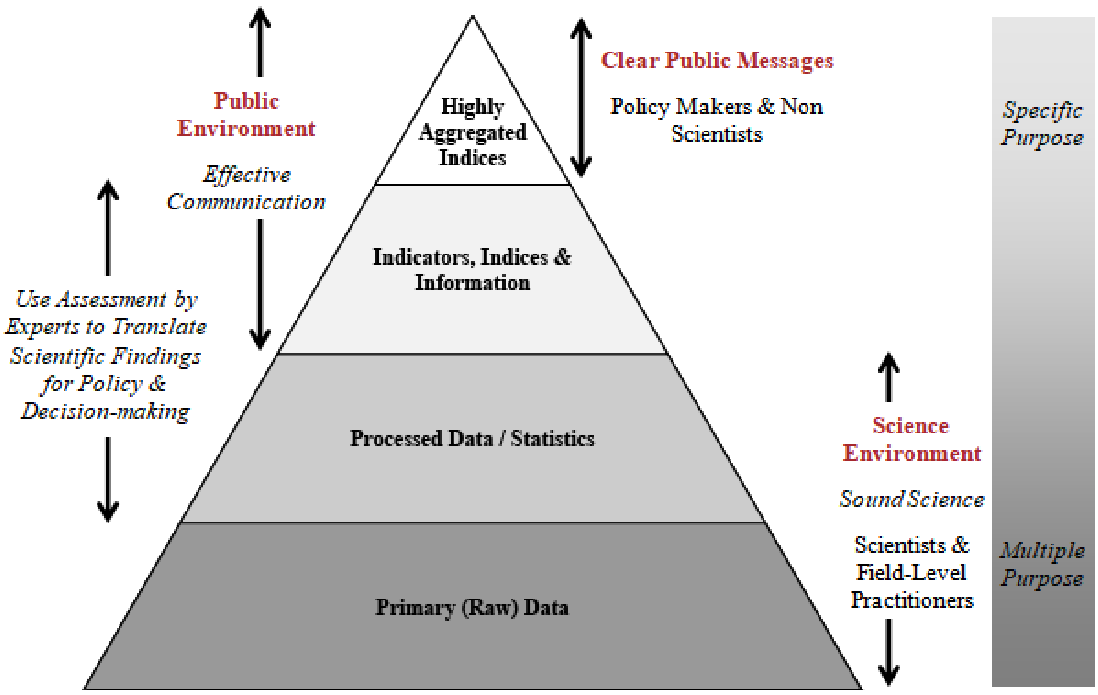

Figure 5-1: The Information Pyramid (Source: Adapted from Hammond et al., 1995; Fancy et al., 2009; Mutch & Sarr, 2012; Eurostat, 2017)

As shown in Figure 5-1, the pyramid's base is formed from large volumes of raw data on a topic of concern; whilst indicators and highly aggregated indices occupy the top part. This entails that information included in the upper levels is contingent upon a solid basis of detailed data, complex statistical analyses and information syntheses (indicators and indices actually reveal more compared with the data they are based on) (Hammond et al., 1995; Fancy et al., 2009; Mutch & Sarr, 2012). Also, raw and statistical, non-contextualized data (the bottom part of the pyramid) can be used to serve various purposes; whereas contextualized, categorized, calculated and condensed data (the upper part of the pyramid) refer only to particular purposes (Statistical Office of the European

Communities [Eurostat], 2017). Moreover, every layer of the information pyramid is associated with different types of users (audiences). Raw data are collected by scientists and field technicians via monitoring, field measurements, etc. Afterwards, experts process, analyse, aggregate, summarize (graphically and statistically), and publish these data as statistics. Proper analysis, re-expression, translation and combination / synthesis of statistics lead to the structuring of indicators, providing in this way specific, concise, comprehensive and simplified information to the various users who require plain and condensed knowledge for decision-making purposes (e.g., managers, policy and decision makers, citizens, etc.) (Corvalán et al., 1996; Fancy et al., 2009; Mutch & Sarr, 2012). Finally, indices emerge when indicators are aggregated on the basis of some formula (combination of indicators) (Dumanski & Pieri, 1997).

Similar to the previous analysis on the fundamental differentiation among data, statistics and indicators, Corvalán et al. (1996) graphically illustrate the 'place' that indicators possess in the *decision-making chain* (see Figure 5-2), drawing in this way a sharp distinction among the concepts involved.

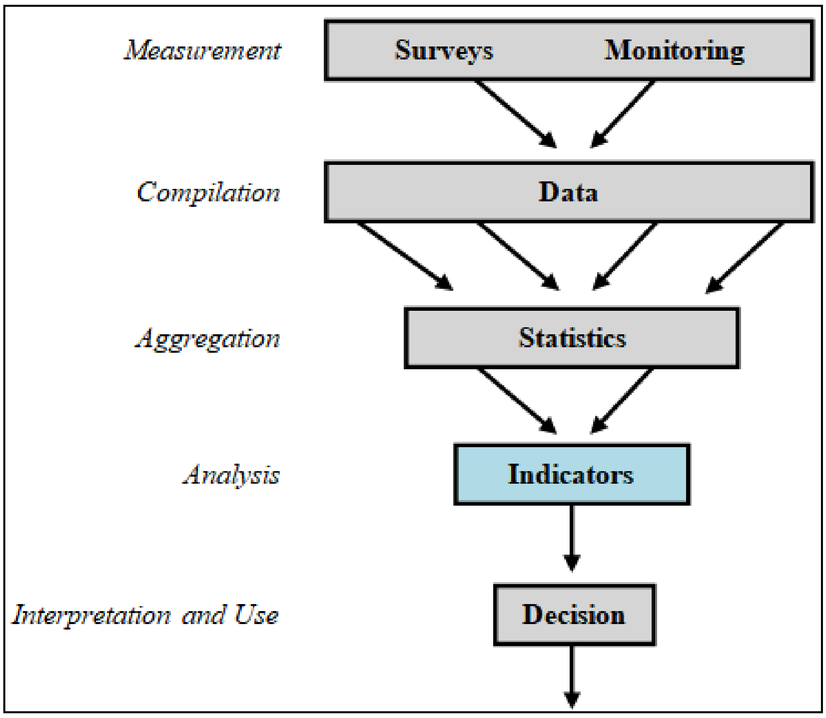

Figure 5-2: The Decision-Making Chain and the Role of Indicators in It (Source: Adapted from Corvalán et al., 1996)

Pursuant to Figure 5-2, the decision-making chain consists of four discrete stages which are (Corvalán et al., 1996):

- *Stage 1* – Production / generation and collection of primary data through relevant measurements and monitoring.
- *Stage 2* – Transformation of primary data into statistics (analysis and aggregation of raw data).
- *Stage 3* – Establishment of indicators via proper analyses, interpretations and re-expressions of statistics.
- *Stage 4* – Enrichment of decision-making process with indicators that emerge from the third stage.

All the above highlight the indicators' critical role in adding value to raw data by transforming large data volumes into simple, meaningful and easy to grasp information. This information, in turn, can be readily used by policy and decision makers in order to end up with more up to date, knowledgeable, sophisticated and sound judgments.

Given all the previous discussion, it is inferred that well-designed, wisely chosen and rationally used indicators are an essential 'weapon' in policy and decision makers' arsenal, since they provide useful, contextual information, therefore mitigating the complexity and uncertainty inherent in decision-making processes; and acting as normative and logical bridges between knowledge and policy (Hezri & Dovers, 2006; Kitchin et al., 2015). Yet, under no circumstances, should they be perceived as panacea. They cannot offer magical solutions to convoluted problems, nor can they help in escaping from making tough and challenging decisions. However, they are able to (Corvalán et al., 1996; Briggs & Wills, 1999): form a common ground for mutual understanding and communication among different actors; quantify and simplify information; underline the critical aspects of a phenomenon or trend; reveal potential solutions and evaluate their possible impacts; act as a means of informing the public and raising its awareness; create window of opportunity for "external scrutiny of decisions and policies" (Corvalán et al., 1996, p. 22).

5.3. Typologies of Indicators – A Succinct Review

Taking a careful look at the available literature, it is concluded that ample different types, formats and potential uses of indicators are met; and thus, their categorization varies significantly depending on a series of criteria every time. In general, although there is no unique way of classifying indicators, certain typologies can emerge on the basis of three fundamental considerations (Eurostat, 2014): a) determine the reason(s) behind the use of indicators (WHY); b) concretely specify what is to be measured through the deployment of indicators (WHAT); and c) assess the degree of *objectivity* and *precision / directness* of the selected indicators regarding their capacity to represent / model reality (HOW) (see Figure 5-3). The aforementioned approaches produce different taxonomies that are contingent upon the question posed every time, however they address three distinct facets of the same problem / phenomenon.

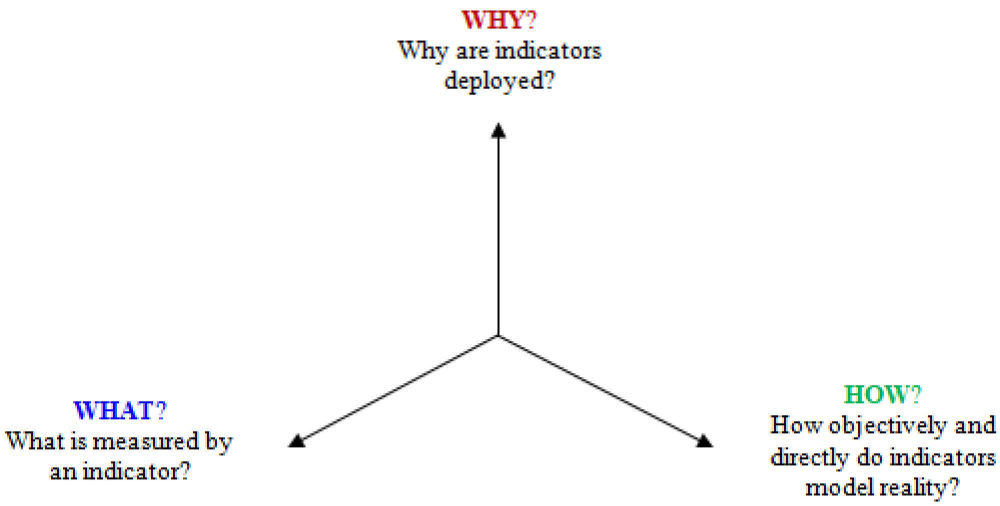

Figure 5-3: Three Fundamental Considerations for Indicator Classification (Source: Adapted from Eurostat, 2014)

5.3.1. Why are Indicators Deployed?

As far as the rationale behind the deployment of indicators (WHY) is concerned, two general categories are distinguished: *descriptive* (or contextual or situational) indicators that delineate and explicate a phenomenon or trend; and *performance* (or normative) indicators, which are used to evaluate the progress observed regarding the attainment of well-articulated goals and objectives. It is pretty typical to 'mix' these two different types of indicators, in the sense that performance indicators can be utilized so as to determine the results / impacts of a phenomenon, intervention, project, etc.; whereas descriptive indicators may provide additional details / knowledge on the topic of interest. It is also worth noting that an indicator can either be descriptive or normative, depending on the context in which it is used; and therefore, this context should always be clearly outlined and elucidated from the very beginning (Eurostat, 2014).

5.3.2. What is Measured by an Indicator?

Various different typologies arise when it comes to the question of what does a specific indicator gauge. A popular categorization regarding this issue divides indicators into *single* and *composite* ones. *Single indicators* refer to the measurement of simple and explicit phenomena, such as the number of businesses or patents per 100.000 population, the NO_2 (nitrogen dioxide) concentration, the number of unemployed people, etc. Conversely, *composite indicators* or *indices* emerge when individual indicators (with different units of measurement) are combined into a single measure, through the use of a system of weights or statistics (Maclaren, 1996; Eurostat, 2014). Composite indicators are deployed to gauge multifaceted, complex and abstract phenomena, which cannot be captured by single measurements, such as the UN-Habitat's City Prosperity Index (CPI) (United Nations Statistics Division, 2019), the Human Development Index (HDI) (Roser, 2014), deprivation indices, indices of well-being, happiness or business cycle indices, to name but a few.

In view of the fact that indicators act as a catalyst for grasping multidimensional and complicated phenomena / topics, respective conceptual / theoretical frameworks – capable of delineating their key concepts (dimensions), as well as their interrelationships; and defining what to measure and which indicators should be deployed for this reason – must be explicitly established (UN, 2007). Such frameworks contribute to the effective organizing / arrangement of the data required for structuring an indicator; they facilitate its accessibility; and boost its value added (Environmental Protection Agency [EPA], 1995). Moreover, efficient frameworks should satisfy two important conditions (Hardi & Zdan, 1997): (i) priority setting in the selection of indicators; and (ii) stimulation of indicators' identification. Additionally, they enable the association of individual monitoring programmes, since they actually provide a mutual and commonly-shared conceptual ground; they detect duplication and gaps, but also instigate the production of new data and relevant indicators so as to bridge those gaps. Finally, they can serve to integrate, process, analyse and visualize data sets on a geographic basis in order to underpin and enhance spatial-based decision-making (location matters!) (EPA, 1995;

Dumanski & Pieri, 1997). Therefore, these frameworks also offer a clear and concrete answer to the fundamental question of what to measure.

Numerous such frameworks, that derive from various scientific realms, are found in the literature, ranging from those rooted in economics to environmental-oriented ones (stress and stress - response frameworks) (Rapport & Friend, 1979; OECD, 1991, 1993; Smeets & Weterings, 1999; etc.) as well as frameworks focusing on ecosystems and human well-being (Alcamo et al., 2003). Major discrepancies are observed among these frameworks, which are primarily justified by the different (Wu & Wu, 2012): conceptualizations of, and emphasis placed on, the key dimensions and their interrelationships; methodological approaches that are followed; ways of classifying and aggregating indicators.

Several broadly recognized and widely used types of indicator frameworks are discussed in the following paragraphs.

Pressure – State – Response (PSR) frameworks

In the field of environmental protection, the *Pressure – State – Response (PSR)* framework, introduced by OECD in the 1980s, is used to establish cause-and-effect relationships between a system's elements and its related indicators (OECD, 1991, 1993) so as to conduct environmental performance monitoring. Several versions of the PSR framework have been developed by various organizations in the recent decades. The principles on which the construction and functioning of the particular framework is founded on are pretty simple (see Figure 5-4): pressures are exerted on the environment by anthropogenic activities (the 'pressure' box), altering thus the current state (quality and quantity) of natural resources (the *'state'* box). Society, in turn, reacts to these changes (the *'response'* box) in an organized manner – through relevant economic and environmental policies – in an effort to prevent, limit or mitigate their negative impacts (OECD, 1993; Hughey et al., 2004). Ultimately, societal responses feed back to the pressures, through human activities. Such causal relationships can assist decision makers and the public in grasping the way environmental, societal, economic, cultural, etc. issues are interconnected. Pursuant to OECD (1993), the above steps can be conceived as parts of "an environmental (policy) cycle which includes problem perception, policy formulation, monitoring and policy evaluation" (p. 5).

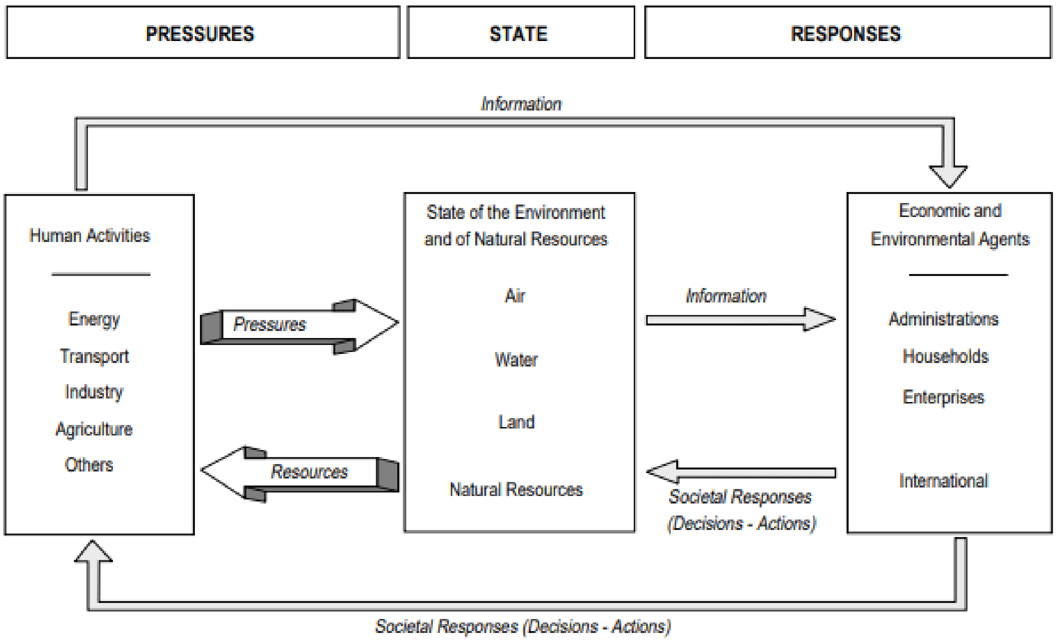

Figure 5-4: The Pressure – State – Response Framework (Source: OECD, 1993)

Figure 5-5 illustrates the typology of indicators that is emerging from the adoption and use of the PSR framework. More particularly, three broad categories are distinguished (OECD, 1993): (i) *indicators of environmental pressures*, pertinent to the stress exerted on the environment (marine and terrestrial); (ii) *indicators of environmental conditions*, relevant to the state of natural resources; and (iii) *indicators of societal responses*, accountable for measuring / determining the intensity of society's reaction when environmental changes occur.

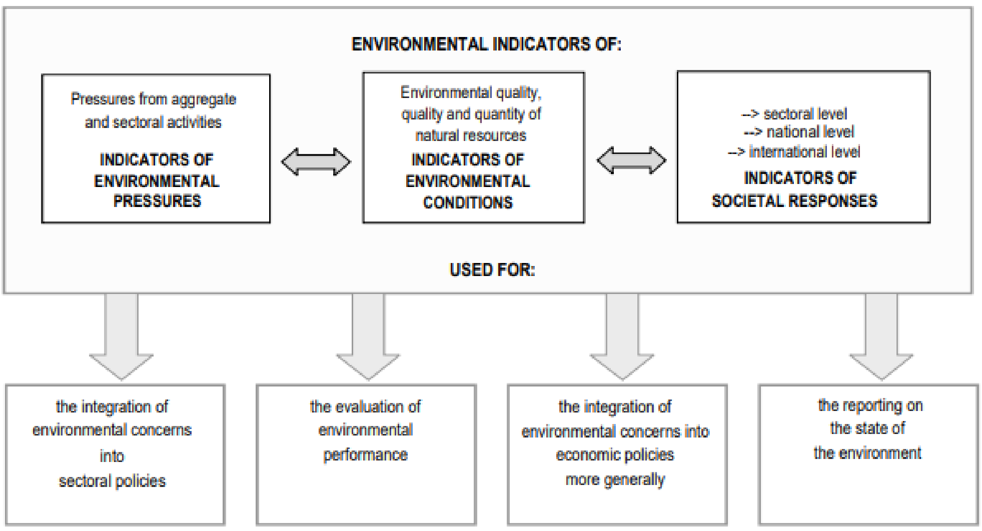

Figure 5-5: Classification of Environmental Indicators according to the Pressure – State – Response Framework (Source: OECD, 1993)

Later on, the European Environment Agency (EEA) used the PSR framework as a foundational basis and further extended it, ending up with the so-called *Driver – Pressure – State – Impact – Response (DPSIR)* framework. The philosophy behind the particular framework can be briefly described as follows (see Figure 5-6) (Smeets & Weterings, 1999): social and economic activities (drivers) exert pressures on the environment, which induce alterations to its state. Changes of environmental conditions, in turn, cause impacts on humans, ecosystems and materials that finally instigate societal reactions. Society's response creates a feedback mechanism leading directly back to the driving forces, the pressures, the current state, or the impacts, through adaptation and reformative or curative actions.

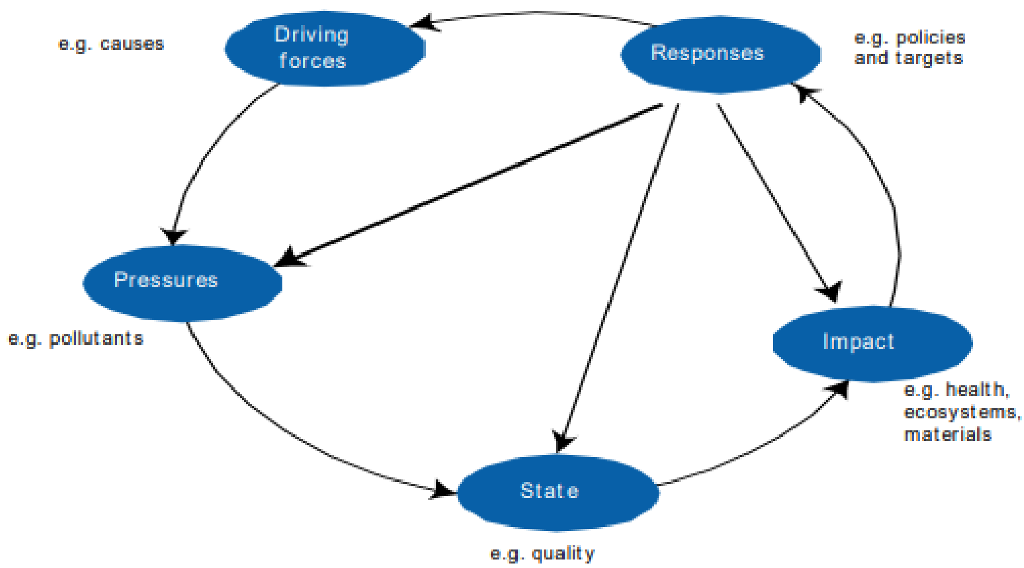

Figure 5-6: The Driver – Pressure – State – Impact – Response Framework (Source: Gabrielsen & Bosch, 2003)

In order to perform decision- and policy-making, as well as assessment processes based on the DPSIR framework, relevant information regarding the driving forces and their consequential stress on the environment, the environmental state, the impacts deriving from environmental changes and the societal reactions to these changes, should be available. Therefore, discrete types of indicators, capable of reflecting all the different parts of the causal chain and providing the necessary pieces of information, are introduced. More specifically, according to the DPSIR framework, indicators are classified into five general categories (Smeets & Weterings, 1999; Gabrielsen & Bosch, 2003): (i) *indicators of driving forces* define the social, demographic, and economic developments and activities that exert stress on the environment; (ii) *pressure indicators* describe developments in the release of substances, physical and biological agents, the use of resources and land; (iii) *state indicators* focus on the delineation of the current environmental state; (iv) *impact indicators* regard the effects on the environment (human health, ecosystems, etc.) that emerge from the various changes occurred, due to the pressures exerted on it; and (v) *response indicators* measure the reactions of society and governments towards hampering, counterbalancing, improving, or adjusting to the changes of the environmental state.

These types of indicators alone compose a 'static' picture of the system under study, since they provide a descriptive analysis with certain emphasis on the system's individual elements. The revolutionary aspect of the particular framework relates to the fact that apart from describing the causal relationships between its elements, it also focuses on their *links* – through the deployment of relevant indicators –, disclosing thus useful information about their dynamics (see Figure 5-7). The significance of these 'in-between' indicators lies in their ability to express the interplay between the constituents of the DPSIR framework. Furthermore, the existence of such linkages actually 'cancels' the simple schema of purely linear relations established between the elements that form a system, since they represent a much more complex network (web) – compared to a linear chain or circle – of numerous interacting factors, with some of them developing highly non-linear interrelationships (Gabrielsen & Bosch, 2003).

EEA has developed an indicator typology on the basis of four simple questions (Smeets & Weterings, 1999; Gabrielsen & Bosch, 2003): (i) what is happening? (*descriptive indicators*); (ii) is this somehow relevant? (*performance indicators*); (iii) can the way things are done be ameliorated? (*efficiency indicators*); and (iv) does this conduce to the overall well-being? (*welfare indicators*). *Descriptive indicators* reflect the current situation of a system, or more technically stated, they express the development of a variable over time (it is most of the times presented as a line diagram); and they are typically state, pressure or impact indicators. Conversely, *performance indicators* are associated with target values or thresholds. They measure the 'distance' between the current and the desired state (target) and they are most commonly used as state, pressure or impact indicators that are clearly connected to policy responses. *Efficiency indicators* belong to the aforementioned 'in-between' indicators' category that expresses the interrelationships of the causal chain's elements. Efficiency indicators, in particular, relate drivers to pressures and offer a deep insight into the efficacy of products and processes.

Moreover, the most relevant and useful efficiency indicators for policy-making are those that connect environmental pressures to human activities. Ultimately, *welfare indicators* aim at providing a general picture on the total sustainability of a system. It is worth noting that later on, an extra indicator category, the one of policy-effectiveness, is added in the proposed typology interrelationships (Gabrielsen & Bosch, 2003). *Policy-effectiveness* indicators are able of connecting the actual change of variables to policy efforts. As such, they constitute a linkage between response indicators on one hand and state, driving forces, pressure or impact indicators on the other. Their role in helping to understand the reasons behind the observed developments / changes / progress is deemed to be extremely pivotal; however, their production requires considerable volumes of quantitative data and expert knowledge.

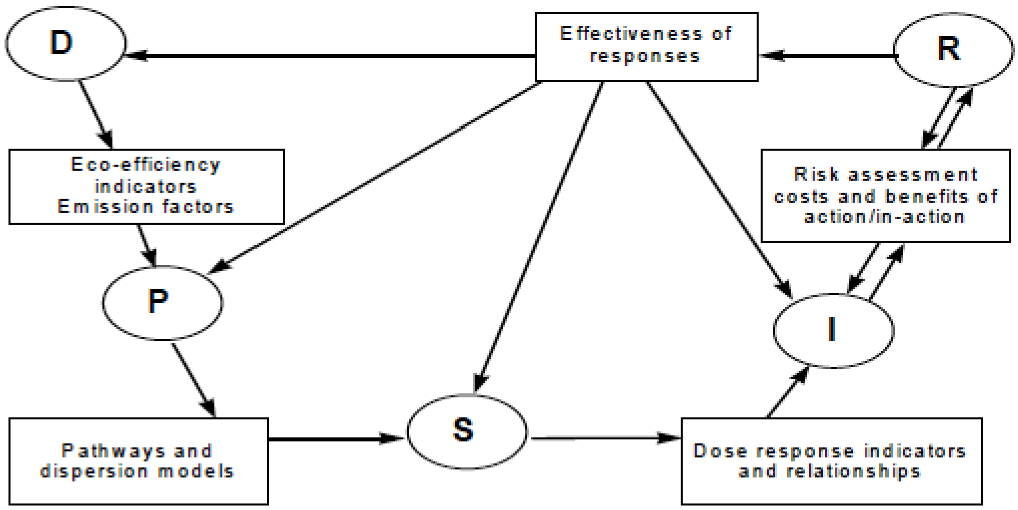

Figure 5-7: Indicators and Relations Between the Driver – Pressure – State – Impact – Response Framework's Components (Source: Smeets & Weterings, 1999; Gabrielsen & Bosch, 2003)

Logical framework – Result chain model

One of the most well-known and broadly used frameworks, especially in public sector programmes, is the *Logical Framework* or *Results Chain* (Figure 5-8) that often sets the ground for assessments. The particular framework is rooted in the field of project management and actually represents a linear chain of causal relations among the different discrete stages of a project or programme (from initial inputs to long-term impacts) (Parsons et al., 2013; Eurostat, 2014). In other words, the Results Chain is a theoretical model developed for identifying all the interrelated critical and fundamental elements of a project that constitute both necessary and sufficient prerequisites for its successful application (inputs, activities, outputs, outcomes and impacts) (Parsons et al., 2013). More specifically, *inputs* form the backbone of every project and imply all the raw materials needed for its development and implementation (e.g., funding, personnel and material resources). *Activities* refer to all those actions that should be taken in order to meet projects' intended objectives. *Outputs* regard the tangible and intangible results that emerge from project activities and inputs. *Outcomes* focus on the benefits, which are expected to be reaped by the successful implementation of a project or intervention (quite often, outcomes are divided into *immediate* and *medium-term* or *intermediate* ones, meaning direct and indirect results); while *impacts* refer to direct, indirect, positive or negative *societal-level changes* that are eventually induced from an intervention (*Results Chain & Results Chain Diagram*, 2016); and are actually related to higher level and more long-term strategic goals to which the project / programme / intervention is anticipated to contribute (Parsons et al., 2013).

Figure 5-8: Indicative Example of the Results Chain / Logical Framework (Source: *Results Chain & Results Chain Diagram*, 2016)

The deployment of proper indicators that correspond to the different stages / components of the logical framework facilitates the determination of (Eurostat, 2014): the way a system / programme / project / policy works; the cause-and-effect relationships developed between its different elements; its efficacy and effectiveness. Moreover, it substantially assists in assessing (Parsons et al., 2013): whether a project / intervention / policy, etc. is implemented as originally planned; if it conduces to improvements (on a topic / theme of concern) or leads to unexpected adverse effects; and whether it is mandatory to modify particular aspects of the project / intervention / policy, etc. – so as to maximize the gains and limit and/or overcome the barriers – or even terminate it. According to all the above, the *input – process (or activity) – output – outcome – impact* indicator typology derives from the Results Chain model (logical framework), which is broadly adopted / used by numerous organizations and institutions around the globe in order to assess the performance of their strategic goals and projects (Huovila et al., 2019). This model is briefly described in the following paragraphs.

Input indicators: provide answer to the question *"What resources are needed?"* and actually measure the human, physical, financial and/or regulatory resources that are necessary for the implementation of a specific project / programme / intervention / policy (Delorme & Chatelain, 2011; Aurino, 2014; Eurostat, 2014). They may also be either quantitative or qualitative (Carvalho & White, 1994). The development and utilization of input indicators, so as to monitor the availability of essential resources, can assist in alerting – those in charge – to potential challenges and risks that may jeopardize the realization of a project (Carvalho & White, 1994; Parsons et al., 2013).

Process or activity or flow indicators: address the question *"What does the project do?"*. They are considered intermediate indicators and directly measure the performance of significant procedures (the processes of allocating the inputs) that generate outcomes / affect an ultimate policy objective (e.g., the quality of training) (Parsons et al., 2013; Aurino, 2014). Therefore, they constitute a vital part of the Results Chain model towards gauging the degree to which the project is delivering what it was initially planned to deliver, but also pointing out possible barriers confronted during the implementation period (Carvalho & White, 1994). Process indicators emphasize things (elements, procedures, inputs, etc.) that are expected to produce desirable results (New Zealand Qualifications Authority, n.d.); and are most valuable when they associate particular activities with specific outputs or outcomes (Parsons et al., 2013). Additionally, such indicators are of great importance and extremely useful in cases where improvement is considered mandatory (mostly in reviews / reports focused on amelioration), in the sense that when outcome indicators' results are below the anticipated levels, process indicators can be used diagnostically, so as to identify the reasons responsible for this discrepancy. On the other hand, process indicators can be utilized for suggesting recommendations for improvement when outcome indicators' results exceed the expected levels. On such occasions, process indicators can assist in validating or explicating the processes that conduce to the achieved fruitful outcomes (New Zealand Qualifications Authority, n.d.).

Output indicators: reply to the question *"What does the project produce?"* and refer to the products, capital goods or services that derive from a given project / programme / intervention / policy (e.g., number of people trained, number of people who received technical assistance, number of established standards or legislative documents, number of investments in infrastructure; number of people employed, etc.) (Parsons et al., 2013; Eurostat, 2014). When coupled with input and activity indicators, output indicators can offer measures of *economy* and *efficiency* by describing the interrelationships between investments and products (Parsons et al., 2013).

Outcome indicators: offer answer to the question *"What does the project attain?"*. They are more directly associated with the final goals of a project / programme / policy, etc., and refer to all the benefits reaped by its implementation (economic, social, cognitive, etc.) (Parsons et al., 2013; Aurino, 2014). More specifically, outcome indicators provide measures of a project's output – short- or medium-term effects (e.g., rates of school enrollment) (Eurostat, 2014) – which entails that they describe what has already happened or been fulfilled. In fact, they define the criteria for assessing if a project is successful or not, and therefore they need to be *realistic* and *feasible*, given the available resources and capacity. Quite often, great confusion regarding the differences between output and outcome indicators is observed. Parsons et al. (2013) establish a clear distinction by stating that output indicators provide *de jure* measures, which are based upon a legal framework and are in alignment with the current regulatory environment (Gräbner et al., 2021); whereas outcome indicators provide *de facto* measures, thereby describing the real-world alterations that these outputs will induce.

Impact indicators: give answer to the question *"How does the project contribute to the strategic goals that are set?"*. Therefore, they measure the positive or negative, indented or unintended, direct or indirect, primary or secondary, long-term effects induced by the implementation of a project and are far beyond its immediate control. Stated differently, they describe / assess the progress made towards the strategic goals and objectives of a project / policy / programme, etc., and "are akin to statements of purpose" (Parsons et al., 2013, p. 17) (e.g., improvement of literacy rates, reduction of poverty, change of consumption patterns).

Economy-based frameworks – The economic cycle framework

The *economic cycle framework* refers to the field of economic analysis and originates in the *theory of economic cycles* according to which economic phenomena are classified into three categories (Eurostat, 2014): (i) *leading* – change before the general economic conditions change; (ii) *coincident* – change simultaneously with the economy; and (iii) *lagging* – change only after the economy has changed. Implementation of this theory conduces to the selection of suitable leading, coincident and lagging indicators that correspond to each stage of the cycle. More specifically (Eurostat, 2014; Konchar, 2020):

- *Leading indicators* point towards possible future events and are perceived to lead overall economic activity; thus, they are useful for prognosticating turning points in the economic cycle, meaning predict how future economic conditions will look like (e.g., consumer expectations).
- *Coincident indicators* occur in real-time, thereby reflecting / clarifying the economic status quo (e.g., GDP).
- *Lagging indicators* are only known after macroeconomic conditions have been altered and their deployment underpins the confirmation of a pattern that is still in progress / economic conditions that have already changed (e.g., unemployment or inflation rates).

Theme- or issue-based or policy-derived frameworks

Even though all the aforementioned frameworks are grounded in solid conceptual foundations, the great majority of the frameworks met in the literature, as well as their related indicators, do not derive from purely conceptual bases, but also emerge from policies (*policy-derived* or *theme-based* frameworks). More specifically, *theme*- or *issue-based*, or *policy-derived* frameworks offer a sophisticated and flexible conceptual structure that organizes indicators around key themes or issues, typically determined by policy relevance; and are broadly used in official national indicator sets for monitoring progress towards fulfilling strategic targets and objectives (UN, 2007; Wu & Wu, 2012). Such frameworks are usually the result of three critical convergent realms (Eurostat, 2014): (i) the *political* realm, which sets strategic goals / objectives and attributes to the framework the necessary credibility; (ii) the *scientific* realm that provides the framework with conceptual soundness through theory, practice and expertise; and (iii) the *statistical* realm, which renders the framework measurable, by offering the available statistical indicators. Proper equilibrium among these three realms guarantees the framework's *political relevance*, its *consistency* with current theory and practice and the *measurability* of its targets.

The main reason behind theme-based frameworks' great significance, prevalence and extended degree of applicability in the context of national sustainable development strategies, lies in their capacity to associate indicators with goals and objectives, as well as with policy processes. In this way, they provide a clear, easy to grasp and direct message to decision and policy makers; they promote communication with the public; they drastically conduce to awareness raising; and they are adjustable enough to adapt to changes observed in priority or target setting over time (UN, 2007).

A very typical example of policy-derived frameworks is the one stemming from the European Union's *Sustainable Development Strategy* (European Commission, 2001b; Council of the European Union, 2006). The strategy defines a set of 10 key objectives / themes (socioeconomic development, sustainable consumption and production, social inclusion, demographic changes, public health, climate change and energy, sustainable transport, natural resources, global partnership, good governance), whose progress is monitored by pertinent sustainability indicators that are identified and proposed by Eurostat.

These indicators are classified into three different levels / categories (Eurostat, 2009, 2014): (i) *first level* or *headline* indicators that are broadly used and suitable for communication purposes, while they monitor the progress of an overall key objective of the sustainable development strategy (e.g., growth of GDP per capita which is falling under the socioeconomic development theme, or greenhouse gas emissions that appertain to the climate change and energy category). Furthermore, they are robust and available for at least five years; (ii) *second level* or *operational* indicators, which focus on operational objectives. They are robust and available for most European Union (EU) Member States for a minimum period of three years (e.g., employment that is relevant to the socioeconomic development theme, or greenhouse gas emissions by sector that refers to the climate change and energy theme); and (iii) *third level* or *explanatory* indicators, which are related to actions suggested by the sustainable development strategy, or to other issues that contribute to the analysis of the progress made towards the strategy's objectives. They can also be the breakdown of higher-level indicators (e.g., by gender or income group). For example, female unemployment, that corresponds to the socioeconomic development theme; or greenhouse gas intensity of energy consumption, which belongs to the climate change and energy category. Moreover, an additional category is detected, the so-called *contextual indicators* that focus only on providing valuable background information, but by no means should they be considered as policy-responsive or relative to monitoring purposes.

Another prominent example of *theme-based frameworks* is the one introduced by United Nations Commission on Sustainable Development (UNCSD) in 2001. UNCSD's theme-based framework is built upon a *hierarchical structure* (see Figure 5-9) that consists of four general *dimensions* (social, environmental, economic and institutional), which are in harmony with the fundamental principles of sustainability. The dimensions are further specified into 15 *themes* that, in turn, are subdivided into 38 *sub-themes*, to which a total number of 58 *indicators* are assigned (United Nations Commission on Sustainable Development [UNCSD], 2001; Hass et al., 2002; Wu & Wu, 2012).

The particular framework was reviewed and updated in 2007. The revised version retains the original hierarchical conceptual structure (themes - sub-themes - indicators). However, the categorization of indicators across the four dimensions (pillars of sustainability) has ceased to exist, new crosscutting themes are added (e.g., poverty and natural hazards), while current ones are better and more efficiently expressed (e.g., consumption and production patterns); thereby highlighting the multi-faceted and purely integrative nature of sustainable development. The 2007 UNCSD framework includes 14 themes, 44 sub-themes and a set of 50 core indicators that is supplemented by an additional group of 46 ones (UN, 2007; Wu & Wu, 2012). Core indicators should be used by all countries in order to monitor and assess the progress towards sustainable development, whereas the rest indicators provide complementary information to core indicators and are not readily available for most countries (UN, 2007). Ultimately, the framework takes into account the principles of Agenda 21 (United Nations Conference on Environment and Development, 1992), the Millennium Development Goals (UN, 2015b), as well as the Johannesburg Plan of Implementation (World Summit on Sustainable Development & UN, 2003).

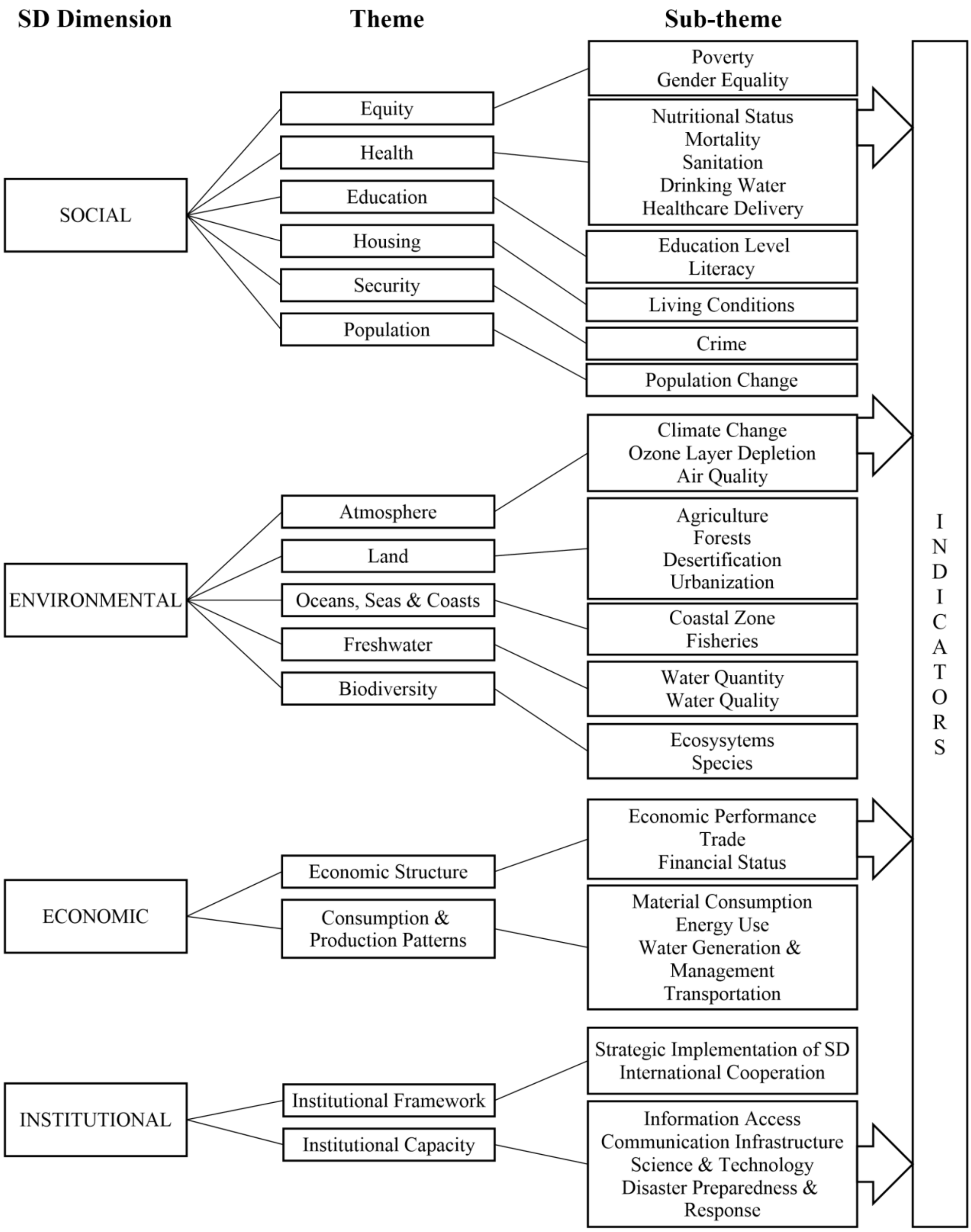

Figure 5-9: The UNCSD's Indicator Framework Conceptual Structure (Source: Adapted from Wu & Wu, 2012)

Capital-based frameworks

Capital-based frameworks endeavor to estimate the wealth of a nation or a region as a function that includes several different types of capital (UN, 2007). In this regard, the term 'capital' is not strictly restricted only to the field of economics and finance, but it is extended so as to incorporate the: natural environment and resources (*natural capital*), capacity of people to work, education, training, skills, knowledge, experience and health (*human capital*), social networks, trust, etc. (*social capital*), institutional arrangements (*institutional capital*); and produced assets that form the economy (*manufactured* or *built capital*).

The above distinct categories, in order to be comparable or aggregated, are usually expressed in the same *monetary* terms (UN, 2007; Wu & Wu, 2012). Therefore, sustainable development may be interpreted differently, depending on how sustainability is perceived in every different context. Some critical questions that demand immediate answers and effective solutions, arise in this respect. For example, can natural capital be substituted by other types of capital at all? Which natural recourses are considered substitutable? Are there any limitations regarding such substitutions (Wu & Wu, 2012)? It is pretty evident that the matter of *substitutability* between the various types of capital may be obvious and feasible on the one hand (renewable for non-renewable energy resources, machines that will supersede human labour, etc.), or impossible on the other hand, in the sense that some assets are considered fundamental, and thus they cannot be replaced by any means (e.g., biological diversity). Other barriers pertinent to the adoption and use of capital frameworks include (UN, 2007; Wu & Wu, 2012): significant divergent opinions on how all forms of capital should be expressed in monetary terms, serious controversies on substitutability, data availability restrictions and issues on intra-generational equity.

An indicative example of such frameworks is the "Daly triangle" (Figure 5-10) that attempts to elucidate the relationships developed among the key elements of sustainability (Daly, 1973). Pursuant to the particular framework, natural environment is perceived as the 'ultimate medium' to attain the desired 'ultimate ends' that coincide with equity and human well-being (Meadows, 1998; Wu, 2013). Economy, technology, politics, and ethics are not treated as 'ends', but they are deemed to be 'intermediate means' that bridge the ultimate means and ends (Meadows, 1998). In 1998, the Daly triangle was reviewed and enriched (see Figure 5-10) by Donella Meadows and the Balaton Group, a global network of researchers and practitioners in the field of sustainability (Meadows, 1998; Wu & Wu, 2012; Wu, 2013).

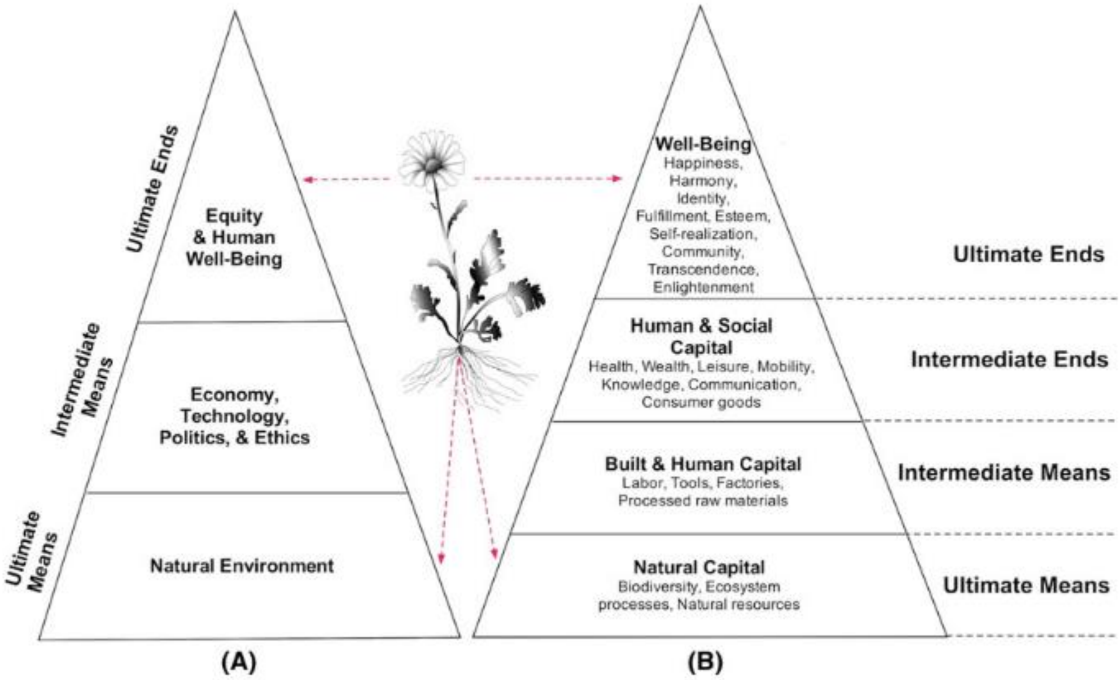

Figure 5-10: The Original Daly Triangle Scheme (A) and the Refined Version as Suggested by the Balaton Group (B) (Source: Wu, 2013)

The message – purpose model

Last, a simplified taxonomy, tightly related to the *combination* of the two above questions (WHY and WHAT) has been introduced by Van den Berghe (1997), who classifies indicators according to two fundamental *dimensions* of theirs (but not the only ones), namely *message* and *purpose* (the so-called *message – purpose model*) (see Figure 5-11). Message refers to the *information content*, *meaning* and *signification* of an indicator; while purpose regards its *function* and *use* (Van den Berghe, 1997). More specifically, message focuses on what is gauged through the deployment of a particular indicator and consequently on the kind of information that is derived, (e.g., description of a system's status quo, performance measurement, quality assessment). Conversely, purpose reveals the deeper *incentives* (*reasons*), which lead to the selection and use of a certain indicator, providing thus answer to the question: Why is a certain indicator chosen? / What is it meant to be fulfilled through its selection? (e.g., communication to policy makers or the public, analysis, standardization).

Figure 5-11 illustrates the respective 'values' that are attributed to the message and purpose dimensions and extend between two extremes on each occasion. More particularly, the message dimension ranges from purely *descriptive* (totally static) content / meaning, to extremely *dynamic* one. Therefore, four categories of indicators are distinguished: *exclusively descriptive* indicators, which merely summarize aspects of the system under study; *management and policy* indicators that offer useful information for crafting policies and strategies; *performance* indicators used for measuring the degree of a systems' performance in a certain domain; and *quality* indicators, which are perceived as a particular subcategory of performance indicators and refer to quality characteristics. In regard to the purpose dimension, the values vary from implementing measurement, analysis, assessment processes, to participating in standardization procedures. In this sense, three categories are identified: *analysis* indicators, which are suitable for performing measurements, analyses and assessments; *communication* indicators, used for communicative reasons; and *normative* indicators that have a standardizing / regularizing view (most of the times deployed for comparison with sets of standards or thresholds) (Van den Berghe, 1997).

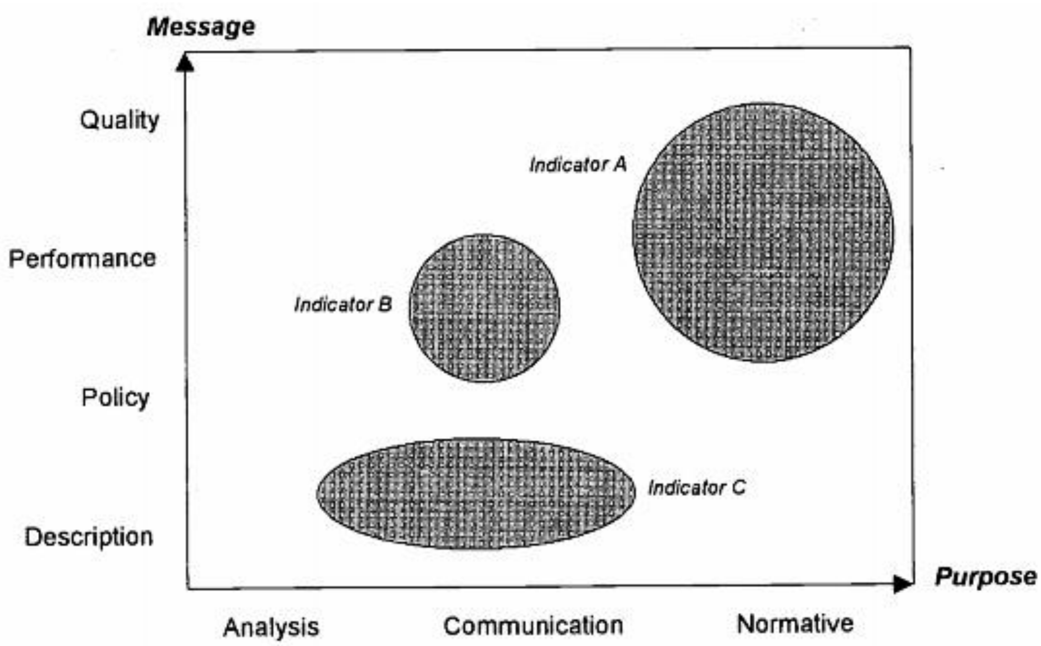

Figure 5-11: The Message – Purpose Model for Indicator Classification (Source: Van den Berghe, 1997)

It is noteworthy that, according to this model, indicators are represented by surfaces rather than points (Figure 5-11). This implies that there are no strict boundaries among the different emergent types of indicators, since they usually cover a wide spectrum of message and purpose values, pertinent to a given context (i.e., an indicator may have a performance view in a specific context and at the same time a totally descriptive one in another context) (Van den Berghe, 1997).

5.3.3. How Objectively and Directly do Indicators Model Reality?

Finally, regarding the third and last question on how objectively and accurately indicators represent reality, two basic typologies are emerging. The first one relates to the *degree of objectivity* that an indicator provides when modeling reality. According to this, two broad categories are distinguished: *objective* indicators that are based on explicit information and criteria; and *subjective* indicators that represent "the individual perception of conditions related to any particular domain" (Lee & Marans, 1980, p. 49). For example, the number of convictions for corruption and/or bribery by city officials per 100,000 inhabitants constitutes an indicator that is based on objective measurements; whereas satisfaction with fight against corruption is a matter of personal judgment. Despite referring to the same phenomenon (that of corruption), individual feelings and opinions on that topic may substantially differ from what actual corruption indices might reveal. It should be noted that indicators' objectivity or subjectivity refers to *what* is measured, rather than *how* something is measured.

As regards the precision of the modeling of reality, two general classes are discerned (Eurostat, 2014): *direct* indicators, which provide information directly pertaining to the topic / phenomenon / system under study (e.g., the determination of adult literacy rates in a country for the last ten years constitutes a direct indication of this country's progress / performance in the educational sector); and *indirect* or *proxy* indicators that implicitly refer to the subject under consideration, either because it is ambiguous and therefore unable to be directly measured; or due to the fact that its determination involves pretty complicated procedures, which cannot be implemented rigorously, efficiently, or frequently enough (e.g., the percentage of female school-aged population enrolled in schools is an indirect / proxy indication for gender equality). In general terms, any indicator which is not perceived as proxy, is a direct one. Yet, it is worth mentioning that it is the *underlying question*, pending to be answered, that attributes to the indicators the characteristic of directness or indirectness.

In closing, by taking into account all the abovementioned frameworks, but also many more that have been proposed, established and are currently in use, someone couldn't keep but wondering how to choose among them. What would be the optimal choice that better satisfies the needs and requirements of a given urban area? In general lines, there are some critical points that should be taken into serious consideration in order to come up with the optimal solution. The identification of the purposes that are served through the deployment of certain indicators is the first of them. According to Shen et al. (2011), indicators can play three fundamental roles: (i) *explanatory tools*, intended to describe the current state of a system; (ii) *pilot tools*, useful for policy-making; and (iii) *performance assessment tools*, suitable for gauging progress towards a policy or programme's objectives and targets. It is notable that performance assessment is deemed to be the most significant role of sustainability indicators [i.e., "indicators that provide information on the state, dynamics and underlying drivers of human-environmental systems" (Wu & Wu, 2012, p. 70)] (Hiremath et al., 2013); and thus, the last category is the most popular and widely used for sustainability issues.

Moreover, the selection of the conceptual framework that includes a representative set of well-defined indicators, and consequently the adoption of a particular perspective for grasping and gauging a phenomenon (e.g., sustainability which constitutes the fundamental axis of this chapter), drastically affects the derived conclusions about the system under study. Therefore, the choice of the proper indicators must be firmly based on a set of *principles / criteria* regarding the phenomenon of concern; as well as on a deep understanding of the available frameworks that cover these principles. Only then the relevant indicators can be properly contextualized and efficaciously deployed for policy-making purposes (Wu & Wu, 2013). Additional concerns regard data *standardization* and *availability*, *locally-relevance* in the sense that indicators need to work at the scale of the city they are applied to (Campell, 1996; Camagni, 2002), and should also reflect the geographical and social context of this city (Hiremath et al., 2013; Moreno Pires et al., 2014). Other technical aspects, pertinent to the qualities of indicators that constitute useful and decisive criteria for their selection, are concisely presented and described in section 5.6 (see section 5.6 – Restrictions posed by the very nature of data and indicators).

5.4. An Inspection of Indicator Frameworks for Assessing the Performance of Smart Sustainable Resilient and Inclusive Cities (S2RIC)

The search of indicators is evolutionary. The necessary process is one of learning

(Meadows, 1998, p. 10)

The endeavors towards the establishment of indicator sets, suitable for assessing smart, sustainable, resilient and inclusive urban performance, have rapidly increased and intensified in alignment with the cities' efforts to smarten up. These sets aim at equipping contemporary urban environments with the necessary technical, environmental and social indicators that efficiently gauge the impact observed on infrastructure, safety, and citizens' quality of life (Midor & Plaza, 2020). Thus far, each individual set appearing in the literature reflects the specific needs for which it has been developed, enriched each time with urban indicators that are a clear manifestation of the current perception of development, well-being, and prosperity (Gómez-Álvarez et al., 2018).

In order to accomplish the goal of introducing a comprehensive and multi-dimensional indicator framework, capable of underpinning assessment, monitoring and critical decision-making as to the sustainability pathways of smart, sustainable, resilient and inclusive cities – in an accountable manner and spirit – a thorough analysis of several global indicator frameworks is carried out at first. More particularly, seven broadly accepted indicator frameworks (see Table 5-1), pertinent to the evaluation of urban sustainability performance, are explored. These incorporate aspects of smartness, resilience, and inclusiveness as integral parts of the contemporary urban development discourse.

All the aforementioned indicator frameworks have a global reference, apart from one (Smart Cities – Ranking of European Medium-Sized Cities), which actually represents an effort originated in the European level. However, the particular framework is deemed as a prominent example, since it introduces the initial steps for dealing with this very intriguing issue in a more systematic way. Additionally, it has paved the way for further progress in the field; and has severely influenced relevant subsequent works, a fact that is made apparent by the meticulous examination of the various global indicator frameworks.

Table 5-1: Indicator Frameworks for Assessing the Performance of Smart Sustainable Resilient and Inclusive Cities (S2RIC)

a/a	Indicator Framework	Year	Spatial Scope	Number of Indicators
1	Smart Cities - Ranking of European Medium-Sized Cities	2007	European	74
2	Smart Cities Wheel	2012	International	62
3	City Resilience Framework (CRF) – City Resilience Index (CRI)	2016	International	156
4	ITU-T Y.4901/L.1601 – Key Performance Indicators Related to the Use of Information and Communication Technology in Smart Sustainable Cities	2016	International	72
	ITU-T Y.4902/L.1602 – Key Performance Indicators Related to the Sustainability Impacts of Information and Communication Technology in Smart Sustainable Cities			37
	ITU-T Y.4903/L.1603 – Key Performance Indicators for Smart Sustainable Cities to Assess the Achievement of Sustainable Development Goals			90
5	Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development – United Nations	2017	International	231
6	Collection Methodology for Key Performance Indicators for Smart Sustainable Cities – United for Smart Sustainable Cities (U4SSC) Initiative	2017	International	91
7	ISO 37120 – Sustainable Cities and Communities – Indicators for City Services and Quality of Life	2018	International	128
	ISO 37122 – Sustainable Cities and Communities – Indicators for Smart Cities	2019		80
	ISO 37123 – Sustainable Cities and Communities – Indicators for Resilient Cities	2019 – Draft International Standard (DIS) 2018 available[2]		75 (according to ISO / DIS 2018)

5.4.1. Smart Cities – Ranking of European Medium-Sized Cities

Smart Cities – Ranking of European Medium-Sized Cities refers to a research project implemented in 2007 (from April to October 2007) by the Centre of Regional Science at Vienna University of Technology, in collaboration with the Department of Geography at

2 Although the ISO 37123 standard "Sustainable Cities and Communities - Indicators for Resilient Cities" was published on December 2019, the present Thesis is taking into consideration the key findings of ISO/DIS 37123 which was released in 2018. The reason for this is that the ISO/DIS 37123 (2018) was the only available official document at the time the author was working on the particular chapter; and on the proposed indicator framework in particular.

the University of Ljubljana and the OTB Research Institute for Housing, Urban and Mobility Studies at Delft University of Technology. The project focuses on the transparent benchmarking of 70 European medium-sized cities, based on an extensive list of indicators intended to cover all the fundamental urban aspects. Moreover, it endeavors to gain a more detailed insight into the different urban environments explored by demarcating their advantages, disadvantages but also the various differences among them. At the same time, the project allows the elaboration of developmental perspectives that emanate from this type of cities, as well as the identification of their strengths and weaknesses, in a comparable manner (Giffinger et al., 2007; Giffinger & Gudrun, 2010).

Giffinger et al. (2007) state that:

> A smart city is a well performing city in a forward-looking way in six characteristics: smart economy, smart people, smart governance, smart mobility, smart environment and smart living, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens. (p. 11)

In order to rigorously delineate the abovementioned smart city working definition, an explicit *hierarchical structure* is suggested (Figure 5-12), according to which every new level is defined by the elements included in the previous one. In this respect, a smart city is described by six characteristics / pillars of vital importance (economy, people, governance, mobility, environment, and living). Every single one of them is further specified / analysed by a number of related factors (overall 31 factors that emerge from the implementation of several participatory workshops) (Figure 5-13). Finally, every factor's performance is assessed on the basis of specific and carefully selected indicators (74 relative indicators in total) (Giffinger et al., 2007; Giffinger & Gudrun, 2010).

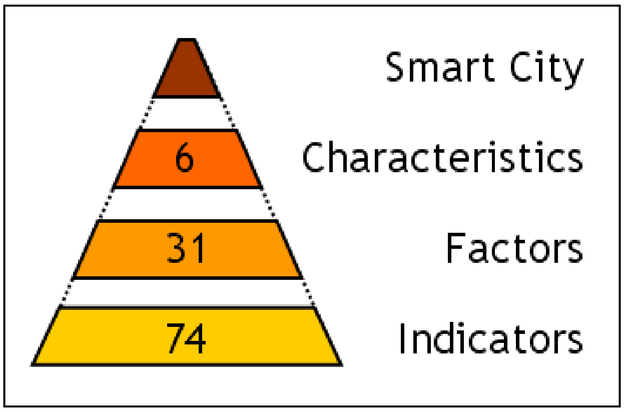

Figure 5-12: Hierarchical Structure for Conceptualizing and Assessing the Performance of Smart Cities (Source: Giffinger et al., 2007)

Figure 5-13 illustrates the six characteristics and their assigned factors that demarcate the smart city concept; but also shape the framework for the selection and use of the most appropriate indicators, so as to evaluate cities' performance in various smart urban dimensions / aspects. These indicators (see Table 1, Annex II) are obtained from official free access European databases such as: Eurostat databases, Urban Audit, various Eurobarometer special surveys, etc. (Giffinger et al., 2007).

A critical look at the European Medium-Sized Smart Cities Ranking indicator framework is leading to the conclusion that although the smart city concept takes center stage, no particular emphasis is put on ICT-related indicators, exhibiting in this way very poor technological orientation. On the contrary, the non ICT-related indicators, mostly focusing on *smart people and smart living*, are overemphasized (2 ICT-related vs. 72 non ICT-related indicators) (Table 1, Annex II).

SMART ECONOMY (COMPETITIVENESS)	**SMART PEOPLE (SOCIAL & HUMAN CAPITAL)**
Innovative spirit Entrepreneurship Economic image and trademarks Productivity Flexibility of labor market International embeddedness Ability to transform	Level of qualification Affinity to lifelong learning Social and ethnic plurality Flexibility Creativity Cosmopolitanism / Open-mindedness Participation in public life
SMART GOVERNANCE (PARTICIPATION)	**SMART MOBILITY (TRANSPORT & ICT)**
Participation in decision-making Public and social services Transparent governance Political strategies and perspectives	Local accessibility (Inter-)national accessibility Availability of ICT infrastructure Sustainable, innovative and safe transport systems
SMART ENVIRONMENT (NATURAL RESOURCES)	**SMART LIVING (QUALITY OF LIFE)**
Attractivity of natural conditions Pollution Environmental protection Sustainable resource management	Cultural facilities Health conditions Individual safety Housing quality Education facilities Touristic attractivity Social cohesion

Figure 5-13: Smart Cities' Characteristics and Factors According to the "Smart Cities – Ranking of European Medium-Sized Cities" Project (Source: Giffinger et al., 2007)

It is worth mentioning that even though the focus of the particular indicator framework is mainly placed on (Giffinger et al., 2007; Giffinger & Gudrun, 2010): exploring the developmental perspectives; identifying strengths and weaknesses; and determining the competitive position of numerous medium-sized European cities – through the implementation of the city rankings method – it has greatly contributed to two additional fields of study. First of all, despite the fact that mainstream research tends to focus on large metropolises, the framework concentrates entirely on medium-sized cities. Although these cities dominate the European urban network (almost 600 medium-sized cities in Europe that gather approximately 40% of urban dwellers) and constitute decisive factors for sustainable, competitive and spatial development, their developmental perspectives and potential or current challenges still remain in the shadows. Furthermore, this framework establishes the very first integrated, well-structured and transparent methodological approach for developing a comprehensive list of indicators, pertinent to the concept and philosophy behind the smart city paradigm. Therefore, it has influenced a great number of related works that followed and is used either at its full capacity (including all six key dimensions), or partially (Stratigea et al., 2017; Santana et al., 2018; Vasuaninchita, et al., 2020; Panagiotopoulou et al., 2020).

5.4.2. Smart Cities Wheel

Boyd Cohen, an urban and climate strategist, has been working on smart cities' ranking since 2012. He has introduced the *Smart Cities Wheel* (see Figure 5-14) as a framework for: (i) understanding and exploring the *six key components / dimensions* of a smart city, as these are first articulated by Giffinger et al. (2007), so as the development of a holistic smart city strategy to be facilitated; and (ii) benchmarking different city contexts (Cohen 2012, 2014, 2018).

Economy, environment, government, living, mobility and people are deemed to be the core components of his approach that are consistent with the basic conceptual structure of the "Smart Cities - Ranking of European Medium-Sized Cities" indicator framework, developed by Giffinger et al. (2007). Core components are further analysed into 18 *working areas* (subcomponents) (Figure 5-14) (Cohen, 2014, 2018). Cohen recognizes that selecting and defining the most suitable indicators for the assessment of smart cities' performance and benchmarking purposes is a highly complex task. In this respect, while he has co-developed a list of approximately 400 potential indicators, he holds the opinion that their final number should be kept at a quite manageable level. In recent updates of his approach, he proposes a set of 62 sustainability indicators in order each of the wheel's working areas to be evaluated (Cohen, 2014). These indicators are almost evenly distributed between the ICT- and non ICT-related categories (26 ICT-related vs. 36 non ICT-related); while particular emphasis is placed upon the dimensions of smart environment (16 indicators), smart mobility (12 indicators) and smart governance (10 indicators) (see Table 2, Annex II).

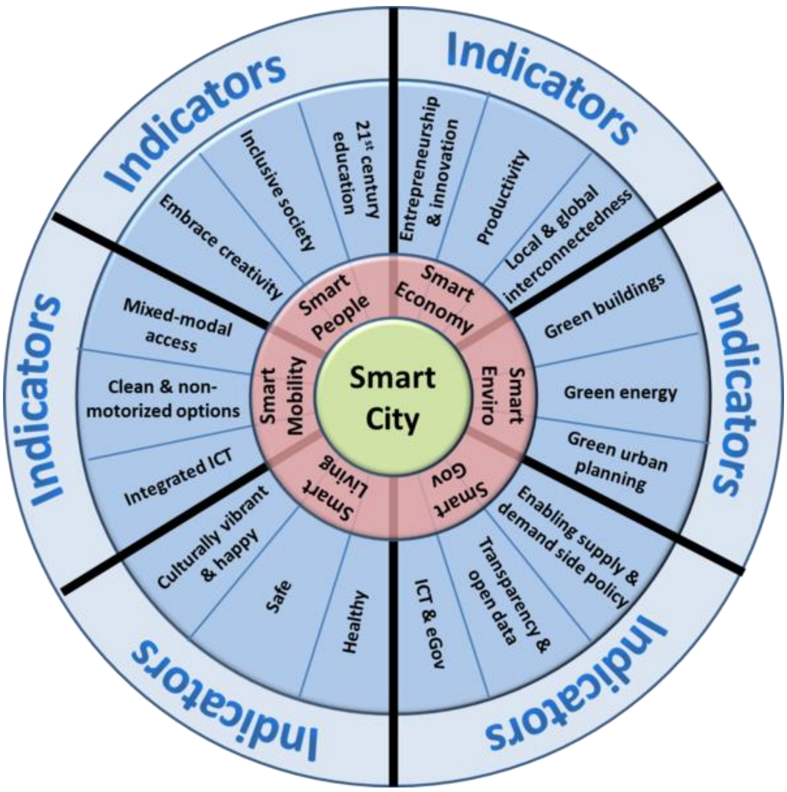

Figure 5-14: Smart Cities Wheel Established by Boyd Cohen (Source: DeAngelis, 2013)

5.4.3. City Resilience Framework (CRF) and City Resilience Index (CRI)

The concept of *resilience* has nowadays gained tremendous importance as a critical dimension in pursuing sustainable urban development goals at the global level (UN, 2015a). Planners and policy makers are challenged to ensure that cities' functioning and day-to-day practices of urban actors contribute to the strengthening of its resilience. In doing so, first, they have to understand their complexities but also define the factors that conduce to urban resilience; and secondly, they need to figure out how these factors can be observed and measured, i.e., what are the most relevant indicators for assessing resilience of an urban context and informing policy action.

Arup, with the support of the Rockefeller Foundation, has developed a comprehensive *City Resilience Framework* (CRF) – through extensive research in different cities and numerous consultations with experts and urban stakeholders – as a means of grasping urban resilience (Figure 5-15). In this respect, resilience is defined as the capacity of individuals, communities, and systems to adapt, survive, and grow in the face of stress and shocks, and even transform when conditions require it (Arup, 2015, 2016a).

The CRF incorporates (Arup, 2015, 2016b) (Table 3, Annex II):

- Four *key dimensions* or *categories* (*health and well-being* of individuals – people, *economy and society* – organization, *infrastructure and ecosystems* – place, *leadership and strategy* – knowledge) that represent the cornerstones of contemporary urban environments.
- Twelve *goals*, which fall into the suggested key dimensions and actually represent the drivers of urban resilience, or stated differently, the city's 'immune system' against chronic stresses or sudden disastrous events.
- Fifty-two *evidence-based City Resilience Indicators* (CRI), that add further meaning to the proposed goals by defining what should be measured (critical factors affecting urban resilience). These are associated with a broad range of assets, behaviours, systems and practices closely relating to resilience goals, as well as to everyday city's functions. The indicators integrate seven specific *qualities* that distinguish a resilient city from others and are articulated by the terms inclusive, integrated, robust, redundant, flexible, resourceful, and reflective, e.g., '*robust* and *inclusive* housing' (Figure 5-15).
- One hundred and fifty-six *metrics*, which explicate how to measure the suggested indicators. Metrics facilitate cities' evaluation of resilience as well as the determination / measurement of progress made, compared to an initial baseline. It is notable that only seven of these metrics are ICT-related (4% of the total number of metrics), whereas the rest 149 (96%) are classified as non ICT-related.

All these elements / *layers* of the CRF are coupled with an assessment toolkit that allows cities to diagnose their strengths / weaknesses, to monitor their resilience over time, and to identify proper interventions / programmes / projects / policies, etc. for ameliorating their state of resilience.

Figure 5-15: City Resilience Framework – Dimensions, Goals, Indicators, and Qualities (Source: Arup, 2015, 2016b)

5.4.4. ITU-T Y.4901/L.1601, ITU-T Y.4902/L.1602 and ITU-T Y.4903/L.1603

In 2013, ITU established the *Focus Group on Smart Sustainable Cities – FG-SSC* – in order to make progress on cities' standardization requirements that aim at boosting sustainability objectives through the integration of ICTs in their infrastructure and operations (ITU, 2014b, 2015, 2016b). The support of urban stakeholders, in their effort to assess the performance of various smart sustainable city (SSC) ventures once they are initiated, was also included in FG-SSC's tasks. As far as this particular task is concerned, work carried out focused on disentangling the concept of smart city; delineating the most prevalent attributes of this concept by elaborating on the large number of smart city definitions; and developing relevant indicators for assessing cities' performance in their going smart journey, taking into consideration a wide number of indicator frameworks, developed at the international and national level.

Apart from the articulation of an integrated SSC definition (ITU, 2014a), the FG-SSC's effort resulted in the development of three sets of international KPIs (in the form of recommendations), thereby establishing an indicator framework that can assist in the assessment / monitoring of progress achieved in SSC transitions. Although these sets of indicators focus – in one way or another – on smart city development, they are considered complementary and should be perceived as a unified / integrated framework, rather than separate and autonomous standards. More specifically:

- ITU-T Y.4901/L.1601 – "Key Performance Indicators Related to the Use of Information and Communication Technology in Smart Sustainable Cities" (ITU, 2016b) offers a general guidance to urban environments and suggests indicators regarding the adoption and use of ICTs in SSC.
- ITU-T Y.4902/L.1602 – "Key Performance Indicators Related to the Sustainability Impacts of Information and Communication Technology in Smart Sustainable Cities" (ITU, 2016c) focuses on indicators pertaining to the sustainability impacts of ICTs on SSC.
- ITU-T Y.4903/L.1603 – "Key Performance Indicators for Smart Sustainable Cities to Assess the Achievement of Sustainable Development Goals" (ITU, 2016d) provides SSC with proper KPIs for efficaciously evaluating the attainment of SDGs.

The conceptual design of the ITU-T Y.4901/L.1601 indicator framework is built upon six main *dimensions* (ICTs, environmental sustainability, productivity, quality of life, equity and social inclusion, physical infrastructure). These are further analysed into 20 *sub-dimensions*, into which 72 ICT-oriented *indicators* are falling (Table 4, Annex II). The particular rationale is also adopted by ITU-T Y.4902/L.1602 indicator framework, which consists of five *dimensions* (environmental sustainability, productivity, quality of life, equity and social inclusion, physical infrastructure), 22 *sub-dimensions* and 37 *indicators* (8 ICT-related and 29 non ICT-related) (Table 5, Annex II). Finally, the conceptual basis of ITU-T Y.4903/L.1603 is quite different and comprises three *areas* (economy, environment, society and culture) that correspond to the three pillars of sustainability (Figure 5-16). The areas are divided into 19 *topics*, which – if properly arranged – can fall under the six characteristics introduced by Giffinger et al. (2007); and are further specified by a group of 90 *indicators*. These indicators assess the performance of each major area and are unevenly distributed between the ICT-related and non ICT-related categories (31 ICT-related vs. 59 non ICT-related); while they are smoothly balanced among the three pillars of sustainable development (Table 6, Annex II). Such a classification is taking into account the definition of SCC as this is introduced, initially by ITU (ITU, 2014a) and later on by ITU in collaboration with United Nations Economic Commission for Europe[3] (United Nations Economic Commission for Europe [UNECE], 2015; ITU, 2016), the United Nations' Sustainable Development Goals (UN, 2015a), the UN-Habitat's City Prosperity Index (United Nations Statistics Division, 2019) and indicators on city services and quality of life proposed by the International Organization for Standardization (ISO, 2018a). All indicators recommended by the ITU are further distinguished into: 'Core Indicators' (CI) which can be deployed by any type of city, thereby exhibiting a more universal applicability; and 'Additional Indicators' (AI), which are more city-specific and reflect the degree of smartness and sustainability of each specific city example, depending on the stage of economic development, population growth, geographical attributes, etc. (UNECE, 2015).

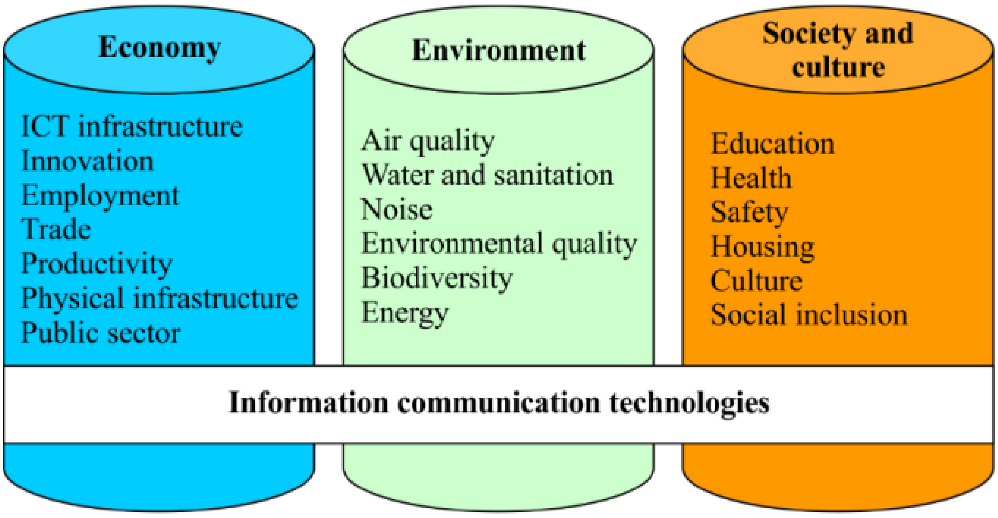

Figure 5-16: Areas and Topics of KPIs on Smart and Sustainable Cities (SSC) Proposed by the ITU-T Y.4903/L.1603 Recommendation (Source: ITU, 2016d)

3 According to the Telecommunication Standardization Sector of ITU Focus Group on Smart Sustainable Cities (ITU-T FG-SSC) and the United Nations Economic Commission for Europe (UNECE) *"A smart sustainable city is an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects"* (UNECE, 2015, p. 3; ITU, 2016a, p. 2).

The set of the three ITU-T indicator frameworks represents a coherent, well-structured and globally accepted pool of ICT and non ICT-related sustainability indicators that places great emphasis on *infrastructure* (technological and physical) and constitutes a significant part of the framework, proposed in the context of the present Thesis.

5.4.5. Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 United Nations Agenda for Sustainable Development

In 2015 all the United Nations' Member States adopted the 2030 Agenda for Sustainable Development that reflects a shared vision for global peace and prosperity for people and the planet. The agenda articulates 17 sustainable development goals (SDGs) and 169 related targets, which form a global policy framework, aiming at covering all aspects of sustainable development. On July 2017, the General Assembly adopted the "Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development", which is incorporated in the "Resolution Adopted by the General Assembly on Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development" (United Nations General Assembly [UNGA], 2017). Pursuant to the Resolution, the indicator framework is annually refined, thereby keeping track of the follow-up and update of the proposed goals and targets and was thoroughly reviewed by the Statistical Commission in 2020 (another major review is expected to take place in 2025, during the Commission's fifty-sixth session). Additionally, the framework is complemented by indicators, referring to the regional and national level, which are developed or suggested by Member States (United Nations Statistics Division, 2020). For 2020, the framework comprises *231 unique global indicators* (UN, 2020; United Nations Statistics Division, 2020).

In the context of this Thesis, emphasis is placed on the indicators related to SDG 11 "Make cities and human settlements inclusive, safe, resilient and sustainable" (selection of 12 out of 15 indicators of this SDG), the only SDG that is strictly dedicated to the urban (local) level. Furthermore, all indicators concerning the rest 16 SDGs (232 in total, including the duplications) were studied and additional ones were selected (21 indicators that fit the global and local level as well), leading to the enrichment of the proposed framework by 33 indicators in total (3 ICT-related vs. 30 not ICT-related) (Table 7, Annex II).

5.4.6. Collection Methodology for Key Performance Indicators for Smart Sustainable Cities – United for Smart Sustainable Cities (U4SSC) Initiative

In 2017, in the context of the *United for Smart Sustainable Cites*[4] (U4SSC) initiative, ITU and UNECE, in cooperation with several international partners, developed a KPI framework, which is based upon the ITU-T Y.4903/L.1603 Recommendation "Key Performance Indicators for Smart Sustainable Cities to Assess the Achievement of Sustainable Development Goals". The particular framework endeavors to provide cities with a standardized method for efficiently collecting the appropriate data from KPIs and evaluating their performance with regard to their smartness and sustainability, but also to the fulfillment of the SDGs at the local level (self-assessment of cities). The framework's structure is akin to that of ITU-T Y.4903/L.1603, with the exception of the fact that it contains one extra hierarchical layer. More particularly, it comprises 91 *indicators*, which are grouped into 22 *categories* (these correspond to the *topics* of the ITU-T Y.4903/L.1603 Recommendation). Categories are aggregated into seven *subdimensions* (the additional hierarchical level) that, in turn, form three fundamental *dimensions* (Economy, Environment, Society and Culture) that are in harmony with the three pillars of sustainability (these correspond to the three major *areas* of the ITU-T Y.4903/L.1603 Recommendation) (ITU et al., 2017).

The *subdimensions* and the pertinent *categories* may, if properly organized, fall under the six main characteristics as these are defined by Giffinger et al. (2007). The suggested indicators, used for assessing the performance of each specific major dimension, are unevenly distributed among the three dimensions / sustainability pillars, since 45 of them are relevant to economy, 17 pertain to the environmental aspect, whereas the rest 29 refer to society and culture (Table 8, Annex II). Such an unbalanced distribution is also noticed as regards the indicators' technological orientation, considering that only 21 of them (23%) are ICT-related, while 70 (77%) are non ICT-related. Moreover, indicators are classified into 'Core Indicators' (CI) and 'Advanced

4 The *United for Smart Sustainable Cities* (U4SSC) is an initiative undertaken by the United Nations, coordinated by ITU, UNECE and UN-Habitat and widely supported by numerous international organizations. It aims at providing strategic guidance on how to attain SDG 11 "Make cities and human settlements inclusive, safe, resilient and sustainable" and implement the New Urban Agenda, as well as other international agreements. Therefore, the initiative acts like a global platform that: fosters discussions, information and practice exchange, knowledge sharing, etc. on SSC issues, supports public policy and promotes the adoption and use of ICTs that are anticipated to ease and accelerate the transition towards SSC (ITU, 2018).

Indicators' (AdI) (the framework includes 54 core indicators and 37 advanced ones). *Core indicators* can be deployed by every city profile and hence exhibit great degree of applicability. *Advanced indicators* are more city-specific; they provide a detailed analysis of the explored urban environment; and refer to the assessment of the progress made on more advanced smart city initiatives (ITU et al., 2017). Indicators are also characterized as: *smart*, which are relevant to measuring progress towards becoming smarter (20 smart indicators included); *sustainable*, that are pertinent to gauging sustainability performance (39 sustainable indicators included); or *structural*, which provide a basis for comparison (32 structural indicators included). It should be noted that the initiative is implementing several case studies in various cities around the globe in order to get a deep insight into the feasibility of the suggested indicators that also form the basis for the development of the global *U4SSC Smart Sustainable City Index* (ITU et al., 2017; ITU, 2018).

5.4.7. ISO 37120, ISO 37122 & ISO 37123

37120 standard, developed by the International Organization for Standardization (ISO, 2018a), represents a holistic and integrated approach to *sustainable development of urban environments* that constitutes the core of the indicator framework that this thesis proposes. It was first published in 2014 and was technically revised four years later, in 2018. The standard provides a broad set of explicitly defined, standardized, consistent and comparable (establishment of a common process / way of measurement) over time and/or across different cities, performance indicators. These indicators can be deployed by cities in order to assist them in (ISO, 2018a): (i) defining the performance of their services and the quality of life they provide over time; (ii) exchanging / sharing precious knowledge and best practices with other cities; and (iii) fostering policy development and effective prioritization. In a nutshell, 37120 ISO standard aims at facilitating cities measure their sustainability performance in several domains; and answers to the question of how urban environments can effectively adapt to contemporary challenges and provide, at the same time, adequate resources and a sustainable future to their citizens (Midor & Plaza, 2020).

The proposed indicators (128 in total) are mainly focusing on *city services* and *quality of life* and are distributed across 19 *themes* that refer to various city sectors and services (Table 9, Annex II). Moreover, they are further subdivided into *'Core' indicators*

(CI), i.e., indicators that are considered essential and are required to demonstrate performance in the delivery of city services and quality of life when following the ISO 37120 standard; *'Supporting' indicators* (SI), i.e., indicators that are recommended to be followed in order to reach the same end state; and *'Profile' indicators* (PI), i.e., indicators that provide useful mainstream statistics and background information for conducting benchmarking (ISO, 2018a). It is also worth mentioning that the ISO 37120 standard demonstrates an extremely limited technological orientation, since from a total of 128 indicators, 126 are perceived as non ICT-related, whereas only two of them are characterized as ICT-oriented (see also Table 9, Annex II).

ISO 37120 standard (ISO, 2018a), the first set of internationally standardized city indicators for *sustainable cities* that offers a uniform approach to the assessment of urban performance as to the provided services and quality of life, is enriched by ISO 37122 standard (ISO, 2019a) on "Sustainable Cities and Communities - Indicators for Smart Cities". The latter proposes a pool of 80 *indicators*, structured around 19 *themes*, that are mainly associated with smart enabling technologies and policies, but few environmental and social impact ones are also included (ISO, 2019a; Huovila et al., 2019). ISO standard 37122 intends to assist cities in (Santana et al., 2018): developing and offering improved, efficient and sophisticated services to citizens and visitors; providing a highly inclusive and sustainable living environment where smart policies and practices, as well as state of the art technologies are at the service of all citizens; attaining sustainable urban development through innovative ways; identifying the necessity for smart infrastructure; forming a dynamic, innovative and knowledge-based economy, capable of efficaciously confronting and overcoming potential future stresses; etc. The profile of the standard possesses mostly a technological orientation, as is evidenced by the distribution of indicators between the ICT- and non ICT-related categories[5] (48 ICT-related vs. 32 non ICT-related indicators) (Table 10, Annex II).

A third standard, ISO 37123 (ISO, 2019b) on *resilient cities*, has come to complete the aforementioned family of ISO standards and shape a comprehensive list of globally accepted indicators. It includes 68 indicators relevant to cities' resilience planning and baseline measurement, and its scope is in total alignment with: the 2030 UN SDGs, the principles and priorities of the Sendai Framework, the current international

5 It should be highlighted that although the majority of the indicators included in the 37122 ISO Standard on "Sustainable Cities and Communities - Indicators for Smart Cities" are characterized as ICT-oriented, they are nevertheless *technology neutral*, which implies that they do not favor one technology over another (ISO, 2019a).

city resilience frameworks like City Resilience Index (Arup, 2016a) and UNDRR's Disaster Resilience Scorecard for Cities (UNDRR, 2017); and considerations on adaptation to climate change. Therefore, it provides a pool of indicators that can support and motivate policy decisions of cities towards risk reduction and enhancement of resilience (Table 11, Annex II).

These three standards are interrelated, they are perceived complementary and thus they should be applied as a complete set. This is justified by the fact that the first standard (37120) is oriented towards *urban sustainability* issues, the second one (37122) supports *smartness* in contemporary urban environments; while the third (37123) focuses on *urban resilience*, thereby forming a family of coherent indicator frameworks that cover all fundamental aspects of sustainability in urban development (Figure 5-17).

Finally, it is notable that the effort towards perceiving the 19 themes of the ISO family standards along the lines of the six key characteristics that derive from the "Smart Cities – Ranking of European Medium-Sized Cities" indicator system (Giffinger et al., 2007), reveals the great degree of influence that the latter has exerted on the way ISO standards are structured, as witnessed by the fact that most of the proposed themes are falling into the six key categories.

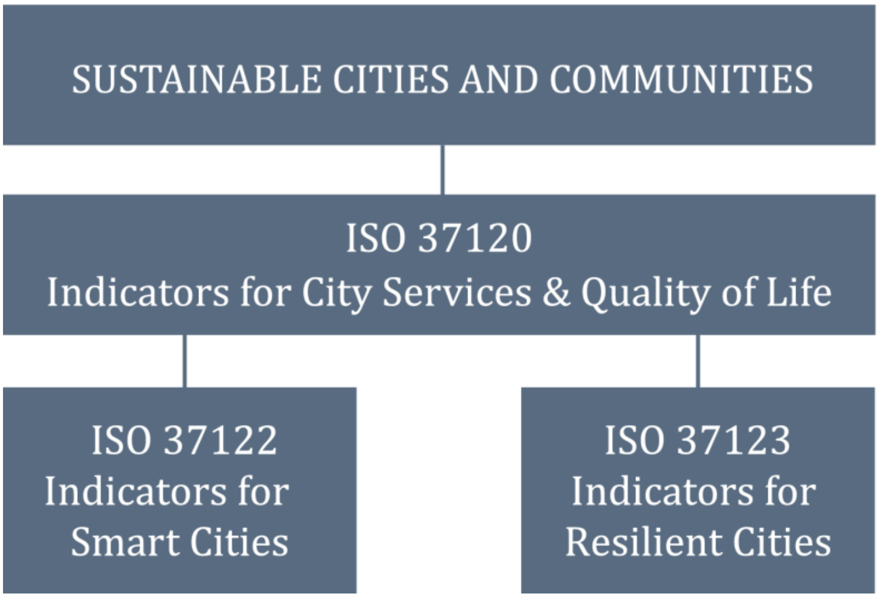

Figure 5-17: Sustainable Urban Development – Relationships Between the Family of ISO Standards for Smart, Sustainable and Resilient Cities (Source: ISO, 2019a)

5.5. Towards a Multidimensional, Enriched, and Comprehensive Indicator Framework for Assessing Sustainability Performance of Contemporary Urban Environments

The aim of the present section is to introduce / establish a multifaceted and comprehensive indicator framework, capable for efficiently assessing *urban sustainability performance*. The proposed framework integrates the concepts of smartness, resilience and inclusiveness, as well as respective emerging concerns; and is grounded in the previously described international indicator frameworks. Moreover, it provides decision and policy makers with valuable guidance for effectively navigating into it, so as to end up with the selection of the most suitable set of indicators.

The rationale behind this framework is based upon the implementation of four general discrete steps (see Figure 5-18) that conduce to the conceptual establishment and construction of an enriched and comprehensive indicator framework, capable of evaluating sustainable urban development performance. The proposed steps are the following (Stratigea et al., 2017; Panagiotopoulou et al., 2020):

- *Step 1* – Thorough exploration and in-depth analysis of the conceptual design / obtainment of a clear conceptual insight of the indicator frameworks under study.
- *Step 2* – Creation of a pool of indicators that stem from the considered indicator frameworks.
- *Step 3* – Establishment of the conceptual design of the proposed indicator framework.
- *Step 4* – Incorporation of each single indicator of the pool (Step 2) into the conceptual design of the proposed framework (Step 3).

Step 1 focuses on the exploration of the seven, previously analysed, indicator frameworks, by thoroughly studying relevant official reports and documents, coupled with other related references. More specifically, the scope, the conceptual design and structure, as well as the respective pool of indicators that emerges from each system are considered.

Step 2 regards the creation of a new pool of indicators which comprises all those that derive from the different frameworks; and sets the ground for building up the content of the proposed sustainable urban development indicator framework. After identifying overlaps and removing duplications, by means of getting an in-depth insight into the full description of each single indicator -wherever this was available-, the resulting pool counts 597 indicators in total (out of 1096 indicators that were initially inspected) and actually fleshes the structure of the proposed framework out.

Step 3 elaborates on the conceptual design of the proposed framework so as an explicit and effective categorization of the different indicators that derive from step 2, to be achieved. Construction and use of a sophisticated and clearly defined conceptual framework is a really critical aspect, since indicators emanate more naturally and can be readily adapted to the needs / peculiarities of a given place or group of decision makers (Hardi & Zdan, 1997). It is worth mentioning that the hierarchical structure, which is developed at this stage (domains – subdomains – key issues – indicators, see Figure 5-19), can facilitate the linkage of a city's vision and respective goals set to relevant indicators and assessment criteria in order for their fulfillment to be properly evaluated and monitored (Hardi & Zdan, 1997).

Step 4 undertakes the task of properly matching, in a qualitative way, relevant paths (domain – subdomain – key issue, e.g., environment – pollution – CO_2 emissions) with specific indicators. As a result, a *tree structure* that follows all the way down the four discrete levels of the suggested framework is developed.

The above steps underpin the establishment of a *holistic, enhanced and comprehensive indicator framework* that is formed by appropriately encompassing the various international explored frameworks. This can be used as a powerful tool for efficacious monitoring, assessment, as well as decision- and policy-making in respect of sustainability performance, in the sense that it may offer a *more balanced set of indicators*. Moreover, it embeds different perspectives and respective indicators that derive from the systems under study, thereby adopting an *integrated approach* and offering a *synthesized view* of contemporary urban environments. Figures 5-19 and 5-20 provide a rough delineation of the suggested indicator framework's conceptual structure and basic components. More specifically, Figure 5-19 illustrates the building blocks, the share of ICT- and non ICT-related indicators, as well as the distribution of indicators across the six subdomains; while Figure 5-20 presents the thematic structure (domains – subdomains – key issues – indicators) of the proposed framework.

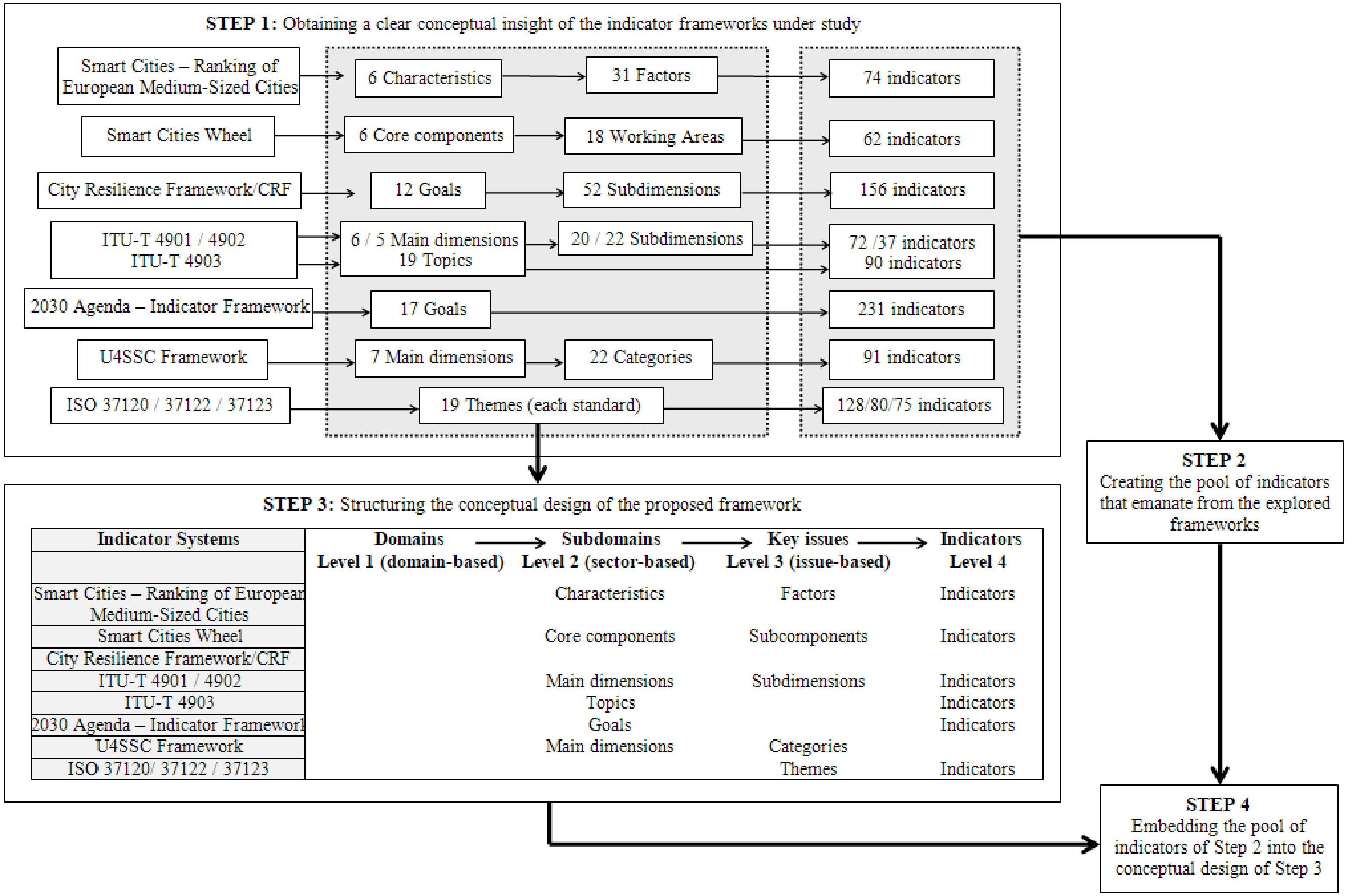

Figure 5-18: Fundamental Steps for Structuring the Proposed Integrated Indicator Framework (Source: Adapted from Stratigea et al., 2017; Panagiotopoulou et al., 2020)

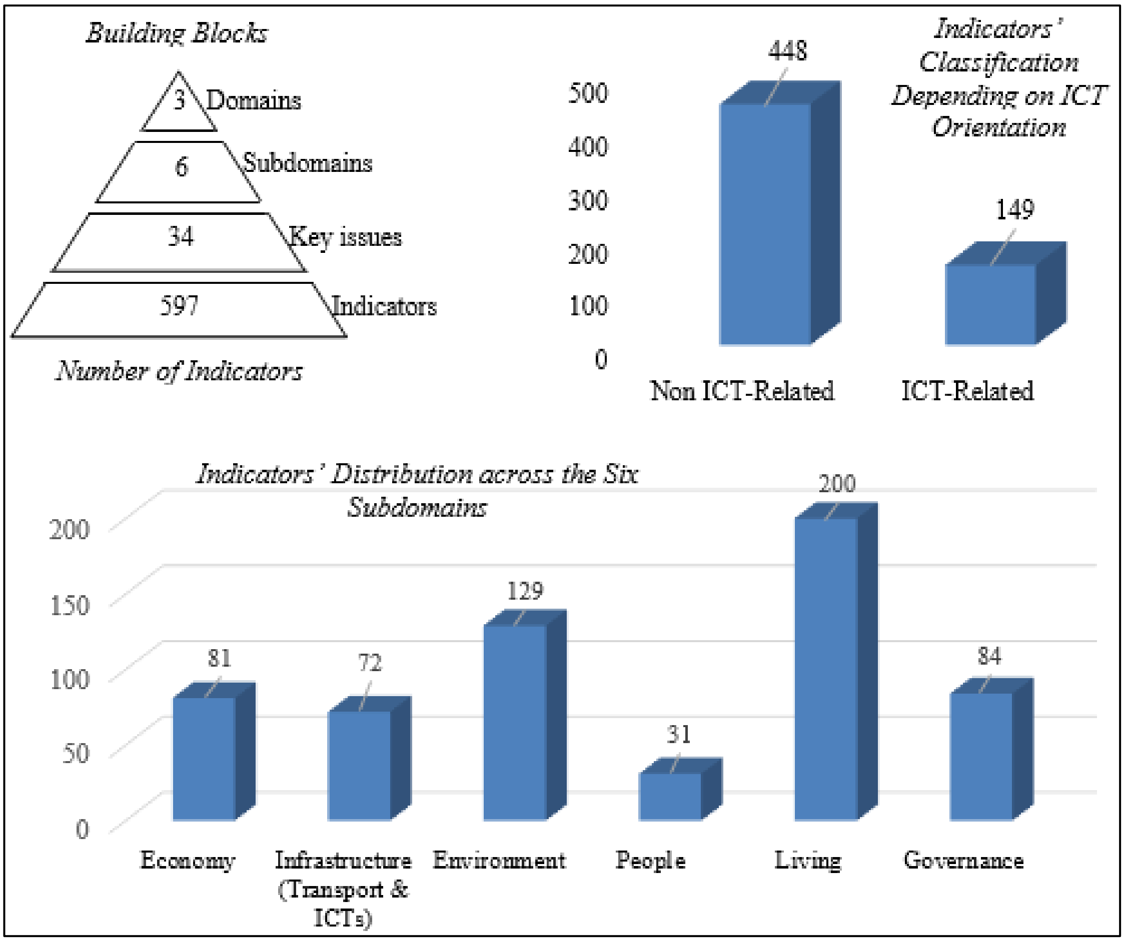

Figure 5-19: Building Blocks and Indicators of the Proposed Framework (Source: Adapted from Stratigea et al., 2017; Panagiotopoulou et al., 2020)

The suggested conceptual framework is in harmony with Maclaren's (1996) classification that discerns five different types of frameworks, namely domain-based, goal-based, sector-based, issue-based and causal. According to this classification, a four-level conceptual design is adopted (see Step 3 illustrated in Figure 5-19) and is concisely analysed as follows (Stratigea et al., 2017; Panagiotopoulou et al., 2020):

- The first level – *domains* of the proposed framework – is a domain-based level that draws upon the three pillars of sustainability (environment, economy, society & culture).
- The second level – *subdomains* – follows a sector-based approach and is in alignment with / is built upon the six characteristics (smart economy, smart people, smart governance, smart mobility, smart environment and smart living) suggested by Giffinger et al. (2007), whose work is perceived as an effective and also extremely influential approach for numerous relative efforts and research work carried out so far.

- The third level – *key issues* – constitutes an issue-based approach in the context of which the key issues of sustainability that fall into the abovementioned sectors, are presented (34 key issues in total).
- The fourth level – *indicators* – refers to single measures of specific sustainability attributes. Based on the conceptual design of the proposed framework, particular emphasis is placed on properly corresponding the design features of the explored frameworks ('characteristics', 'factors', 'themes', 'goals', 'core components', 'subcomponents', 'main dimensions, 'topics', 'categories' and 'subdimensions') to the features of the proposed one ('domains', 'subdomains' and 'key issues') (see Figure 5-18).

Pursuant to Figure 5-19 and Table 12 (Annex II), the greatest share (75%) of the indicators included in the suggested framework are non ICT-oriented (448 indicators); whereas only 25% (149 indicators) are ICT-related. Nevertheless, it should be noted that in a few cases some indicators may be deemed to be both ICT- and non ICT-related, in the sense that their description insinuates the use of technologies, but also the deployment of traditional, 'non-tech' methods and techniques. For example, the indicator "number of public library book and e-book titles per 100,000 inhabitants" encompasses both the technological and non-technological dimensions; however, it is classified as a non ICT-related indicator, since its purpose and meaning does not focus on the technology used per se, but rather on giving an indication of people's educational status. In the context of the Thesis, such 'mixed' indicators are treated in exactly the same manner so as to be classified on the basis of their technological orientation or the lack thereof.

Additionally, 33.5% of the total number of indicators (200 indicators) refer to the living conditions of contemporary urban environments (health, safety, educational facilities, social cohesion, etc.) and comprise the most populous subdomain of the proposed framework. This is followed by the environmental subdomain, which includes 129 indicators (21.6%). The governance subdomain consists of 84 indicators (14%); while the economy and infrastructure (transport & ICTs) subdomains accrue 81 (13.6%) and 72 (12.1%) indicators respectively. Last comes the subdomain of people that incorporates 31 indicators (5.2%) (Figure 5-19).

The conceptual / thematic structure of the proposed indicator framework is illustrated in Figure 5-20.

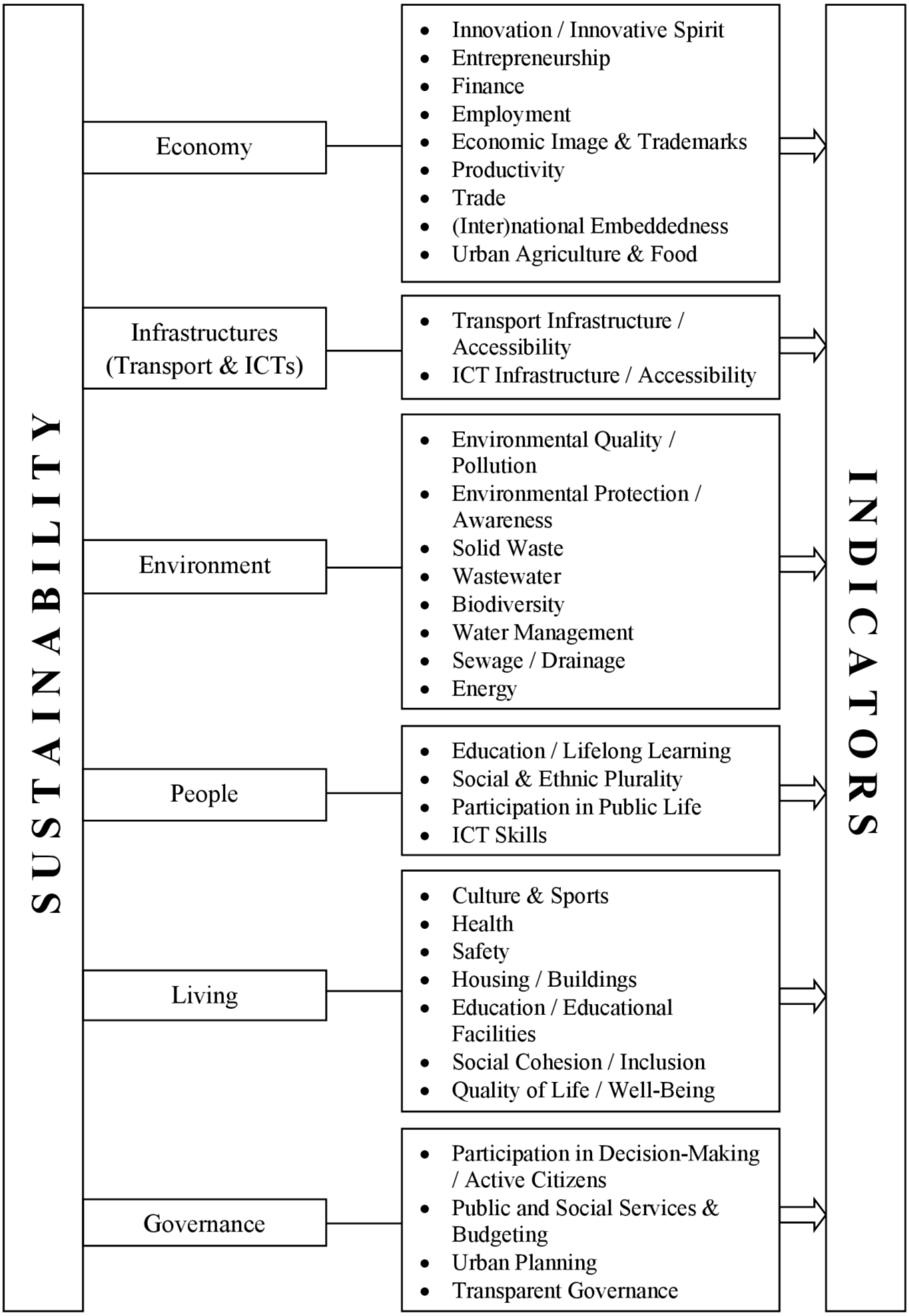

Figure 5-20: Conceptual / Thematic Structure of the Proposed Indicator Framework
(Source: Own Elaboration)

5.6. Selection of the Most Appropriate Indicators for Assessing Sustainable Urban Development

When indicators are poorly chosen they can cause serious malfunctions

(Meadows, 1998, p. 3)

After the theoretical conception and the consequent construction of the suggested integrated indicator framework, some critical questions remain unanswered. How can planners and decision makers safely select the most suitable and relevant indicators for efficaciously measuring / evaluating the impacts of smart, sustainable, resilient, and inclusive policies? Which steps do they need to follow? How can they navigate into the proposed indicator framework? The current section of the thesis aims at shortly offering some guidance, by means of paving the way for picking up the most suitable indicators in order to assess case-specific urban sustainability performance and help ensure the accountability of all local stakeholders involved. More particularly, a *sound* and *city-oriented* indicator framework, capable of transforming set of goals and objectives into a useful *management tool* for assisting cities in developing and implementing strategies as well as allocating resources accordingly, is indented to be constructed.

The suggested framework consists of two *complementary* parts and combines a *top-down* or *expert-led* and a *bottom-up* or *citizen-led* approach (see Figure 5-21).

The *top-down* or *expert-led part* intends to provide available options of indicators, stemming from the extended pool that is structured by capitalizing on international experience and knowledge. Navigation into this indicator pool constitutes a *city-specific process*, guided by the steps involved in the bottom-up approach.

The *bottom-up* or *citizen-led part* is based on local expertise, needs, specificities, vision, etc., and constitutes a collaborative process that attempts to engage all actors of an urban ecosystem (decision-makers, community, entrepreneurs, public and private institutions, etc.). It focuses on a number of significant issues that need to be taken into serious consideration so as to navigate into the proposed indicator framework and properly select the most relevant, to the specific city context, indicators. These issues, which are concisely described in the following paragraphs, relate – inter alia – to the two fundamental requirements that the resulting set of indicators should satisfy (Bossel, 1996): (i) provision of all essential information about the current state of a system and its rate of change; and (ii) indication of their contribution to the achievement of given goals, objectives, needs, and interests (information on how the selected indicators contribute to the attainment of a goal, with the assistance of the system under study).

Cities are led by visions and related goals / objectives – Need for place-based understanding and city context assessment: Sustainability, smartness, resilience and inclusiveness can be reached by the deployment of effective ICT-enabled solutions, but also by the implementation of non ICT-oriented policies, interventions, etc., both aiming at specific *targets' attainment*. Different city contexts entail different sustainability targets and related policy paths for their fulfillment, largely dependent on the cities' (Stratigea et al., 2017; Panagiotopoulou et al., 2020): current sustainability achievements; attributes and strategic priorities; vision for the future and the selection of relevant -socially and culturally driven- smart, sustainable, resilient and inclusive policies; relating or possible (based on available resources) pace of change; level of ICT infrastructure, etc.

City-specific targets and associated evaluation criteria, as well as policy orientation delineate *domains and subdomains affected* (Figure 5-21), guiding in this respect navigation in the suggested indicator framework. This whole process results in the shaping of a *'flexible' indicator set* that incorporates carefully identified / selected 'context-specific' indicators, which exhibit great degree of adaptability to local conditions, and therefore increased suitability for gauging sustainable urban development of a given locale (Lützkendorf & Balouktsi, 2017).

Moreover, this adjustable and context-dependent indicator set enables the *diagnosis* of specific problems and stresses, drastically contributing in this way to the identification of particular areas that would profit from being properly addressed through certain policies, actions or interventions. The above remark is beautifully summarized in the words of Habicht and Pelletier (1990), who claim that "there is no best indicator, best measure of an indicator, or best analysis of an indicator in a generic sense. The definition of 'best' depends ultimately on what is most appropriate for the decision that must be made" (p. 1519).

This statement implies that the final choice of proper indicators is a *case-specific* procedure, highly contingent upon local specificities and varying needs of different stakeholders (Sharifi & Murayama, 2015); and thus, the selection of assessment criteria may be completely different, depending on the specific context concerned every time. According to all the above, the great challenge for urban planners and policy makers today is – inter alia – to decide (Science for Environment Policy, 2018):

- which indicators best reflect the vision of a particular city and effectively address its needs and requirements;
- which indicators would be easily measurable but significantly useful at the same time; and
- which ones actually worth the financial and human effort.

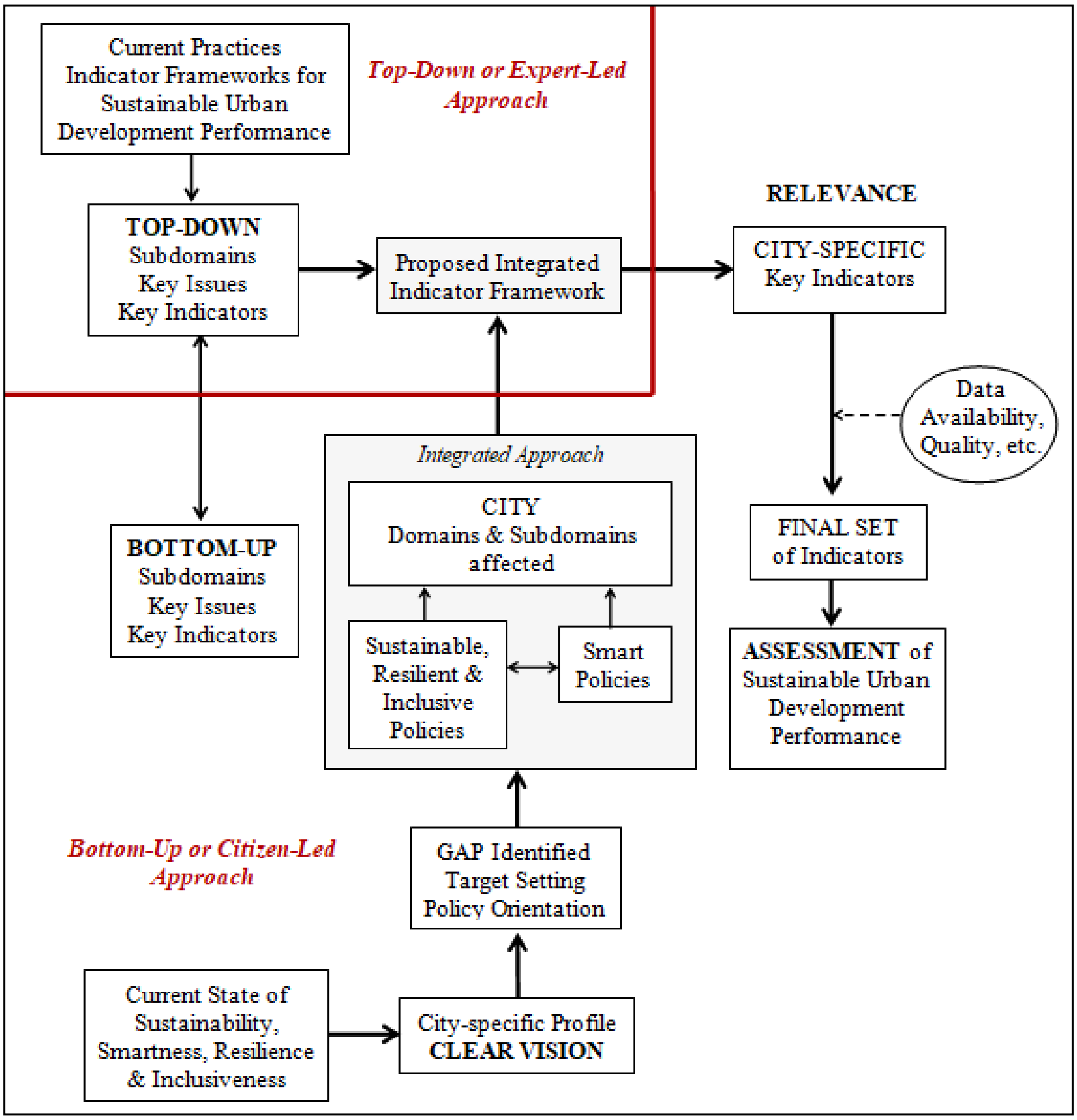

Figure 5-21: Assessment of Urban Sustainability Performance – Combination of Top-Down and Bottom-Up Approach (Source: Adapted from Panagiotopoulou et al., 2020)

Cities should be treated as an organic whole (Kanter & Litow, 2009): Cities are complex systems and they should be treated as such. Current empirical experience though uncovers a mostly fragmented implementation of policies (smartness, sustainability, resilience and inclusiveness policy measures). In order to effectively assess cities' sustainability performance, an integrated approach needs to be adopted. This implies that a city should be perceived as *a network* or a *linked system* (Kanter & Litow, 2009), improving interconnections / interactions and integration among different silos, e.g., transport, energy, education, health care, buildings, physical infrastructure, food, water, public safety. Proper navigation into the proposed indicator framework and selection of suitable sustainability performance indicators demands shedding light on the domains and subdomains affected by policy implementation, considering both the *direct impacts* of these policies on a targeted field (e.g., transport); but also, their *indirect impacts* that emanate from the interplay of this field with others, in each specific city context (e.g., energy, congestion, environment, affected by transport policies).

Undertaking of this task entails the availability of a sufficient *knowledge stock* on:

- the urban system and the interrelationships among its subsystems;
- the way smart, sustainable, resilient and inclusive policies interact with targeted problems;
- the synergies that can be developed between the different types of policies and their respective impacts; etc.

In fact, it requires accounting for the dynamics of complex systems (Hilty et al., 2014), especially for the identification of the *impacts of smart, resilient and inclusive solutions to sustainability*. As this is not an easy task to accomplish, recent research efforts stress the need for developing the *ontology of the city* in order to better grasp the effects of smart, sustainable, resilient and inclusive policies (Fox, 2013; Komninos et al., 2015; Panagiotopoulou, 2018; Panagiotopoulou et al., 2019). The same holds for smart applications, where the *ontology of each application* and its alignment with the *city ontology* are expected to support a better understanding of subdomains and key issues that are affected (Komninos et al., 2015), resulting thus in a more efficacious identification and selection of sustainability assessment indicators.

Restrictions posed by the very nature of data and indicators: City-specific key indicators, selected for assessing sustainable urban development performance should be further evaluated before the set of indicators is finalized (Figure 4-21). Some critical selection criteria of indicators in this process, which should be taken in serious consideration, are (Maclaren, 1996; Meadows, 1998; European Commission, 2001a; Darcy & Hofmann, 2003; UN, 2003; Joint Research Centre of the European Commission

& Organization for the Economic Co-operation and Development [JRC-OECD], 2008; Brown, 2009; Aurino, 2014; UNECE, 2015):

- *Availability of accurate accessible data*: available and accessible or cost-effective collection of accurate data, regarding these indicators, need to be ensured.
- *Availability of historical data*: several time series of data should be available, in order trends, evolutionary patterns, etc., to be explored.
- *Validity and meaningfulness*: indicators must capture the essence of the problem and they should be able to meet the users' needs and requirements.
- *Consistency over time*: indicators should be able to be defined and measured consistently over time, in order to achieve accurate monitoring of phenomena and trends.
- *Comprehensibility* to potential users: indicators must be explicitly defined and readily grasped by users.
- *Sufficiency*: indicators should offer a 'balanced amount' of information to the users. Not too much to handle or grasp, and not too little to provide a clear and complete picture of the system / phenomenon / trend under study.
- *Supplementation*: indicators should provide information on things that common people cannot measure.
- *Hierarchy*: when the system under study is hierarchical (in terms of detail and scale), so must the indicators be (Aldanondo & Archimède, 1996). In this way, a user has the chance either to go deep in details or directly grasp the general idea, according to his/her wish.
- *Ability to be disaggregated*: indicators should be able to be broken down by age, sex, social or economic status, ethnicity, areas of particular interest, etc., in order to render relevant comparisons, between different groups, feasible. Moreover, indicators should not be over- or under-aggregated.
- *Comparability with indicators developed in other jurisdictions*: indicators developed within different jurisdictions should be comparable.
- *Coverage*: indicators ought to be representative of the population in the sample.
- *Statistical soundness*: indicators' development should be based upon the use of high-quality data and statistically robust methods.

- *Attractiveness to the media / people*: reflects the power of indicators for communicative purposes in order awareness raising objectives to be fulfilled.
- *Ambiguity*: indicators should be completely unambiguous and able to provide a crystal-clear understanding of their meaning and metrics.
- *Potential to establish target and threshold values*: these correspond to desired / visionary and liveable conditions of city dimensions that each indicator assesses.
- *Independence*: indicators that evaluate different dimensions of a subdomain should be independent or almost orthogonal, i.e., overlapping indicators should be avoided as much as possible.
- *Feasibility*: indicators' determination / measurement should include reasonable costs.
- *Sensitivity* to change.
- *Democracy*: the public should be offered the opportunity to affect the selection of indicators and to have access to results.
- *Participation*: deciding what to measure should be a joint discussion among all the stakeholders involved in a project / intervention / programme, etc.
- *Policy relevance*: indicators should be capable of addressing key sustainability policy issues for monitoring performance and leading to more informed and knowledgeable decision-making.

Current state of the system and its future vision (Figure 5-21) intent to identify gaps, set targets and define policy paths (sets of short, medium and long-term policy measures) so as targets to be reached. These policy paths, implemented by smart, sustainable, resilient and inclusive policies (or certain combinations of them), aim at affecting system's dynamics towards a desired end state. Moreover, they define the domains, subdomains and key issues that are influenced, which in turn properly guide navigation in the pool of the proposed indicator framework.

Through this process the final set of indicators can be defined (Figure 5-21), in support of sustainable urban development performance evaluation. It should be noted that data availability can be a rather restricting factor that may limit impact assessment of policies concerned. This is clearly evident in case of smart policies, a quite unexplored issue in respect of the profusion of smart applications currently in use; and the ongoing discussion on the direct and indirect impacts they introduce to each specific urban environment (Hilty et al., 2014).

5.7. Discussion and Conclusions

The relationship between (urban) indicators and strategic planning is symbiotic and mutually reinforcing (see Figure 5-22). A set of norms – which actually represent basic and broad aspirations / goals of a given community – guide the setting of certain policy objectives, which, in turn, call for the deployment of appropriate indicators to measure progress towards these objectives. Well-crafted action plans – designed to operationalize strategies – are also developed, with the ultimate aim of pursuing the policy objectives and reaching the targets as regards indicators' values (Westfall & de Villa, 2001).

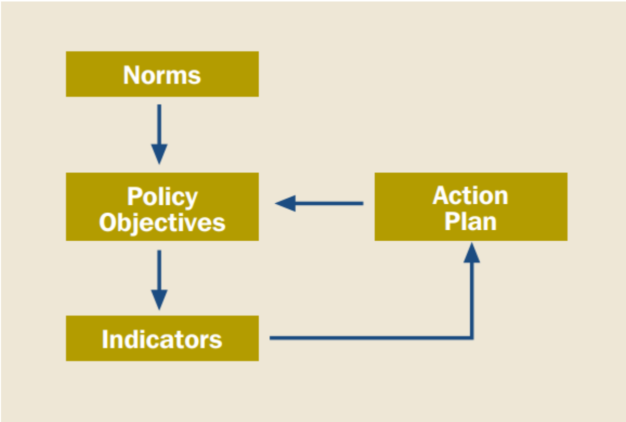

Figure 5-22: Policy Indicator Model (Source: Westfall & de Villa, 2001)

Indicators serve as critical sources of information that enable knowledgeable decision making, evidence-based policy formulation, and effective monitoring and assessment. The planning practice benefits from the insights gained through the analysis of indicators, leading thus to more sustainable, inclusive, and resilient urban areas. As cities continue to face complex challenges and opportunities, the integration of indicators into strategic planning processes has become a necessary condition for achieving well-planned and thriving urban environments.

However, the assessment of sustainable urban development performance remains an intractable and intriguing issue, while empirical evidence as regards the impact of smart applications on cities' functions and sustainability gains is rather scarce (Komninos et al., 2015). Furthermore, little has been done so far towards measuring cities' performance with respect to their endeavors to promote the recently emerging goals of resilience and inclusiveness, as well as to identify disastrous risks and stresses and get prepared for effectively confronting them. Ample global, but also national / local, indicator frameworks have been developed so far, in an effort to support planners and decision makers in gauging urban sustainability. Despite the continuously increasing number and diversity of suggested indicators, a lack of consensus regarding (Hammond et al., 1995; Ramos et al., 2004; Moreno Pires et al., 2014): the use of optimal conceptual framework and standardized options to measure urban sustainability; and the selection of the most appropriate methodologies that should be followed, is pretty evident. The dissection of these frameworks reveals various differences among them, mainly stemming from (Stratigea et al., 2017; Science for Environment Policy, 2018; Panagiotopoulou et al., 2020): their conceptual orientation and structure; the purpose they are meant to serve; the methodological approach they adopt for measuring sustainability performance; their spatial scale; and the indicators they incorporate. However, the common basis that they share lies in their effort to promote sustainable urban development by distilling diverse data into meaningful and applicable information and knowledge (Hiremath et al., 2013).

Many of these established frameworks have been heavily criticized for adopting a *performance-oriented approach* (measurement of performance at a specific point in time), thereby terribly failing to reflect the dynamic and constantly evolving nature of urban environments. Also, most of them demand expert knowledge so as to be properly comprehended (Huovila et al., 2019). Several other frameworks are imbued with a notion of severe *stiffness / rigidity*, in the sense that they provide a 'fixed' set of indicators; whereas the assessment of urban sustainability performance should be based on a highly *flexible* and *adjustable* set of indicators, capable of expressing the *local vision* and responding to *emerging issues* (Lützkendorf & Balouktsi, 2017). Additionally, many of the indicators incorporated in such frameworks are often blamed for being susceptible to manipulation, non-transparent and scientifically dubious (Kitchin et al., 2015). Moreover, they usually lack standardization, consistency or comparability through time and space (Fox, 2013; ISO, 2018a); while they also lack sufficient endorsement so as to be used as ongoing benchmarks (Hoornweg et al., 2007).

According to all the above, the scope of the particular chapter is threefold: (i) it attempts to elaborate on a number of globally-initiated and recently developed indicator frameworks and to establish a new one, by complementing and integrating different indicator sets and views reflected by these frameworks; (ii) it provides general guidelines on the steps that should be followed so as to navigate into this framework and select proper indicators for assessing urban sustainability achievements; and (iii) it establishes part of the conceptual ground for the construction of the ontological representation for smart, sustainable, resilient and inclusive cities that takes part in chapter 8, considering that many concepts and relations that enrich the proposed ontology originate from the various global indicator frameworks that are studied.

The selected indicator frameworks stem from the international scene and constitute the outcome of cohesive and laborious efforts made by greatly experienced global organizations, based on methodologically sound, well-structured multidisciplinary / multi-stakeholder work. Endeavors carried out by these organizations during the last few years have led to a certain revision of the indicator frameworks and their respective enrichment with recently evolving concepts, such as smartness, resilience and inclusiveness. This results in updated frameworks that are in alignment with (Panagiotopoulou et al., 2020): current urban sustainability discourse and prevalent key drivers (i.e., smartness, inclusiveness, resilience, disaster risk management); and relative global policy frameworks towards the enrichment of sustainable urban development aspirational goals, challenges and assessments. However, it should be highlighted that current frameworks still assess sustainable urban development in a rather *fragmented* way and, in many cases, a user has to adopt complementary frameworks in order to cover multiple aspects of sustainability performance. It is also worth mentioning that the discrepancies / inconsistencies that appear among the various frameworks as to the assessment of the same issue (e.g., patents per inhabitant or per 1,000 inhabitants or per 100,000 inhabitants) are tremendously confusing and lead to severe cacophony. Nonetheless, a decent number of indicators is shared among the different frameworks, in the sense that they adopt a mutual approach regarding the definition of what they attempt to measure and the way of measuring it, ensuring thus a certain level of conceptual interoperability (Panagiotopoulou et al., 2020).

The suggested framework aims at expressing a more comprehensive and integrated view of sustainable urban development indicators by delivering an enriched knowledge base / pool of potential indicators, which (Panagiotopoulou et al., 2020): has its origins in contemporary international indicator frameworks; adopts a digestible and easy to grasp conceptual design; attempts to integrate key issues of current discourse that are tightly interwoven with sustainability, i.e., smartness, resilience and inclusiveness, in a single indicator framework; and contains all the available information / documentation regarding every single indicator incorporated (development of factsheets that contain definitions, data sources and requirements, metrics and ways of calculating them, units, target groups, etc.), thereby optimizing information management. Based on its structural attributes, the proposed framework is able to: steer cities' sustainability assessments by offering a more widely differentiated amalgam of performance indicators, i.e., a broader range of options to those engaged in such a task that can better serve their needs, data availability, targets, etc.; provide guidance to city managers on the additional type of standardized data that is required in order to improve their assessments in the different domains; assist city managers in better understanding the multidimensional nature of sustainable urban development evaluation, useful for target setting and policy formulation; keep track of other cities' efforts for serving city-to-city learning processes (mutual exchange of knowledge, best practices, know-how, etc.).

Furthermore, the last part of the chapter attempts to roughly sketch certain guidelines and significant issues raised in an effort to navigate in the proposed indicator framework. Even though this can be of certain help to planners and decision makers' tasks, several problems that need to be faced in every sustainability assessment process, still remain. These relate to the limited knowledge on the way smart applications / policies, as well as policies regarding inclusiveness and resilience interact with a particular urban environment, but also the way they create synergies and add value to pure sustainability policies. Resolving such problems largely depends on a thorough analysis and deep understanding of the specific urban environment, where these policies are implemented; and the peculiar characteristics of the policies per se. These constitute the current research streams of the field through the *ontology development* of both the cities and the concepts of smartness, resilience and inclusiveness. Moreover, although the proposed indicator framework can provide a common basis for sustainability assessments, the barriers of data availability and quality, the way of understanding, defining and measurement, etc. are still evident. The issue of indicator ontology is also coming to the forefront by Fox (2013), who has developed – inter alia – the ontology of *ISO 37120 Global City Indicators*. In this work, Fox claims that indicator definitions are citizen- and city-oriented and elaborates on the different interpretations assigned to each indicator in varying city settings, which is due to the different understanding of the language, but also the specificities of the environment in which this applies (i.e., how each city and its people may define some terms). The vagueness that emerges from the abovementioned indicator drawbacks implies a limited potential for benchmarking different city contexts. Although benchmarking is considered a powerful and useful tool for identifying each city's position as to the rest of the world; and collecting good practices for further improvement, it does not really reflect the very uniqueness of each city's economic, environmental, social and cultural attributes and progress. Additionally, the necessity for developing indicator ontologies, but also for embedding them into the cities' ontological representations, brings to the surface the problem of 'linear thinking' that many indicator frameworks espouse. Gallopin (2018), stresses the need to abandon the obsolete and short-sighted categorizing of concepts (pertinent to goals, objectives, indicators, etc.) under relevant themes (theme-based hierarchical structures) and adopt a more integrated and holistic approach that takes into account interrelationships, synergies and antagonisms among the related concepts.

Finally, as Pintér et al. (2012) highlight, a greater share of case study-based research is necessary in order to create and offer a "practical and more useful guidance" (p. 26) concerning Sustainability Assessment and Measuring Principles (STAMP), by detecting possible generic patterns on what delivers optimal results and what doesn't (Bell & Morse, 2018). More particularly, case studies regarding sustainability indicators may reveal new emerging patterns, they may pose new research questions or uncover contradictions to the currently established norms (Bell & Morse, 2018). Given these remarks, more case studies are required to be conducted in order to better grasp the malign and benign forces that are at work in the sustainable urban development assessment field.

Bibliography of Chapter 5

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Part 1 Contextual Background

Part 2 Bibliographic Review on Smart Cities

Part 3 Construction of an Integrated Indicator Framework for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 4 Bibliographic Review on Semantics & Ontologies

Part 5 Development of an Ontology for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 6 Conclusions & Future Research

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CHAPTER 6: SEMANTICS AND ONTOLOGIES OF GEOGRAPHIC CONCEPTS

Synopsis*: Despite the tremendous and constantly escalating interest in the smart city developments, there is still no unambiguous and broadly accepted definition of the concept, although numerous interpretations have been suggested from time to time. Given the intense polyphony and the consequent serious lack of semantic interoperability it instigates, the present chapter endeavors to provide a concise but clear picture of the scientific discipline of semantics and ontologies; thereby setting the basic theoretical background for the following two chapters. More particularly, the semantics of geospatial concepts; the factors that affect the way these are perceived and understood; the most common semantic problems / barriers; and the close relationship between semantics and ontologies, are explored. Moreover, the chapter proceeds with outlining the various aspects of the ontology concept, with special focus on geographic ontologies. The usefulness of ontologies and the most important fields of their application; the different types of ontologies; the fundamental stages of ontology design and development; and the process of ontology alignment, merging and integration are also investigated.*

6.1. Semantics

Semantics is defined as the study of *meaning* (what meaning is, how it can be described, represented, and conceived). Exploring the nature of meaning (what meaning is) constitutes a critical and intriguing research subject in many scientific fields, such as Philosophy, Psychology, Linguistics, etc.; and various theories have been occasionally articulated. The other facade of the study of meaning lies at the heart of Linguistics and primarily concerns methods of *semantic description* and *representation* (Kavouras & Kokla, 2008). Pursuant to the Merriam-Webster dictionary (n.d.-b), semantics is defined, inter alia, as: (i) the study of meanings (mainly the suggestive / implied) or the relationship of meanings of a symbol or a group of symbols (connotative meaning); and (ii) a branch of Semiology (or Semiotics) that focuses on the relationships among symbols and their referents, while it also incorporates theories of denotation, extension, naming, and truth.

Ogden and Richards (1923) have managed to illustrate the world's semantic relationships between words and objects by introducing the so-called *triangle of reference*, also known as the *triangle of meaning* or *semiotic triangle* (Figure 6-1), which actually tries to explain – in a simplified form – the way language works.

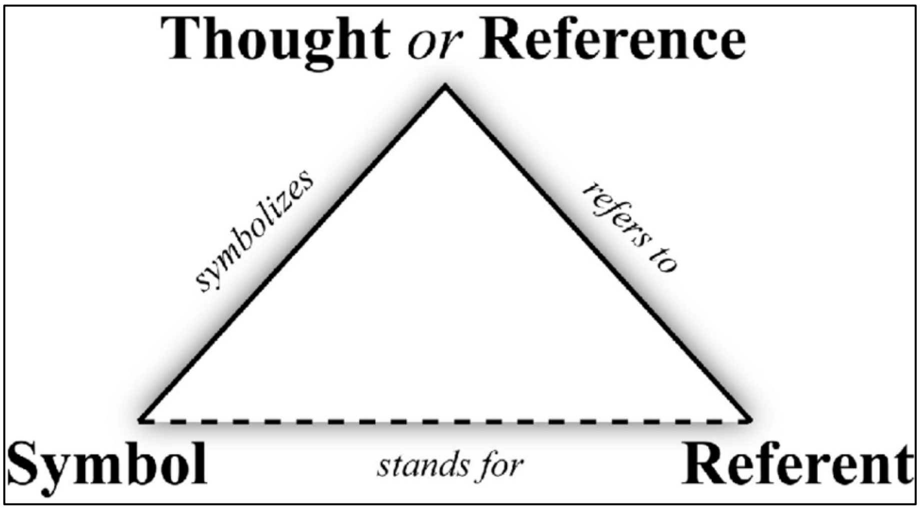

Figure 6-1: The Triangle of Reference (or the Triangle of Meaning or the Semiotic Triangle) (Source: Vogt, 2011)

According to Figure 6-1, the meaning-making process consists of three parts: (i) the *symbol* (*word*); (ii) the *concept* (*thought* or *reference*); and (iii) the *referent* (*object*); which form a triangular structure. The base of the triangle is occupied by the symbol that indicates the meaning and the real-world object (referent); whereas the meaning of the object (concept) is placed at the apex of the triangle. Moreover, the concept and the object are connected with a solid line, a fact that implies their direct relationship, while the same holds true for the relationship between the concept and the symbol. On the contrary, the linkage between the symbol and the object is illustrated by a dashed line, thereby insinuating an indirect relation. The last remark constitutes the main conclusion that emerges from the triangle of meaning, that is, the symbols do not refer directly to objects, but only indirectly through the concepts. The referent needs some *prior experience* and *reference* about the word or sign, in order for the latter to be comprehensive.

Although the triangle of reference is still being used as a model for semiotic relationships' representation, nonetheless, it exhibits some noteworthy flaws that limit its applicability. Most importantly, it focuses only on the relationships among objects, concepts, and symbols as these are captured in the mind of a single person, without taking into consideration any other possible variances (words bear different meaning to different people in different situations; a sign or word, which has its own meaning, is grasped with certain references to it; etc.) (Daw, 2022).

6.2. Semantics of Geographic Concepts

Semantics of geographic concepts or *geospatial semantics* is the scientific field that lies at the meeting point of three other sciences: Geographic Information Science (GIScience), computer science and knowledge engineering (Ballatore, 2016). It investigates and analyses how spatial data is made public, retrieved, reused, and integrated; how geospatial information is described through conceptual models; and how formal data structure specifications are developed to reduce incompatibility issues (Janowicz et al., 2013). Kuhn (2005, p. 5) suggests that "geospatial semantics is about understanding GIS contents and capturing this understanding in formal theories".

Additionally, geospatial semantics is characterized by a curious paradox, since it both limits and extends the original scope of semantics, as this is demarcated above. On one hand, it is dedicated to those concepts that have some geographic substance, rather than on any other more generic ones. On the other hand, it focuses on studies that are not only related to the meaning of linguistic expressions, but mainly to the meaning of geographic locations, geospatial data, and the geospatial Web. Moreover, it facilitates the design of GIS by enhancing distributed systems' interoperability and developing more intuitive user interfaces (Hu, 2017).

Semantics of geographic entities is an uncommon, obscure, and interesting case, as these entities exhibit specific peculiarities, such as (Kavouras & Kokla, 2008):

- *Complexity* and *difficulty* in their *analysis* and *formalization*, unlike everyday-life entities (organisms and artificial objects).
- They sometimes have *indeterminate / unclear boundaries* (Laurini, 2012; Laurini & Kazar, 2016). Besides being vague, boundaries can be *seasonal* or *gradual* (Ballatore, 2016). Streams are deemed to be the most typical example of a geographic entity with seasonal boundaries (many streams have water during the winter and dry up during the summer, loosing thus their boundaries). Additionally, deserts are a perfect example of geographic entities with gradual boundaries.
- They do not always fall into *explicit categories*. Very often, the question as to whether there are characteristic properties of entities that clearly and uniquely define them arises, thereby causing taxonomical issues (e.g., semantic confusion observed regarding the concepts of hills and mountains).

As an integral part of the Geographic Information Science (GIScience) (Mark et al., 2004; Agarwal, 2005), geospatial semantics places emphasis on the establishment and development of theoretical and practical means to address the *semantic heterogeneity* that stems from geographic concepts (Ballatore, 2016). However, as Janowicz et al. (2013) argue, geospatial semantics is not about imposing standards for assigning meaning to a concept but aims at preserving and managing the diversified definitions of different heterogeneous datasets through the development and use of high-precision / accurate *translation mechanisms*.

Semantics of geospatial concepts is a broad field that adopts innovative scientific perspectives, approaches, methodologies and techniques. Its applications are pertinent to six major research areas (Hu, 2017):

- Semantic interoperability and ontologies.
- Digital geographic dictionaries (digital gazetteers).
- Geographic information retrieval.

- Geospatial semantic Web and linked data.
- Place semantics.
- Cognitive geographic concepts and qualitative reasoning.

6.2.1. Sources of Taxonomic Diversity

The most critical factors that deeply affect the way individuals perceive different geospatial concepts, and, therefore, act as instigators of semantic heterogeneities, are (see also Figure 6-2) (Kavouras & Kokla, 2008):

- *Perspective / interest*: the needs and requirements of each application determine the concepts that should be used, as well as the relationships among them. Thus, different applications – hence the different needs / requirements – result in the creation of different classifications.
- *Disciplinary training*: disciplines develop a common understanding of the concepts they utilize (a common language). These concepts are deployed to describe specialized rather than general or common-sense knowledge, which – most of the times – is independent of languages, countries, and cultures.
- *Methodology*: determines how reality is structured / divided. Essentially, it refers to those parameters (general methodological approaches, methods, techniques, instruments, materials, procedures, etc.) used in the context of a research effort (Dimitropoulos, 2004). The most typical example is the one of defining land cover nomenclatures, based on the sources and the method of interpretation used (e.g., remote sensing).
- *Granularity*: the scale of analysis determines a classification's level of detail on one hand, but can also lead to the creation of completely different taxonomies (e.g., the categorization of land cover at a scale of 1:100,000 differs significantly from that at a scale of 1:5,000). As a general rule, large scales allow the representation of more categories compared to smaller ones (as the scale decreases, so does the number of thematic categories).
- *Ethno-/cultural-/socio-based view*: many geographic concepts are the figment of social conventions / agreements, causing thus significant differences – hence the different classifications – among countries, societies, and cultures.

- *Human cognitive diversity*: regards the difference in the perception of concepts at the personal level. People that work autonomously tend to conceive space differently, thereby creating their own cognitive classifications.

It should be mentioned that the above factors are *independent / uncorrelated*, and their combination can create significantly more convoluted taxonomic conflicts.

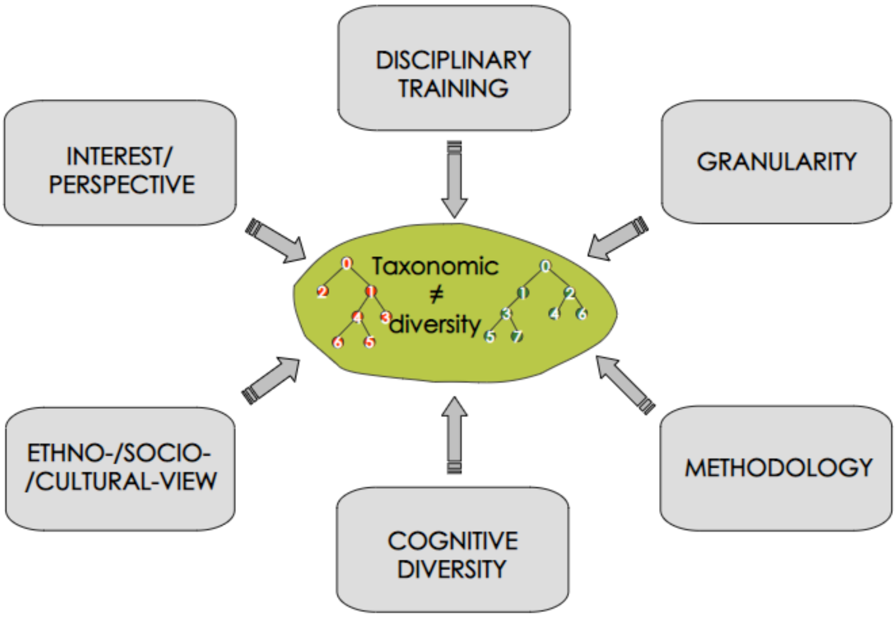

Figure 6-2: Sources of Taxonomic Diversity (Source: Adapted from Kavouras & Kokla, 2008)

6.2.2. Dimensions of Geographic Concepts

Any reference to geographic reality includes concepts that describe entities of the physical world (e.g., mountains, watercourses), as well as constructed / artificial geographic entities (bridges, buildings, transportation networks, etc.). At this point it is useful to analyse the framework of the main dimensions used to manage geographic concepts, which are organized into four main categories (see Figure 6-3) (Kavouras & Kokla, 2008): *reference – container*, *semantics*, *semiotics / pragmatics*, and *quality*.

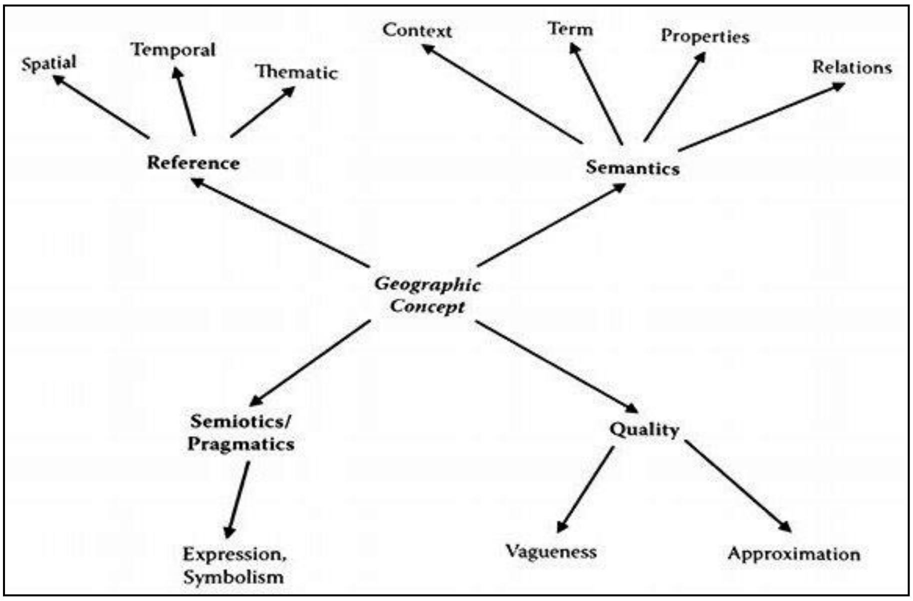

Figure 6-3: Dimensions of Geographic Concepts (Source: Kavouras & Kokla, 2008)

More specifically:

- Reference – container
  - *Spatial frame*: a reference system for determining the location of geospatial entities, properties, and relations.
  - *Temporal frame*: temporal reference system for describing temporal properties and relationships.
  - *Thematic frame*: thematic reference system, where thematic properties and relations are projected.
- Semantics
  - *Context*: the "perspective, framework or situation, in which concepts are formed, and information is interpreted, obtains meaning, and becomes relevant" (Kavouras & Kokla, 2008, p. 8).
  - *Term*: the name of the concept, which is considered to be an essential part of its identity.
  - *Semantic properties (internal properties)*: internal properties of geospatial concepts are independent of other concepts and may be *spatial* (shape, location, structure, area, etc.) or *aspatial* (purpose, material, time, periodicity, etc.) (Figure 6-4).
  - *Semantic relations (external relations)*: the relations of geospatial concepts with other concepts may be *spatial* (e.g., relative position, distance,

orientation, proximity, adjacency) or *aspatial* [hierarchical (IS-A), part-whole (PART-OF), dependency, correlation, role, etc.] (Figure 6-5).

- Semiotics / pragmatics
  - *Expression – symbolism*: geographic concepts are associated with signs (images, words, symbols) that express their meaning.
- Quality
  - *Vagueness*: regards the degree of imprecision and uncertainty of geospatial concepts, properties, or relations among them (spatial or otherwise).
  - *Approximation*: refers to the granularity of the: (i) *conceptualization* (i.e., how the geographic world is perceived from different 'distances'); (ii) *representation* of spatial and thematic properties at different levels of detail; and (iii) *visualization* (i.e., the symbolization and portrayal) of detail.

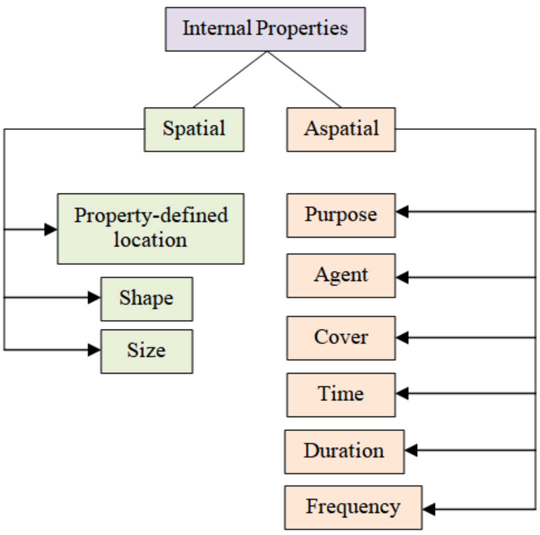

Figure 6-4: Indicative Internal Properties (Source: Panagiotopoulou, 2018)

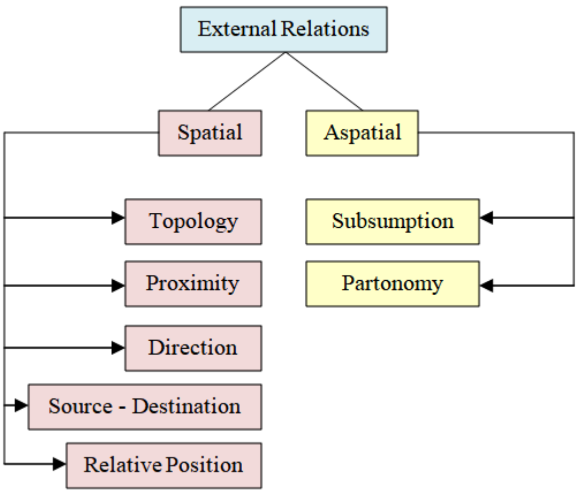

Figure 6-5: Indicative External Relations (Source: Panagiotopoulou, 2018)

6.3. Semantic Barriers

The recent extensive reference to semantics is deemed to be the consequence of the tremendous upsurge in the access and use of geospatial data and information. Today, "both data and methods may be retrieved and combined in an ad hoc way from anywhere in the world, escaping their local contexts" (Kuhn, 2005, p. 1). Moreover, a particularly urgent need for:

- exempting users from the process of data collection, which is characterized by high degree of complexity and increased requirements for resources (financial resources and time),
- using existing data – leveraging the growing trend towards making spatial data available; and
- integrating spatial data that are generated independently by different actors,

has arisen.

Based on the above, several critical and interconnected problems emerge, regarding the production, communication, dissemination, sharing, reuse, and correlation of spatial data generated from heterogeneous sources. The following sections briefly delineate the most significant ones (Kavouras & Kokla, 2008).

6.3.1. Barriers Inherent in Categories

Synonymy

Synonymy is related to the state in which different terms are used to describe the same categories (words that bear similar meanings). For instance, a category that refers to a large geological mound of the earth's natural surface is called 'mountain' in one case and 'alp' in another. Therefore, it is concluded that although these two categories have the exact same meaning, they are assigned different names (mountain and alp).

Polysemy

Polysemy constitutes an important aspect of *semantic ambiguity* that concerns the *multiplicity* of a concept's meanings (Figure 6-6). In other words, it regards the different definitions that are attributed to homonymous categories (i.e., different understandings of homonymous concepts). For example, more than 1.600 definitions of the term 'forest' are met in the international literature (Lund, 2018). The 'smart city' term also suffers from polysemy issues, with more than 116 relevant definitions having been introduced by various researchers, industries, NGOs, standardization organizations, etc., until now (International Telecommunication Union [ITU], 2014a).

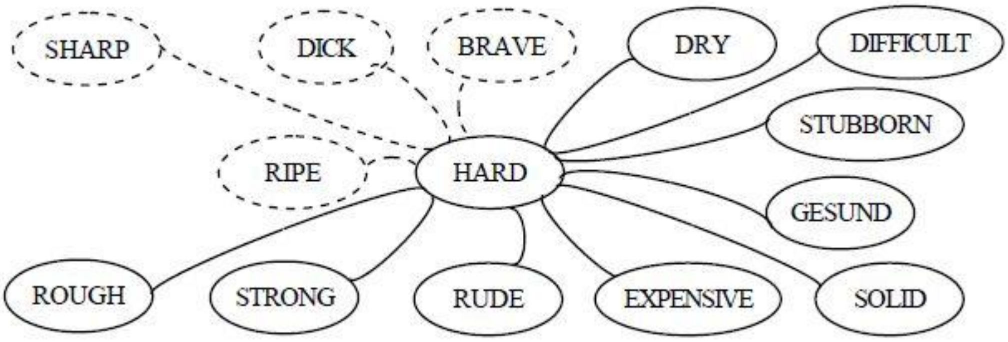

Figure 6-6: Polysemy Case – Multiple Meanings of the Word ‘Hard’ (Source: Perrin, 2010)

6.3.2. Barriers Inherent in the Relations between Categories

When it comes to classes / categories, two particularly important obstacles – concerning their in-between relations – may appear. The first one is pertinent to the fact that same categories correspond to different super classes (Figure 6-7); whereas the second relates to the mixing / co-existence of hierarchical (IS-A) and meronymic relations (HAS-PART, PART-OF) in the same hierarchical structure (Figure 6-8).

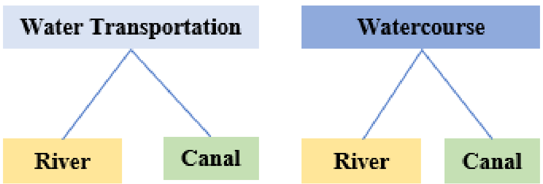

Figure 6-7: Same Classes Fall Under Different Super-Classes (Source: Adapted from Panagiotopoulou, 2018)

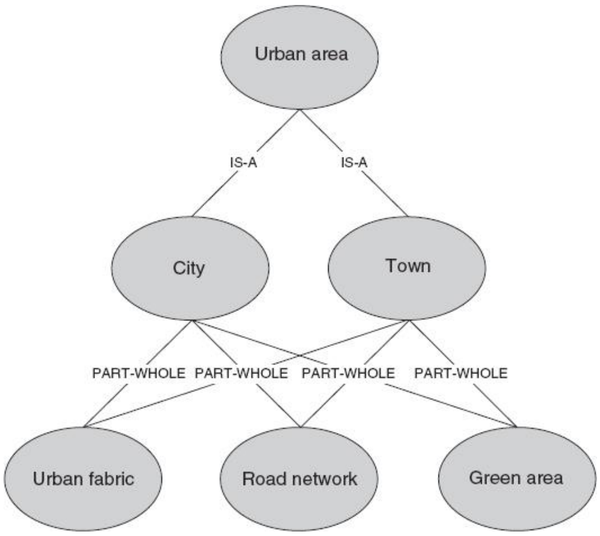

Figure 6-8: Mixing of Hierarchical and Meronymic Relations (Source: Kavouras & Kokla, 2011)

6.3.3. Heterogeneous Hierarchies

The problem of dealing with different hierarchical structures that represent the same category, due to a diversified degree of detail observed in some branches of their tree structure (see Figure 6-9), constitutes a relatively common phenomenon. Simply put, heterogeneous hierarchies refer to the state in which the division of a category into sub-categories, their subsequent breakdown into more specialized ones and so on, can considerably vary from one case to another.

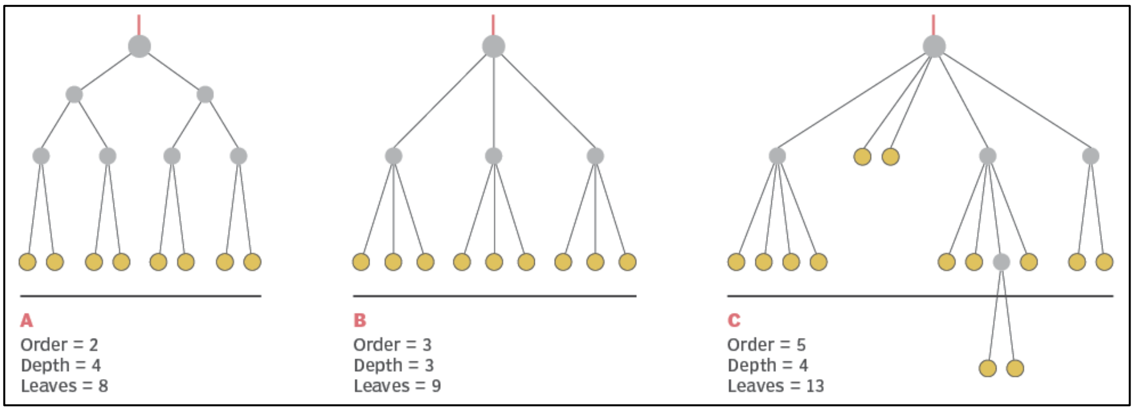

Figure 6-9: Case of Heterogeneous Hierarchies (Source: Awati & Wigmore, 2022)

6.3.4. Instance-Related Issues

As respects the instances of an ontology, the following problems may occur:

- common instances among two or more databases are classified under different categories (e.g., an instance is falling under the 'College' category in database A, but under the 'University' category in database B – Figure 6-10); and
- common instances among two or more databases are classified under categories with different degree of generality (e.g., an instance is falling under the 'Green Area' category in database A, but under the 'Urban Green Area' category in database B, which constitutes a more specialized class compared to the one of 'Green Area' Figure 6-11).

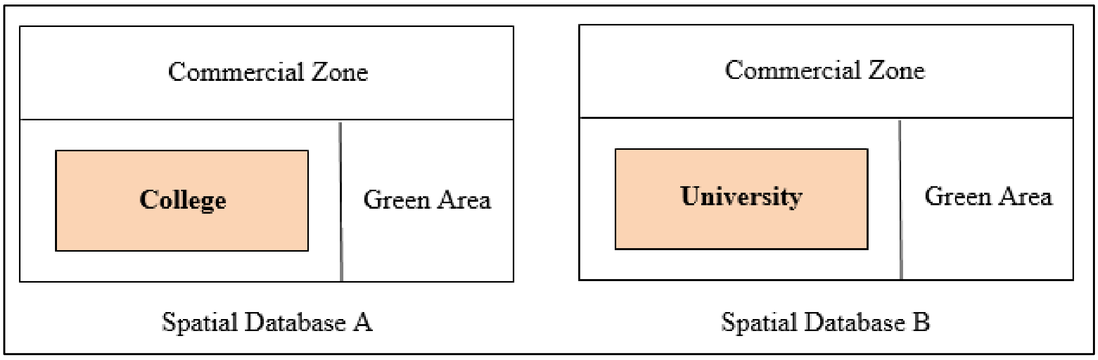

Figure 6-10: Common Instances Under Different Categories (Source: Adapted from Panagiotopoulou, 2018)

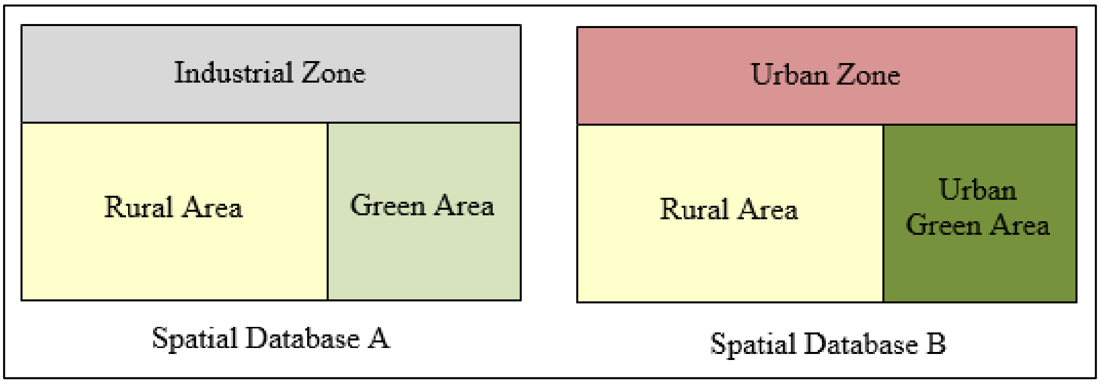

Figure 6-11: Common Instances Under Categories with Diverse Degree of Generality (Source: Adapted from Panagiotopoulou, 2018)

6.4. Semantics and Ontologies

A concept may potentially represent all things (real or abstract) that exist or are likely to exist. *Ontology engineering* – a fundamental branch of geospatial semantics – focuses on ontology development in order to support / enhance the conceptual modelling of geographic space (Kuhn, 2009). In this way, any semantic comparison, correlation, or integration of different cognitive domains necessitates the possibility of unifying their respective ontologies (Kavouras & Kokla, 2008).

Compared to the Philosophical realm, where ontologies explore the structure of reality and existence in the context of knowledge representation, ontology aims at limiting the use of terms in the data, moving thus towards the elimination of *semantic heterogeneities* and the restoration of *semantic interoperability* (Ballatore, 2016).

In recent years, a surge of attention has been witnessed in the fields of ontologies and semantics, with almost every discipline trying to embed them in its research agenda. The relevant literature is vast and pretty rich, and a plethora of ontological representations with disparate levels of formality (informal, semi-formal, formal) and\or generality (top-level, domain, application, task), different scope and domain of interest, etc., have been developed. Despite the fact that the adoption of semantics and ontologies has been significantly broadened, the proliferation of diverse integration paths has posed considerable challenges. The dearth of commonly shared standardized approaches and methodologies has made it difficult to correlate different integration efforts. Each discipline often develops its own specialized ontologies and semantic models, rendering the alignment or merging of these resources across domains particularly tough. Therefore, it becomes crystal clear that the tricky challenge of integrating heterogeneous information brings to the surface the even more labyrinthine issue of correlating diverse integration approaches (Kavouras & Kokla, 2008).

Despite any skepticism and doubts regarding ontologies as well as the controversial views on their utilization or relevance, a great deal of progress has been marked in the field of *knowledge representation* and *information integration*, as far as the adoption of ontological approaches is concerned. Ontologies, depending on the way they are perceived and used, provide an important *semantic tool* for various applications, such as: formal data representations; ontological alignment, merging and integration; knowledge discovery and learning; data mining; intelligent reasoning; similarity comparisons; and so on.

Regardless of all the progress made in the area of ontology and information science research, a great deal of confusion on several issues is still evident. The most critical one appertains to the diversified meanings of numerous ontological concepts, as these are defined / shaped by various disciplines. Terms such as concepts, categories, classes, semantics, attributes, properties, relations, merging / integration, etc., are used differently in many cases. This differentiation usually stems from the prevalence of two fundamental, generic perspectives, which are (Figure 6-12) (Kavouras & Kokla, 2008):

- The *'higher' ontological perspective* that seeks the appropriate representation of knowledge about reality. Issues such as concepts, meaning, semantics and representation form the core of this approach, as they are related to domain and conceptualization differences. Semantic conflicts, owing to different conceptualizations and models, are treated at this level.

- The *'lower' design / implementation perspective*, which focuses on the formalization, processing, and correlation of existing data or information. Issues pertinent to databases, attributes, structural, schematic, and syntactic matters are considered to be very critical, as they are associated with explication differences. Conflicts in the conceptualization's specification (e.g., encoding differences or representation language mismatches) as well as terminological conflicts can be resolved at the explication level, but they often carry some semantic weight.

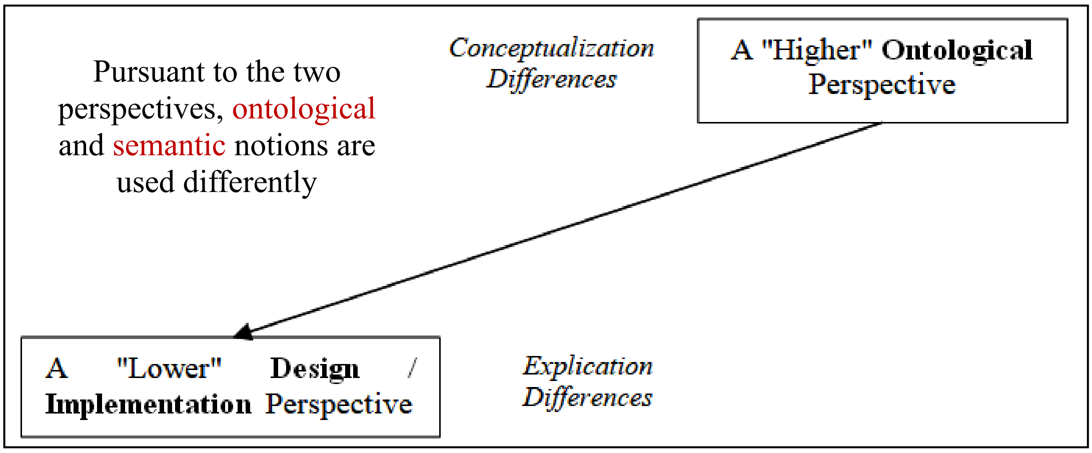

Figure 6-12: Higher Ontological and Lower Design / Implementation Perspectives (Source: Adapted from Kavouras & Kokla, 2008)

6.5. Ontologies

Considering that the present Thesis focuses – inter alia – on the development of an ontology for smart, sustainable, resilient, and inclusive cities, this section attempts to outline ontology's multifaceted character, with particular emphasis on its geospatial aspect (geographic ontologies). More precisely, it analyses in detail their usefulness and their various fields of application; their structural components; the different ontological types according to specific criteria; the main steps of ontology design and development; and the process of ontology alignment, merging and integration.

6.5.1. Definition of Ontology

A profusion of definitions, that endeavor to describe the nature of ontologies and attach some sort of meaning to them, are detected in the international literature. In general lines, this term can be conceived in the light of two completely different and distinct scientific streams – Philosophy and Computer Science – that exhibit fundamental disparities in the way they address ontologies' meaning and purpose. Traditionally, ontology has been defined as the philosophical study of existence (what actually exists), but in recent years, it has been used in the context of any application that requires knowledge representation and management (Gruber, 1993; Akkermans et al., 2004; Kosman, 2013).

Ontology has its roots in *Philosophy* and refers to the systematic explanation of *'the being'*, which describes elements / characteristics of reality (Solodovnik, 2011). According to the Merriam-Webster dictionary (n.d.-a), ontology is: (i) a branch of Metaphysics that studies the very essence of beings and the relationships among them (it deals with abstract entities); and (ii) a theory that focuses on the nature of being or kinds of things that exist. Sommers (1963) argues that ontology is the science of categories (it investigates the categories of entities), since it tries to provide answers to questions such as which categories do exist, how these are defined, how they are related to each other, and so on.

Ontology has entered the *Computer Science* arena relatively recently, since the development of information systems and the Internet has made it imperative that conceptual differences are addressed, so as to enable information exchange and reuse. Pursuant to Computer Science, an ontology is a formal and explicit description of the knowledge of a particular domain (modelling of a domain through a set of concepts, relations among them and properties). This formal representation of knowledge is pretty useful for drawing inferences (reasoning) and generating new knowledge, while it can be also shared and reused by everyone.

In 1991, Neches et al. are the first to introduce ontologies to the area of Artificial Intelligence (AI) by suggesting that "an ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary" (Neches et al., 1991, p. 40). Therefore, an ontology does not only include the terms that should be clearly defined, but also the extracted knowledge, which is based on the ontology's inherent rules.

The most widespread, perhaps, definition of ontology is established by Gruber in 1993, who states that "an ontology is an explicit specification of a conceptualization" (Gruber, 1993, p. 199). *Conceptualization* refers to an abstract and simplified capture of the world that someone wishes to model, which – according to the above definition – should be represented in a form that renders it both machine-readable and machine-processable. The term *explicit* insinuates that the concepts used, as well as the constraints imposed on their utilization, are clearly defined.

Later, in 1997, Borst slightly modifies Gruber's definition by claiming that "an ontology is a formal specification of a shared conceptualization" (Borst, 1997, p. 12). In this particular case, the term *'shared'* refers to the fact that an ontology ought to reflect knowledge of common acceptance within a community, i.e., it must be the result of consensus rather than personal opinion and it should be machine-processable (Guarino et al., 2009). In 1998, Studer et al., combine the aforementioned definitions and end up with a synthesized one that perceives ontology as "a formal, explicit specification of a shared conceptualization" (Studer et al., 1998, p. 184).

A more recent definition of ontology, also by Gruber (2009), stresses that – in the context of Computer and Information Science – an ontology defines a set of *representational primitives* that are used to model a domain of knowledge or interest. Representational primitives may be classes, properties, and relationships between members of classes. Definitions of representational primitives include information about their meaning, as well as constraints (i.e., axioms, constraints, rules) that ensure their consistent use (e.g., narrowing down their possible interpretations).

Despite the plethora of definitions having being introduced by several researchers and experts, Guarino's (1998b) interpretation is also widely used and suggests that:

> An ontology is a logical theory accounting for the *intended meaning* of a formal vocabulary, i.e., its *ontological commitment* to a particular *conceptualization* of the world. The intended models of a logical language using such a vocabulary are constrained by its ontological commitment. An ontology indirectly reflects this commitment (and the underlying conceptualization) by approximating these intended models. (Guarino, 1998b, p. 5)

In conclusion, ontologies define a common vocabulary among people with mutual interests. It allows sharing of pieces of information that are relevant to a particular domain of knowledge and includes definitions (which can be understood and processed by computer programs) of key concepts (of the domain of knowledge) and their relations.

At this point it should be highlighted that ontologies should not be confused with *databases* and *database systems* in general and *conceptual data models* in particular, such as the Enhanced Entity-Relationship model (EER) or the Unified Modeling Language (UML) model, despite the fact that they all represent knowledge of a certain domain (Dillon et al., 2008; Horrocks, 2013) and they can be queried and updated (Horrocks, 2013). The most substantial differences between ontologies and conceptual data models are (Spyns et al., 2002):

- Conceptual data models focus on representing data that are used in a particular application, without taking into any consideration the way this application will be implemented. They are designed to meet specific needs (those of the application) and therefore are inextricably dependent on the task they are meant to accomplish. The users, the goal / purpose, the objectives, and the intended use are important factors that strongly determine the modelling process, but also the level of detail. Conversely, ontologies aim at providing a conceptual representation of a specific domain, regardless of the application, and thus, they are as generic as possible.
- They differ in the *scope* and *kind* of knowledge they cover. Data models focus on relating data organization to the concepts for which that data is entered into a database; whereas ontologies focus on rendering knowledge graspable and therefore, they constitute more complete representations of concepts and their in-between relations.
- Ontologies possess greater *expressive power* as ontology languages are able to express some kinds of meaningful constraints, such as taxonomy or inferencing and contribute to more efficient and accurate knowledge representation.
- They operate at *different levels of detail*. Ontologies are general and operate at a higher level of abstraction; while data models operate at a lower level of abstraction.
- Ontologies, unlike databases, make *open world assumptions* (Horrocks, 2013), meaning that they assume that what is not known to be true (missing information) is just considered unknown. The opposite holds true in the case of *closed world assumption* – adopted by databases – where everything that is not known to be true is treated as false.

6.5.2. Geographic Ontologies

Geographic, *geospatial ontologies* or *geo-ontologies* are *domain ontologies* that integrate both the approaches of Philosophy and Informatics and aim at systematizing the knowledge of geographic space, entities, phenomena, processes, as well as their interrelationships (Kavouras & Kokla, 2008; Laurini, 2012, 2015; Laurini & Kazar, 2016). Moreover, they contribute to (Kavouras & Kokla, 2008):

- Comprehension of the discrepancies observed between the perception and definition of geographic entities.
- More efficient semantic description and representation of geographic space.
- More efficacious sharing of geographic information (development and extension of spatial data transfer standards).
- Re-use of knowledge.

According to Laurini and Kazar (2016), geographic ontologies may be conceived as a kind of semantic network (Quillian, 1967; Lehmann, 1992) for the representation of the real world. These networks refer to *graphs* that link concepts via relations such as IS-A, HAS-PART, HAS_TYPE, etc. The fundamental purpose of geographic ontologies, however, besides describing geographic entities and their semantic relations, mainly focuses on defining their *spatial relations*.

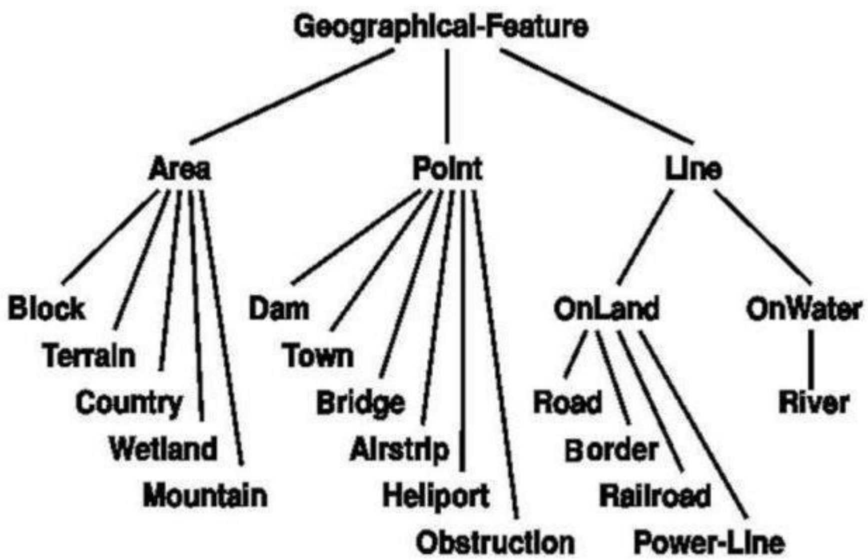

Figure 6-13: Classification of Geographic Entities Based on Geometric Types (Source: Sowa, 2009)

In the past, the classification of geographic entities within an ontology was implemented through the establishment of conventional relationships (e.g., IS-A) among them (see Figure 6-13 and Figure 6-14). Nonetheless, it was rapidly realized that although such an approach can significantly contribute to the semantic organization of geographic concepts, it completely defies their spatial dimension, a fact that necessitates the introduction of more efficient ways of representing space.

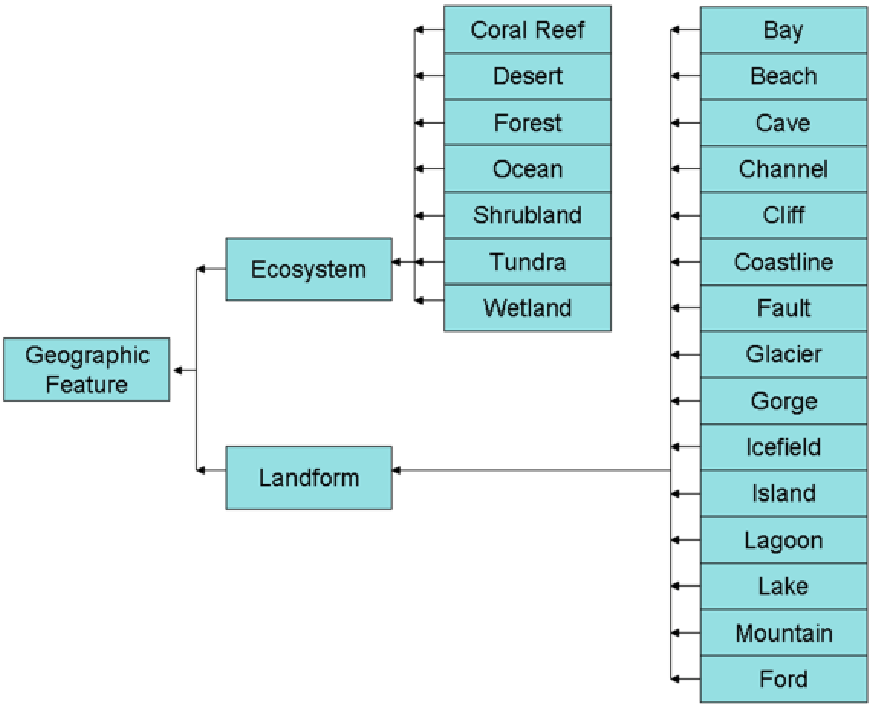

Figure 6-14: Classification of Geographic Entities Based on their Hierarchical Relations (Source: Laurini, 2015; Laurini & Kazar, 2016)

In an effort to achieve better and more complete spatial representation, spatial relationships have been incorporated into geographic ontologies, with the most significant and popular of them being the *topological* (Allen, 1983; Egenhofer & Franzosa, 1991; Randell et al., 1992; Egenhofer, 1994) (Figure 6-15).

It is worth noting that even though topological relations are the most widespread, other spatial and geographic relationships (direction, relative position, proximity, distance, etc.) should be also considered (Laurini, 2012; Laurini & Kazar, 2016; etc.).

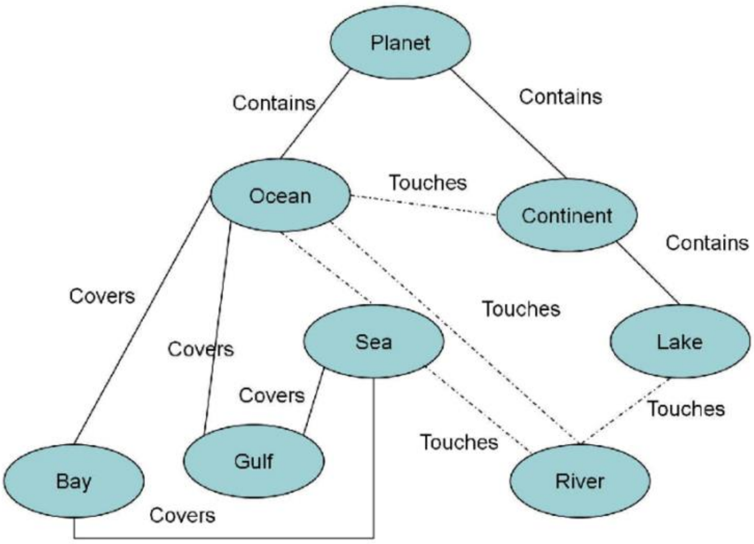

Figure 6-15: Classification of Geographic Entities Based on Topological Relations (Source: Laurini, 2015; Laurini & Kazar, 2016)

6.5.3. Usefulness of Ontologies

In general lines, the development and wide use of ontologies stem from the need to facilitate communication among people, organizations, and computers, with the ultimate goal of sharing and reusing knowledge.

According to Noy and McGuinness (2001), ontologies:

- Conduce to the mutual understanding of the structure of information exchanged among people or agents (Musen, 1992; Gruber, 1993), which is – perhaps – the main reason behind ontology building.
- Promote the reuse of knowledge of a particular area of interest.
- Make explicit assumptions about a certain domain – they assist in unravelling hidden / implicit assumptions.
- Separate domain knowledge from operational knowledge for problem solving.
- Help to analyse domain knowledge.

Furthermore, Uschold and Gruninger (1996), point out that ontologies:

- Facilitate mutual understanding and communication among people with different needs and views, coming from different backgrounds.
- Enable interoperability among systems that use different software tools.

- Bring benefits for system engineering in terms of *resource reuse (re-usability)*, *reliability*, and *specification*.

Finally, ontologies contribute to a more efficacious and cost-effective database design, since their main objective is, inter alia, data categorization (Tomai, 2005).

6.5.4. Ontology Applications

Ontologies are widely used in many scientific fields, such as (Sure, 2003):

- Natural language processing and machine translation.
- Knowledge engineering.
- Knowledge management.
- Engineering principles.
- E-commerce.
- Information retrieval, sharing, integration, and extraction.
- Internet catalogues.
- Intelligent search engines.
- Digital libraries.
- Improved user interfaces.
- Software agents.
- Business process modelling.
- Conceptual database design.
- Intelligent information retrieval – Semantic Web.

Furthermore, Gruber (2009) states that ontologies can play an important role in the field of databases by contributing to their interoperability, to Web search and to the integration of Web services. In addition, ontologies are widely used on the World Wide Web (WWW), both as a semantic interoperability framework among different Web applications and services, and as a framework for organizing online content (for more details on ontologies and the WWW, see chapter 3 "The Technological Evolution and Its Contribution to the Smart, Sustainable, Resilient and Inclusive Urban Development – The Participatory Spatial Planning Scope", section 3.6.3. "Web-Based Technologies", sub-section "Semantic Web").

6.5.5. Ontology Components

Knowledge standardization, through the deployment of ontologies, is achieved by utilizing their fundamental components, which are (Gruber, 1993; Gómez-Pérez & Benjamins, 1999; Noy & McGuinness, 2001; Sure, 2003; Gruber, 2009; etc.) (Figure 6-16):

- *Classes* constitute the core of most ontologies. They refer to sets / collections of objects or entities and are represented by *concepts*. There are two types of concepts (Stevens et al., 2000): i) *primitive concepts*, which only satisfy necessary prerequisites in order to be a member of a class; and ii) *defined concepts*, whose description is both a necessary and sufficient condition for being categorized under a class.
- *Properties* attribute characteristic features to classes.
- *Relations* express a kind of interaction / interrelationship between concepts of a domain of interest (e.g., IS-A, PART-OF).
- *Functions* refer to a special case of relation, according to which its n^{th} element is uniquely identified by the n-1 previous ones. In general lines, functions represent complex structures deriving from certain relationships that can replace an individual term in a statement.
- *Axioms* represent statements that are always true and help to confine the interpretation of concepts incorporated in an ontology. In a nutshell, axioms "specify constraints or rules about the values of properties, relations, properties of relations, and instances" (Kavouras & Kokla, 2008, p. 29).
- *Constraints* are typical descriptions of what should be true, in order for an instance to belong to a class.
- *Rules* are statements in the form of IF-THEN (assumption-conclusion) sentences, which outline the logical inferences that can be drawn on the basis of certain assumptions.
- *Instances* represent specific objects / entities of a class. For example, New York is an instance of the concept 'city'.

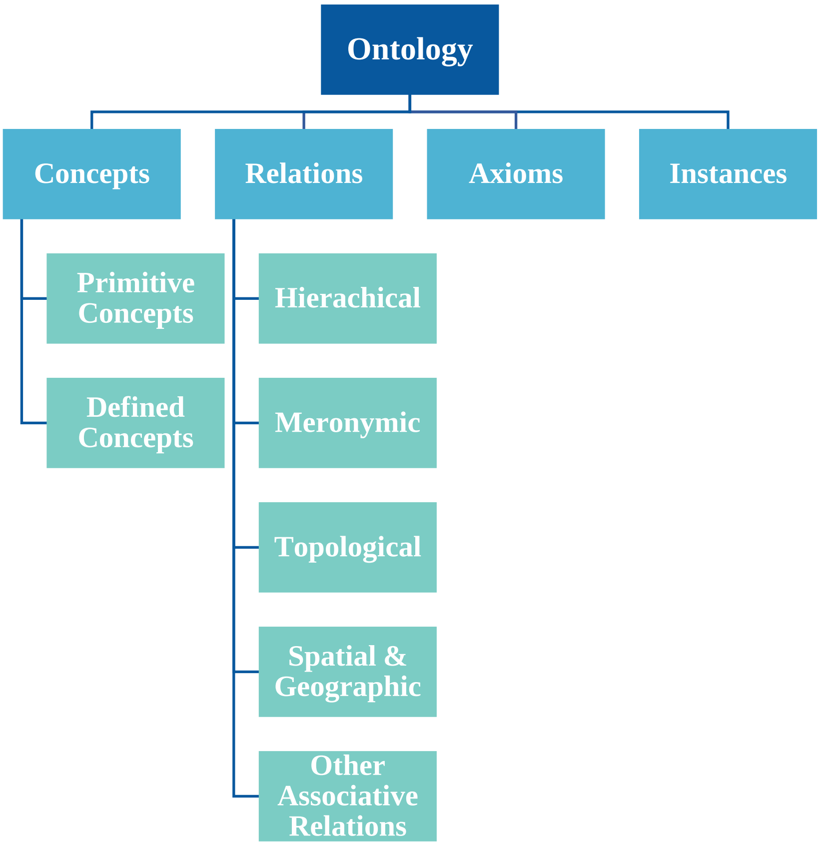

Figure 6-16: Key Components of an Ontology (Source: Own Elaboration)

The fundamental components of a pretty simplified ontology are illustrated in Figure 6-17. More specifically, the terms ‘Place’, ‘City’ and ‘Country’ constitute the ontology concepts and are linked to each other through various relations. ‘City’ and ‘Country’ concepts are connected with the ‘Place’ concept via hierarchical (IS-A) relations (i.e., City IS-A Place and Country IS-A Place), whereas ‘City’ and ‘Country’ concepts are associated through the ‘isLocatedIn’ relation (City isLocatedIn Country). Additionally, the ‘Place’ concept is described by the ‘name’ property, while ‘City’ and ‘Country’ are defined by the ‘name’ and ‘population’ properties.

Generally, ontologies may consist of four key components: *concepts*, *relations*, *axioms*, and *instances* (Figure 6-17). As far as geographic ontologies are concerned, the least that is expected to be incorporated into them is a set of *concepts* expressed as a vocabulary of the *terms* used, a description of the terms’ meaning (through definitions), their *properties* and the *relations* among concepts or concepts’ properties. There are also cases (quite scarce nowadays) where concepts are described only by terms (total absence of definitions) whose meaning can be inferred indirectly by using common sense, expert knowledge or available structural knowledge of the concepts involved (e.g., a hierarchy) (Kavouras & Kokla, 2008).

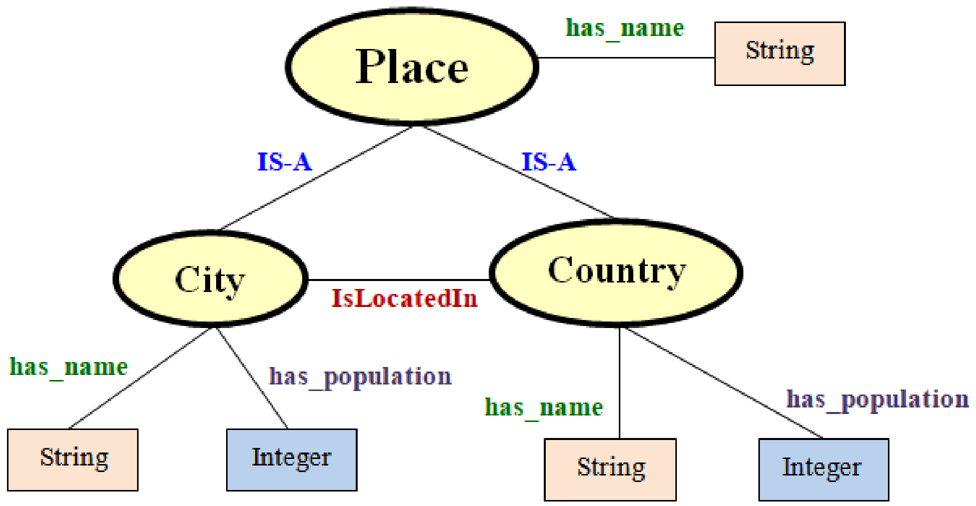

Figure 6-17: Main Components of an Oversimplified Ontology (Source: Panagiotopoulou, 2018; Panagiotopoulou et al., 2019)

Hierarchical (IS-A) relations

Hierarchical structures are implemented through the establishment of IS-A relations that form the ontology's backbone. Their wise and rational use constitutes a critical parameter for the success of the *ontology development process* (Mizoguchi, 2004). As Guarino (1998a) points out, there are several cases of inappropriate use of IS-A relations in existing ontologies, due to the dearth of a deeper understanding of the specific relation.

IS-A hierarchies are based on properties shared by similar concepts. *Generic concepts* (super-concepts or super-classes) are characterized by fewer properties; while *more specialized* concepts (sub-concepts or sub-classes) inherit the properties of the super-concepts under which they are classified, but they also have additional properties that differentiate them.

Occasionally, critical problems – pertinent to hierarchical relations – such as sub-concepts with no distinguishing characteristics or sub-concepts that sometimes do not inherit all the properties of their super-concepts, are identified.

Meronymic (PART-OF) relations

Meronymic (PART-OF, PART-WHOLE, etc.) relations are very often detected in ontologies. Knowing the parts of which a concept is composed enhances its better understanding / perception as a whole. Mixing hierarchical (IS-A) with meronymic relations in a semantic structure is theoretically feasible, but must be implemented with great caution, since it can cause severe confusion (see also Section 6.3.2. "Barriers

Inherent in the Relations Between Categories”). This is mainly due to the fact that, in contrast to hierarchical (IS-A) relations, the inheritance of properties does not apply in meronymic relations, i.e., parts do not necessarily inherit the properties of the whole.

Multiple inheritance

The hierarchical (IS-A) structure adopted by most geographic ontologies is a tree structure, which means that it is characterized by the principle of *single inheritance*. According to the fundamentals of single inheritance, each class can be a sub-class of one and only one class. Simply put, each child node (sub-concept) has only one parent node (belongs to only one super-concept). Thus, single inheritance represents a particular view of reality where “everything which holds of a parent term holds also of (is inherited by) all descendant terms at lower levels” (Rudnicki et al., 2016, p. 11).

There are cases, however, where adherence to single inheritance is not enough and it is necessary to represent additional views of reality in which a child node has more than one parent node. Such *multiple inheritance* hierarchies are sometimes unavoidable when two different trees are merged and both views of reality need to be preserved for some reason (Figure 6-18) (Kavouras & Kokla, 2008).

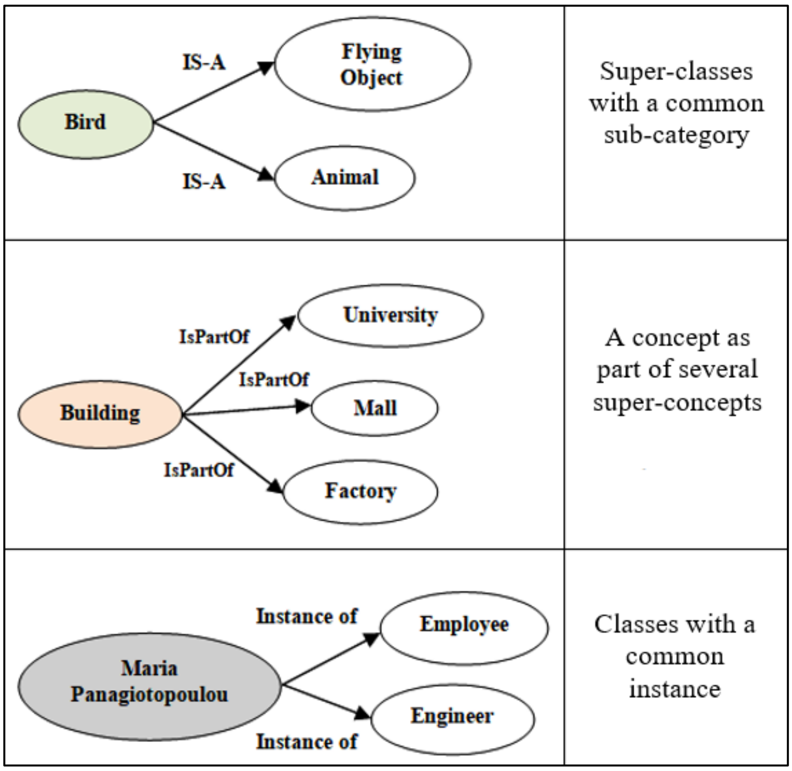

Figure 6-18: Typical Cases of Multiple Inheritance (Source: Adapted from Panagiotopoulou, 2018)

Figure 6-18 illustrates three ordinary cases of multiple inheritance. More specifically, a concept can be a common sub-category of two different super-categories (e.g., the 'Bird' concept may belong to the 'Flying Object' and 'Animal' categories). Multiple inheritance is a common phenomenon in meronymic relations, where the same concept can be part of several other super-concepts (e.g., the 'Building' concept can be part of the 'University', 'Mall', and 'Factory' super-concepts). A third case of multiple inheritance is observed when an instance is falling under more than one class (e.g., 'Maria Panagiotopoulou' can be an instance of the 'Employee' and 'Engineer' classes).

6.5.6. Types of Ontologies

Bibliographic review unveils ample, diversified ontology classifications, on the basis of various criteria (Lassila & McGuinness, 2001; Gomez-Perez et al., 2004; Borgo, 2007; etc.). However, *formality* and *generality* seem to be the most important ones (Figure 6-19).

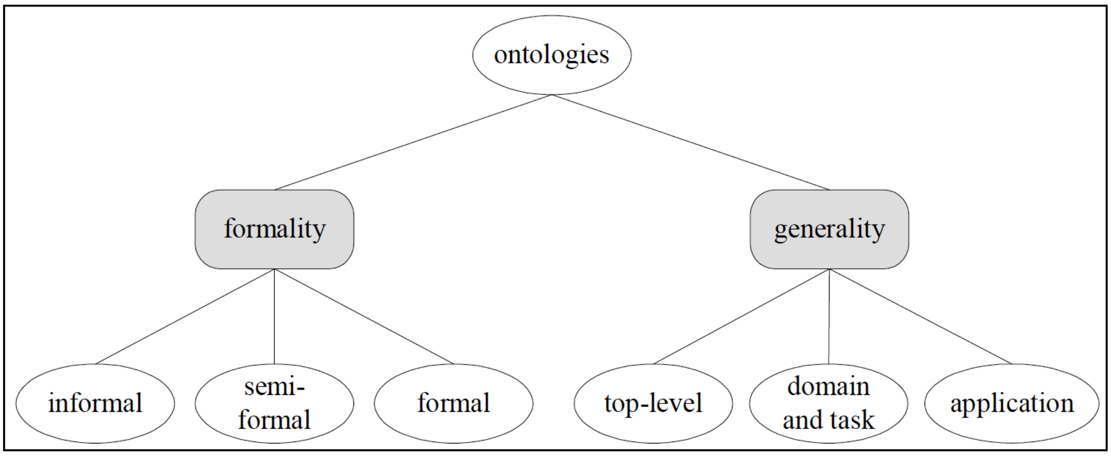

Figure 6-19: Ontology Classification according to the Criteria of Formality and Generality (Source: Kavouras & Kokla, 2008)

Gruber (2003, 2004) proposes an ontology categorization, founded on the criterion of formality. Thus, ontologies are classified into:

- *Informal*: meaning is expressed in natural language.
- *Semi-formal*: meaning is expressed via some artificial formal language.

- *Very formal*: meaning is expressed by the use of formal language with structured semantics, theorems, and proofs.

However, this distinction is ambiguous, since very often ontologies incorporate both formal and informal parts. Formal parts (e.g., axioms) support automated processing and analysis; while informal parts (e.g., definitions) enhance and boost human understanding (Gruber 2003, 2004).

Semi-formal ontologies – the most widespread type of ontologies – include a few formal and a plethora of informal parts (Gruber, 2004); and are especially useful in cases where: (i) many people manage a particular ontology; or (ii) information should be extracted from different sources and integrated afterwards. This is because they exhibit a greater degree of flexibility and adaptability to real-world applications as they have the capacity to encompass incomplete / partial information (Sheth & Ramakrishnan, 2003).

Guarino (1998b), classifies ontologies according to the level of their *generality* into (Figure 6-20):

- *Top-level ontologies*: define fundamental and general concepts, such as space, time, entity, object, property, relation, quality, process, identity, etc., which are independent of a given scope or problem. In addition, these ontologies shape the frame of reference for the definition of more specific concepts.
- *Domain and task ontologies*: provide the vocabulary of a domain or a general task and specialize the concepts defined by the top-level ontology.
- *Application ontologies*: define concepts that depend on a specific domain and task and serve as a specialized form of the domain and task ontologies.

Van Heijst et al. (1997) categorize ontologies on the basis of *two dimensions*, namely the *amount and type of structure of a conceptual representation*; and the *subject of the conceptual representation*. Regarding the first dimension, three types of ontologies emerge:

- *Terminological ontologies*: define the terms used to represent the knowledge of a particular domain (e.g., dictionary).
- *Information ontologies*: define the structure of a database (e.g., database schemata).
- *Knowledge modelling ontologies*: define the conceptual representation of knowledge, usually focusing on a specific use of the knowledge. Unlike

information ontologies, knowledge modelling ontologies have a richer internal structure.

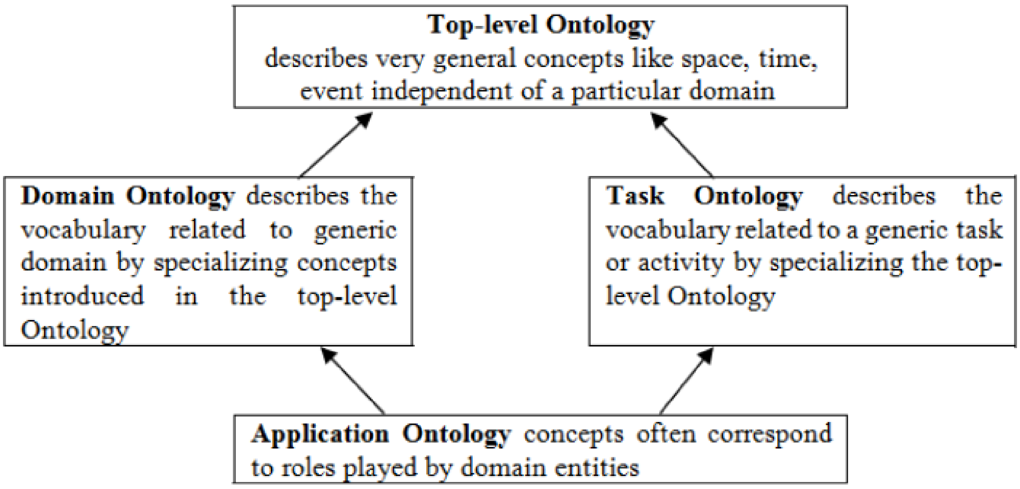

Figure 6-20: Ontology Distinction according to the Criterion of Generality – Arrows Represent Specialization Relationships (Source: Solodovnik, 2011)

As respects the second dimension (subject of the conceptual representation), four types of ontologies are identified (Van Heijst et al., 1997):

- *Generic ontologies*: define general concepts, such as entity, property, relations, processes, etc., which are independent of the scope.
- *Domain ontologies*: describe concepts that refer to a specific domain. Very often, the concepts described by domain ontologies are specializations of those defined by generic ontologies.
- *Application ontologies*: define the concepts that are necessary to describe a specific application.
- *Representation ontologies*: interpret the conceptual representations that underlie the formalisms of knowledge representation and remain neutral with respect to real-world entities. They provide the basic principles adopted by generic and domain ontologies for describing reality, without making any assertions about it.

Another distinction of ontologies is based on the criterion of *complexity*. The complexity of an ontology ranges from simple concept classifications to highly convoluted classifications that include constraints related to concepts and the relationships between them (Slimani, 2014). Two types of ontologies are distinguished according to the degree of complexity they exhibit (Mizoguchi, 2003; Slimani, 2014):

- *Light-weight ontologies*: usually characterized as more hierarchical and designed to represent hierarchical relationships or other simple relationships between concepts. In general terms, such ontologies do not contain many or particularly complex relationships.
- *Heavy-weight ontologies*: designed with particular attention to the strict clarification of concepts and their in-between relationships (completeness constraints, classification of relationships, axioms, constraints, etc.). Top-level ontologies are typical examples of heavy-weight ontologies.

6.5.7. Steps of Ontological Development

Thorough exploration of the literature leads to the conclusion that there is a certain polyphony regarding the *methodology* to be followed during the process of *ontological development*. Various ways of building ontologies have been suggested from time to time (Ushold & King, 1995; Gruninger & Fox, 1995; Mizoguchi et al., 1995; López et al., 1999; Staab et al., 2001; etc.), but the prevalent view is that ultimately there is no right or wrong way to model a domain (Noy & McGuinness, 2001). In most cases there are many alternative – equally good and efficient – methodologies available; while ontologies' *domain* and *scope* are two decisive factors that should guide the selection of the most suitable one. Moreover, ontology development is an *iterative* process, in the sense that its constant revision – throughout its entire lifecycle – is rather unavoidable. Finally, concepts incorporated in an ontology must be close to objects (physical or logical) and to relationships that are valid for a certain domain (Noy & McGuinness, 2001).

Since there is no standardized and strictly defined way of building an ontology, the following subsections list some basic, general, and empirical ontology design and implementation stages that any methodology should incorporate, as these are articulated by Noy and McGuinness (2001) (Figure 6-21). The proposed methodology does not constitute a rigid sequence of steps, but is rather flexible, as some of them might be repeated several times or others may be completely omitted.

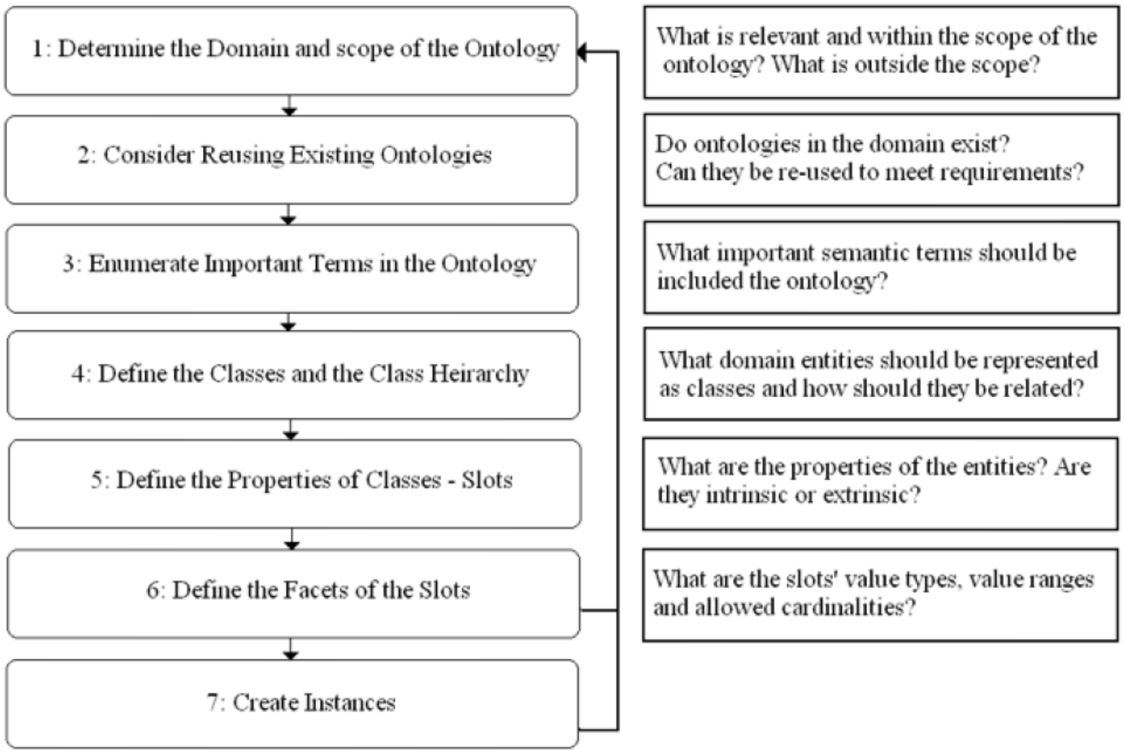

Figure 6-21: Proposed Methodology for Ontology Development by Noy and McGuinness (Source: Grzybek et al., 2014)

Determination of the domain and scope of the ontology

The first stage of the ontological development process is related to the determination / demarcation of the ontology's *domain* and *scope*. These issues can be properly addressed by providing answers to a series of key questions (Noy & McGuinness, 2001):

- What is the domain of interest that the ontology will cover / what will it represent?
- Which is the ontology's intended use?
- What types of questions should it be able to answer?
- Who will use and maintain it?

Of course, the answers to the above questions may be altered during the ontology building process, as this is a totally *dynamic* procedure rather than a static one. However, these queries drastically contribute to the demarcation of the scope of the model, irrespective of any possible changes (Noy & McGuinness, 2001); and serve as a testing mechanism for deciding whether the ontology design models effectively and sufficiently the domain of interest and satisfies its intended purpose (Grzybek et al., 2014).

Gruninger and Fox (1995) also suggest that the scope of an ontology can be often outlined by answering a set of *competency questions* (e.g., does the ontology incorporate enough information in order to answer these questions? Do the replies require a certain level of detail or representation of a specific area?).

Reuse of existing ontologies

Use of existing ontologies or controlled vocabularies is a common but not a mandatory step in the ontological development process, as it is possible that some of them may cover the domain of interest as a whole, partially or they might model related domains (Noy & McGuiness, 2001). Therefore, it is wise to investigate whether some ontologies can serve as the ground for developing a more target-oriented one. Ontology reuse involves the development of a new ontology "through maximizing the adoption of pre-used ontologies or ontology components" (Lonsdale et al., 2010, p. 318); and exhibits several advantages, such as increasing the quality of the developed ontology, facilitating mapping among input ontologies, and enabling ontology update (Lonsdale et al., 2010).

Enumeration of important terms in the ontology

This step refers to the identification and collection of all those terms that are considered essential for describing the domain of interest and may refer to concepts, relationships, or properties, without taking into account any semantic equivalence or overlapping at this point.

Definition of classes and class hierarchy (hierarchical structures)

This is the initial phase of organizing the terms gathered in the previous step. Particular attention should be paid to their proper classification, in order to end up with hierarchical structures that efficiently describe the domain of discourse. Terms representing entities that are characterized by independent existence (not terms that describe entities) are selected as classes. These classes are used to denote all entities included in a concept and are associated with other classes through hierarchical (IS-A) relations.

Uschold and Gruninger (1996), claim that several approaches may be adopted while structuring a class hierarchy:

- The *top-down approach* begins with the identification of the most general classes, which are then specialized into various sub-classes.

- The *bottom-up approach* starts with the identification of the most specialized classes (leaves of the hierarchy) and proceeds with gradually grouping them into more general classes.
- The *combination* of the above approaches is achieved by identifying the most representative concepts first and generalizing or specializing them accordingly.

It should be highlighted that, as in the case of the ontology development process, there is no optimal way to structure a hierarchy. The combination approach is usually the one followed by most researchers, as concepts that are not too specialized or too general tend to describe a domain more efficiently (Rosch, 1978).

Definition of properties of classes – slots

Properties of classes actually describe the 'internal structure of concepts' (Noy & McGuiness, 2001, p. 8). Classes have already been chosen from the pool of terms that is created in the third step (enumeration of important terms in the ontology), while the rest of these terms are likely to serve as properties (e.g., color, shape, location, name, population). An object property becomes a *slot* of this class. Properties may be *intrinsic* (e.g., flavor, color, shape), *extrinsic* (e.g., name, population), *parts* – in cases where objects are structured – (e.g., the courses of a curriculum), *relationships to other individuals* that refer to relations between individual members of a class and other items (e.g., the producer of an electrical component represents an association between the electrical component per se and the production premise).

Definition of the facets of the slots

Slots may have different *facets* that describe the value type, allowed values, number of values, etc. The most common facets of a slot are:

- *Slot cardinality* defines how many values a slot can have.
- *Slot-value type* determines what types of values can fill in the slot, such as string, number, boolean, enumerated, and instance-type.
- The *domain* of a slot refers to the class to which this slot is attached, or the class whose property is described by this slot.
- The *range* of a slot regards the allowed classes of type instance for that slot.

Creation of instances

The final step of the ontology development process regards the population of classes with instances to create knowledge bases, and involves the:

- selection of the class to which an instance refers;
- creation of an individual instance of the chosen class; and
- assignment of values to the properties of the instance (filling the slots).

6.5.8. Ontology Design Criteria

Ontology design is a challenging task and an indispensable step in the development of perplexed, knowledge-based applications (Liu et al., 2008). This section summarizes several fundamental criteria and principles that should be considered during the process of ontology development, since they guarantee an acceptable and useful final outcome. These refer to (Gruber, 1995; Bernaras et al., 1996; Borgo et al., 1996; Uschold & Gruninger, 1996; Arpírez et al., 2000; etc.):

- *Clarity* and *objectivity*: ontologies should convey with absolute lucidity the meaning of the terms they include.
- *Completeness*: ontologies must contain all the necessary semantic components, depending on the domain of interest and the purpose they serve.
- *Coherence*: ontologies must not contain conflicting information (Cordi & Mascardi, 2004) and inference should be consistent with the definitions.
- *Extendibility*: an ontology's ability to be reused and extended with new – usually more specific – terms.
- *Minimal ontological commitments*: "an ontology should make as few claims as possible about the world being modelled, allowing the parties committed to the ontology freedom to specialize and instantiate the ontology as needed" (Gruber, 1995, p. 910).
- *Ontological distinction*: the classes of an ontology must be disjoint.
- *Diversification of hierarchies*: aims at strengthening the power of the ontology and is implemented by multiple inheritance mechanisms.
- *Minimization of the semantic distance between related sibling concepts*: same primitives are grouped and used to represent the similar concepts.

- *Standardization of names*.

6.5.9. Ontology Alignment, Merging, and Integration

As ontologies started to dynamically permeate a multitude of scientific fields, their number has dramatically escalated, necessitating thus their *alignment*, *merging* or *integration*. Before delving into the main features of these processes, their meaning should, first of all, be completely elucidated.

Ontology alignment or *ontology matching* has originally emerged from the need to integrate heterogeneous databases that are created independently, and each one adopts its own dictionary / thesaurus. It endeavors to define correspondences between concepts and relationships that are incorporated into two or more ontologies (Figure 6-22). The ultimate goal of such a process is to identify those classes or relationships that are considered *semantically equivalent* without necessarily being *logically equivalent*.

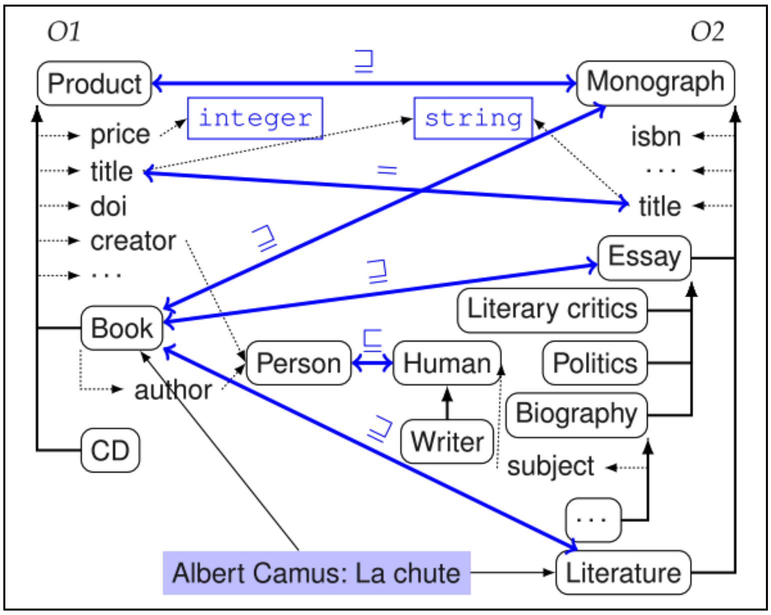

Figure 6-22: Example of Ontology Alignment (Source: Shvaiko & Euzenat, 2013)

The main difference between ontology alignment on the one hand and ontology merging and integration on the other, lies in the fact that the former process results only in *semantic mapping* between concepts or relations of at least two ontologies, without being brought together under no circumstances, as in the cases of merging and integration.

As far as *ontology merging* and *integration* are concerned, plentiful definitions are met in the literature (Pinto et al., 199l; McGuiness et al., 2000; Sowa, 2000; Pinto & Martins, 2001; etc.). It should be mentioned that although both concepts refer to processes of reusing existing ontologies, nevertheless they do not bear the same meaning (Pinto et al., 1999).

Pinto et al. (1999) and Pinto and Martins (2001) point out that merging is the procedure of structuring an ontology on a particular topic by reusing two or more discrete ontologies of the same topic (see Figure 6-23). Initial ontologies are consolidated to form a single one, while it is pretty difficult to discern the original parts that are inherent in the final ontology or to assess whether these have changed. Moreover, original ontologies are substantially different and do not constitute updated, revised, or improved versions or variants of the same ontology.

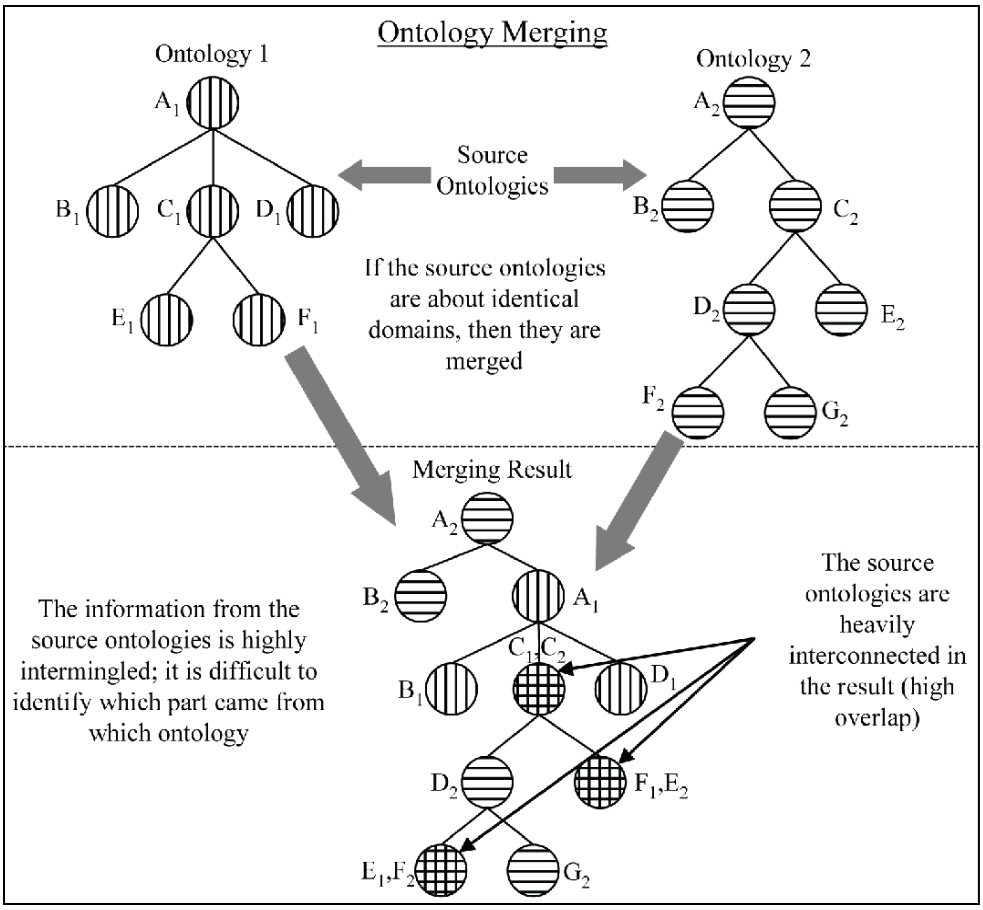

Figure 6-23: Example of Ontology Merging (Source: Flouris et al., 2008)

Conversely, *integration* relates to the process of building an ontology on a particular topic by reusing two or more existing ontologies on different topics (Figure 6-24). During integration, original ontologies are brought together, combined, and 'assembled' to form a final one, after possibly undergoing some changes, such as *extension*, *specialization*, and *adaptation*. It is noted that the parts / areas of the original ontologies can be detected in the final product, while the knowledge incorporated in them remains almost unchanged. It should also be mentioned that both cases of ontology reuse (merging and integration) are integral steps of the broader process of ontology development (Pinto et al., 1999; Pinto & Martins, 2001).

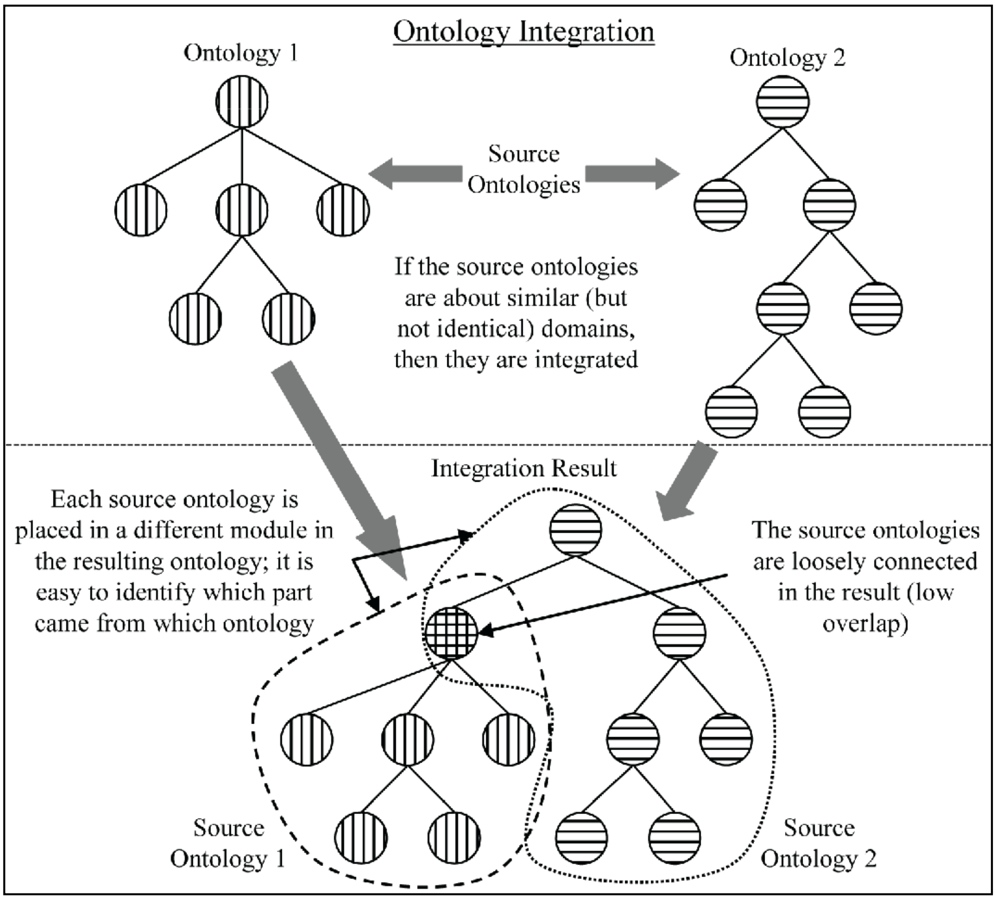

Figure 6-24: Example of Ontology Integration (Source: Flouris et al., 2008)

Sowa (2000) describes ontology integration as the process of identifying similarities between two different ontologies A and B and extracting a new ontology C that facilitates interoperability between computer systems, based on ontologies A and B. New ontology C may replace ontology A or B or may be used only as an intermediary between an ontology A-based system and an ontology B-based system. Depending on the degree of alteration that ontologies A and B are subject to in order to obtain ontology C, four different levels of integration can be distinguished (Sowa, 2000):

- *Alignment*: the simplest and weakest case of integration. It requires minimal changes to the original ontologies and is particularly useful for information classification and retrieval. It can only support very limited types of interoperability and cannot support reasoning and computation.
- *Partial compatibility*: demands greater degree of intervention in the original ontologies so as to support interoperability, despite the fact that there may be some concepts or relationships in the one or the other system that could pose barriers to full interoperability.
- *Unification or total compatibility*: usually requires extended interventions or major reorganizations of the original ontologies, but can lead to fuller interoperability. It is a concept synonymous with merging, as this is defined by Pinto et al. (1999) (Gao, 2012).
- *True integration*: results in the creation of a new ontology without changing the original ones though. It is synonymous with integration, as this is established by Pinto et al. (1999). The process of true integration is particularly practical in cases where original ontologies have to be used autonomously, after integration has taken place.

Considering all the above, it is evident that a lot of valuable research has been carried out in the field of ontology merging. A clear definition, describing the process (Sowa, 2000) is introduced; there are available methodologies for its implementation; while several ontologies have appeared as a result of merging existing ontologies.

6.6. Discussion and Conclusions

Semantics and ontologies are two essential and ‘popular’ concepts in computer science and especially in the fields of knowledge engineering, natural language processing, machine learning, artificial intelligence, and information management. Semantics refers to the meaning of terms and its interpretation in a given context. Ontologies are described as formal representations – comprising concepts, relationships, and properties – of the available knowledge on a certain domain of interest.

Their immense significance lies – among others – in their capacity to render possible the comprehension and process of natural language by computers, a quite critical and decisive factor for the development of intelligent systems. Apart from that, they lay the foundations for the construction of knowledge-based / expert systems that can reason, infer, and make decisions grounded in available knowledge, while they also act as facilitators of knowledge sharing and reuse.

Additionally, they establish *conceptual bridges* between machines and users, thereby fostering their communication and interaction. Through this shared conceptual ground (common vocabulary), computing systems analyse, understand, and interpret the meaning of language and respond to the users' queries.

Finally, semantics and ontologies constitute an integral part and basic building elements of the so-called *semantic Web*, an extension of the World Wide Web, designed to assist machines in understanding and processing information; but also, to optimize information discovery, sharing, and reuse across different applications and systems.

Focusing on the urban planning realm, semantics and ontologies' role might prove to be quite prominent, considering that they provide a solid, structured, and formalized framework for grasping and organizing the complex systems, processes, and functions that shape contemporary urban environments. Their extensive deployment allows interested parties to better understand the relationships among different city aspects and, thus, get a deep insight into a specific urban context. For instance, ontologies may be used to model the relationships among transportation systems, land use patterns, and environmental factors. This can help urban stakeholders to identify critical areas for appropriate interventions so as to increase service efficacy, reduce traffic congestion, and improve environmental sustainability.

Moreover, the adoption of semantic-based and ontological-oriented approaches in urban planning may contribute to the early identification and proper address of potential conflicts or trade-offs that appear among various urban domains (e.g., a proposed developmental plan might exacerbate traffic congestion in the surrounding area, which could have negative repercussions on air quality and the public health). Mapping the relationships among the key urban factors leads to the detection of possible divergences and can support planners and policy makers to craft appropriate strategies to mitigate their impacts.

Semantics and ontologies may also conduce to the overall improvement of the efficacy of the urban planning process per se. By providing a coherent, structured, and standardized framework for organizing and analysing data, information and knowledge, time and resources required to make informed decisions can be significantly diminished.

This might help cities to accelerate the pace of urban innovation and to effectively respond to the rapidly changing patterns of their actors.

However, apart from the abovementioned opportunities, critical challenges might also emerge when using semantics and ontologies in urban planning. The most important ones focus on the difficulty to delineate and model complex systems and relations in a way that is both accurate and easy to understand; but also, on the arising disagreements among various stakeholders over how to define and prioritize their cities' key aspects.

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CHAPTER 7: ONTOLOGICAL REPRESENTATIONS OF SMART CITIES

***Synopsis**: Even at this very moment that these lines are written, smart city remains a highly ambiguous, fuzzy and controversial concept, a fact reflected in the absence of an operational definition and the consequent lack of semantic interoperability it provokes. Experience and knowledge gained so far through various smart city examples highlight the immense prevalence of purely technology-pushed strategies and initiatives; and the limited performance of such approaches in many urban aspects. This entails the need for delineating the different notions, uses and applications of the term through the underlying concepts and the interrelationships among them or, in other words, via a better understanding of a city's ontology. Actually, many recent studies (Poveda-Villalón et al., 2014; Komninos et al., 2015; Abid et al., 2016; Rani et al., 2016; etc.) claim that ontologies and ontology-based technologies may find widespread application and use in the field of smart cities, while they have gradually begun to gain traction, becoming thus a novel and promising (in terms of prospects and results) research topic. An ontology, as a formal description of knowledge of a specific scientific realm, provides the essential concepts to be modelled, as well as the relationships among them. Ontologies have been used in various fields, such as medicine, biology, law, engineering, robotics, artificial intelligence, geography, etc.; and they are particularly useful in applications that require a common understanding among different actors (semantic Web, information extraction, retrieval, integration, etc.). Given the above, this Chapter attempts to offer a brief analysis of some notable, existing urban ontologies developed to model the field of smart cities, as this is grasped by a planner's perspective; thereby shedding light on the current scenery of smart city ontological representations in urban planning and management.*

7.1. Ontological Representations of Smart Cities – Getting a Deep Insight into the Current Status

Considering that ontologies constitute a recently introduced research domain to the broader field of smart cities, the available literature is quite limited and poor; while a significant gap regarding the ontological representations of the smart city and its sub-systems is observed. This gap has also been identified by the Joint Technical Committee of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) in their joint report on smart cities (International Organization for Standardization & International Electrotechnical Commission Joint Technical Committee [ISO & IEC JTC 1], 2015), in which the need for developing formal models for mutual understanding of the smart city concept is severely stressed. It is also highlighted that a widely accepted conceptual city model will shape a common framework in support of cooperation among different interest groups as well as standardization organizations. In spite of the insufficient literature on the development of smart cities' ontological representations, some remarkable efforts have been made in this direction and are briefly outlined in the following sections.

At this point it should be stressed that the explored ontologies are developed to represent diversified smart city aspects, ranging from the description of physical infrastructure to the modelling of the relationships among different entities. Each one of them has a different scope, serves a very particular goal and thus focuses on specific city dimensions. Nonetheless, they all serve as a well-structured, shared vocabulary, used to describe and categorize various smart city aspects (e.g., physical infrastructure, social systems, technologies, economic activities) – depending on their scope – thereby contributing to the integration of heterogeneous data and facilitating the communication among different civic actors and stakeholders (Panagiotopoulou, 2018; Panagiotopoulou et al., 2019).

7.1.1. Smart Objects For Intelligent Applications (SOFIA) Ontology

SOFIA ontology is developed in the context of the Smart Coruna Project (Spain) and is a fundamental constituent of a platform that facilitates semantic interoperability among different embedded urban systems and heterogeneous devices by establishing a semantic layer, so that information of the real world is widely available in smart applications. The aim of the platform is the improvement of monitoring and control of urban environments by properly utilizing information provided by various sources (sensor networks, users, organizations, municipal services and institutions, etc.) in order to describe a city's available services and information. Interoperability is achieved by constraining the number of ontologies used by each different system, as every single ontology deployed should be in alignment with the standards already defined by the SOFIA platform (Indra, 2014; Otero-Cerdeira et al., 2014; Komninos et al., 2015).

SOFIA ontology is developed to address problems that correspond to three discrete occasions (use cases), differentiated on the grounds of the space these represent, in terms of scale and consequently of potential applications and services. Ranging from very personal areas, to smart housing / buildings and further to smart cities, the ontology defines the specific aspects of these spaces and combines the prerequisites for common smart solutions (CORDIS Project, 2022). So far, SOFIA, includes 143 classes, 54 relations, 93 properties and 16 instances (see Figure 7-1 for indicative part of its structure).

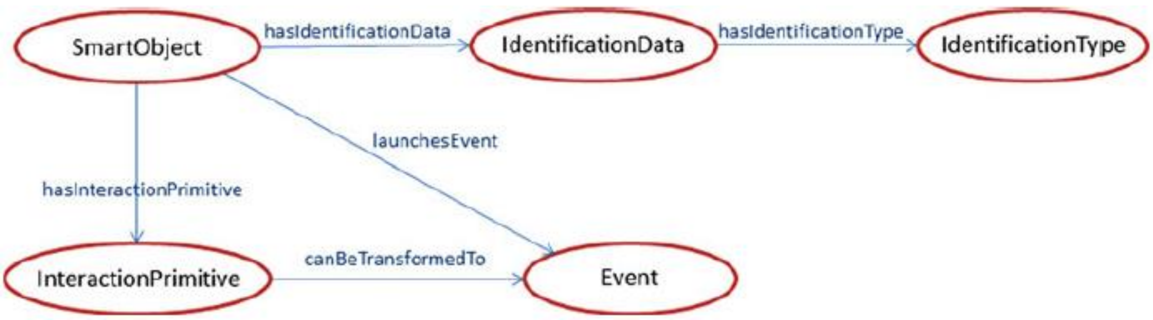

Figure 7-1: Indicative Classes and Properties of the SOFIA Ontology (Source: Bartolini et al., 2012)

7.1.2. Smarter Cities Reusable Information Model and Business Events (SCRIBE)

SCRIBE (*Smarter Cities Reusable Information Model and Business Events*) is a non-normative, authoritative, modular and extensible semantic model for smart cities developed by IBM. It is designed on the basis of data collected from various cities and consists of three key components (Uceda-Sosa et al., 2012): (i) a *core model* that includes common classes, such as events and messages, departments, services, stakeholders, landmarks, Key Performance Indicators (KPIs), etc.; (ii) *extensions* based on the sector / domain (buildings, transportation, energy, water, etc.); and (iii) *customizations* depending on the city (Figure 7-2). SCRIBE represents the different types of city services (events, assets and resources, location data, business organizations, KPIs, etc.) by modelling the city data, but not the *organization of the city* per se (the spatiotemporal relations among people and objects in the city).

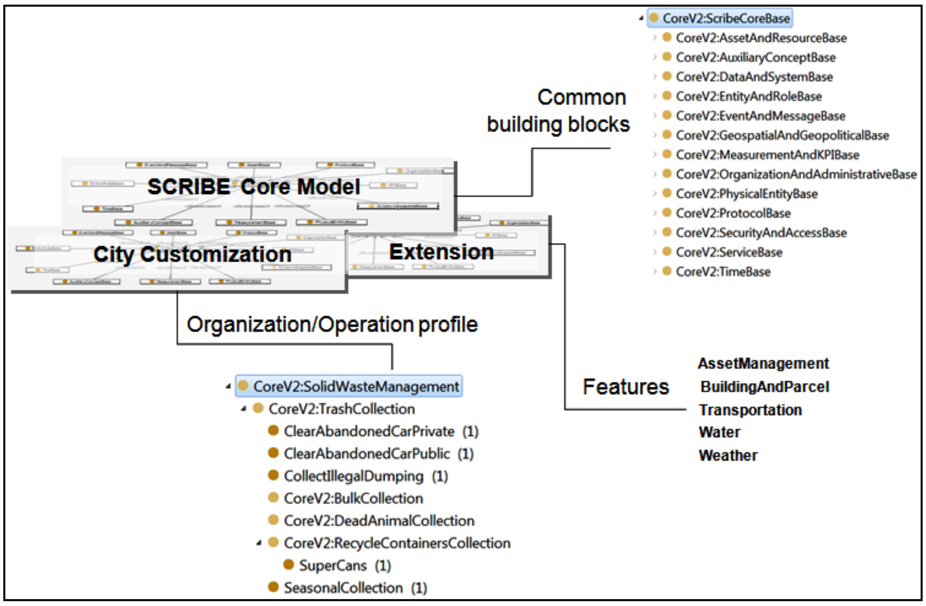

Figure 7-2: Building Blocks of SCRIBE Ontology (Source: Uceda-Sosa et al., 2012)

Its purpose is to support the proper and smooth functioning of the city's operational center and coordinate its services (Uceda-Sosa et al., 2012). Finally, through the whole process of the development of SCRIBE ontology, IBM researchers highlight the dearth of available relevant ontologies (Uceda-Sosa et al., 2011), while their own effort paved the way for formal descriptions of city services, events, metadata, etc. Additionally, they point out that this model is not closed and may be subjected to several future changes, depending on the system that will utilize it (Otero-Cerdeira et al., 2014).

7.1.3. Neighbourhoods of Winnipeg (NOW) Ontology

NOW ontology is created to model and interrelate, in a structured way, all the different aspects of the city of Winnipeg (Canada); while it is the largest instance of the *Civic*

Dynamics Platform - *CDP* (Komninos et al., 2015), a portal for accessing, managing and publishing local government data and sustainability indicators (Civic Dynamics Inc., n.d.).

The ontology describes 236 neighbourhoods of the city, including all facilities and services per neighbourhood, zoning, economic growth, living conditions and the environment (Figure 7-3) (Neighbourhoods of Winnipeg [NOW], n.d.-a). Twelve domain ontologies are deployed for the construction of NOW ontology, with two of them being developed exclusively for the city of Winnipeg (NOW ontology and a Canadian census ontology); while all the rest are external ontologies (FOAF, GeoNames, etc.) (Bergman, 2013; Komninos et al., 2015).

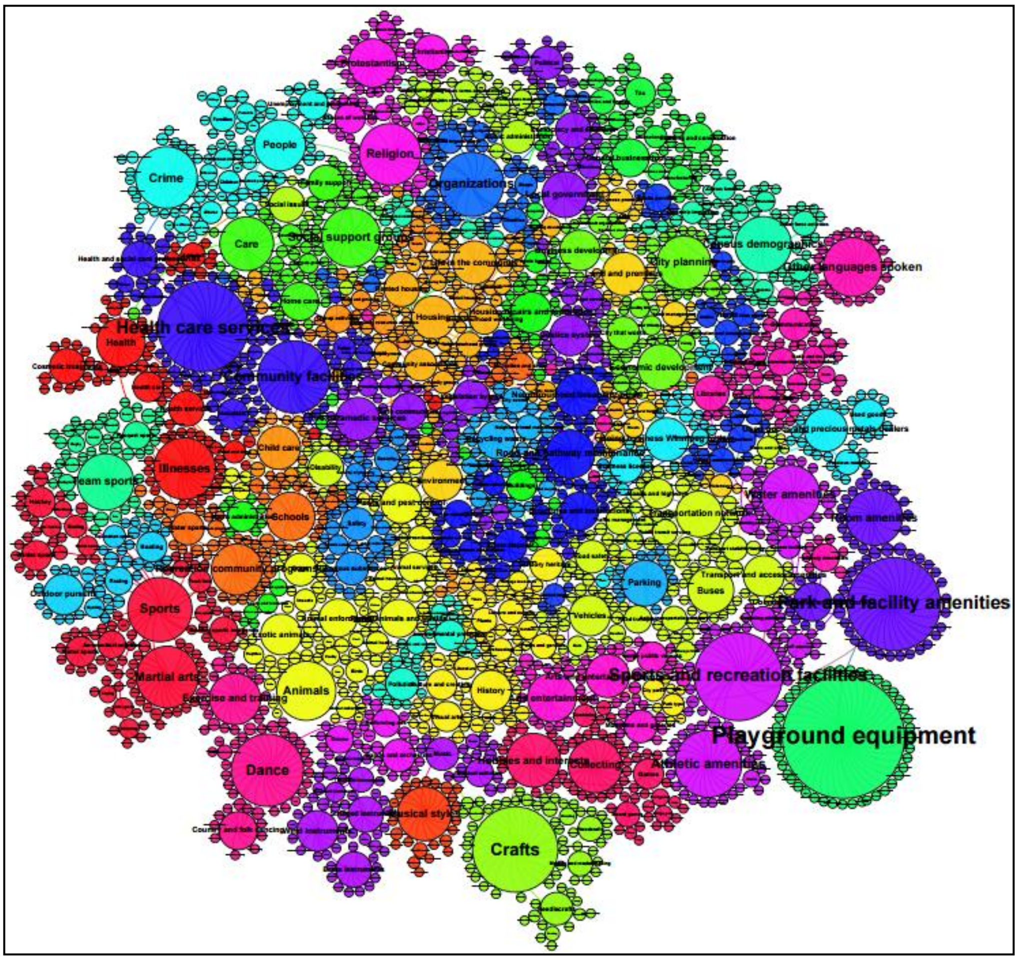

Figure 7-3: NOW Ontology (Source: NOW, n.d.-b)

NOW ontology contains almost 3,000 concepts, all linked and related in a coherent way (Figure 7-3), which fall under nine neighbourhood profile topics / thematic categories (life in our community, our local government, leisure and culture, economic development, neighbourhood wellbeing, transportation network, sports and recreation, libraries and information, safe communities) (Figure 7-4). These categories are differentiated by colour and also by their in-between distance, while the labels denote the concepts (Figure 7-3).

Figure 7-4: The Nine Thematic Categories of NOW Ontology (Source: NOW, n.d.-c)

7.1.4. Osmosys Ontology

Osmosys is a knowledge representation framework for the efficacious planning and management of smart cities, which contributes to the semantic integration of heterogeneous urban data, deriving from different sources. The framework consists of *three interconnected key components* (Psyllidis, 2015): (i) an ontology for smart cities that describes the various domains, urban sub-systems, data sources and defines the relationships among them; (ii) a Web ontology browser, which allows full access to the ontology (Figure 7-5); and (iii) an interactive Resource Description Framework (RDF) graph that facilitates the exchange of common semantic definitions and interrelationships among different interest groups through an online Graphical User Interface (GUI).

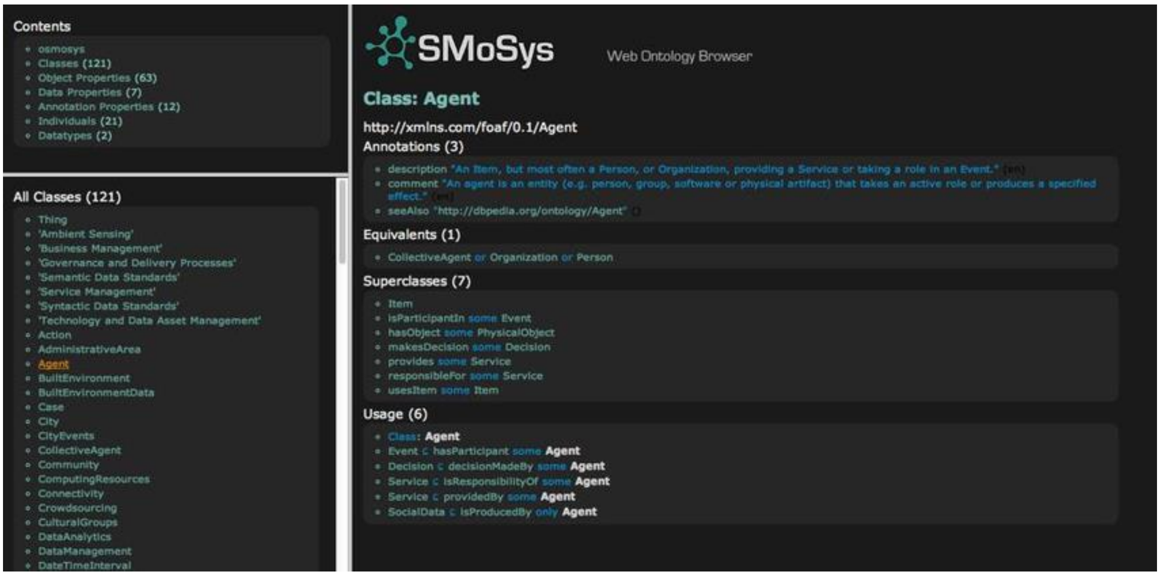

Figure 7-5: Osmosys's Web Ontology Browser (Source: Psyllidis, 2015)

As regards its basic structure, Osmosys ontology is organized into eleven super-classes (Case, Decision, Document, Event, Method, Place, Sampling, Situation, Technologies, TemporalEntity and WebEntity) that represent broader and cross-sectoral concepts, thereby setting the ground for a coherent and comprehensive framework for the fields of urban planning and management. The complete ontology includes 121 classes, 82 relationships, properties, and annotation properties, 23 instances, and data types representing a total of 226 entities (Psyllidis, 2015).

Moreover, an innovative feature of the Osmosys ontology is related to its ability to integrate concepts from user-generated data, stemming from smart devices and social media platforms (Psyllidis, 2015).

7.1.5. Km4City Ontology

The *Km4City* ontology is a knowledge representation model for smart cities and the services these offer, with a particular focus on public transport and mobility (more than 800 datasets referring to the regions of Tuscany and Florence are used). It intends to facilitate the interconnection, storage and integration of heterogeneous data (i.e., data that emanate from different sources). Initially, the ontology covered seven super-classes (Figure 7-6), with five of them being exclusively city-specific (administration, street guide, points of interest local public transport and sensors) and the other two focusing on representing time and metadata (temporal and metadata) (De Nicola & Villani, 2021). More particularly, the seven macro-classes of Km4City ontology are (Bellini et al., 2014):

- *Administration*: includes classes related to the structure (hierarchy) of the Italian public administration.
- *Street guide*: represents the whole Tuscan road system.
- *Points of interest*: contains all services and activities that may be useful to citizens.
- *Local public transport*: refers to data on public transportation systems.
- *Sensors*: regards data stemming from sensors.
- *Temporal*: comprises time-related concepts (instants and time intervals) so as to facilitate various time correlations and predictions.
- *Metadata*: concerns the collection of metadata related to the datasets used.

It is worth mentioning that a new super-class – *Internet of Things* – has been added in the KM4City ontology since version 1.6.5., which endeavors to effectively model sensors, actuators, their brokers, and the types of measurements that these are able to perform (Bellini et al., 2020).

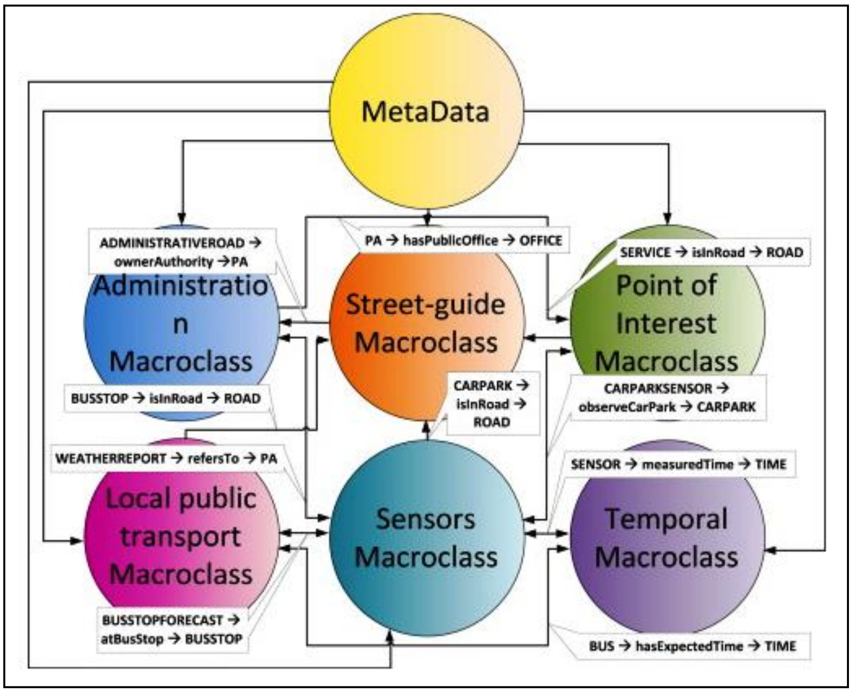

Figure 7-6: The Super-Classes of the Km4City Ontology and their In-Between Relationships (Source: Bellini et al., 2014)

7.1.6. SEMANCO Energy Model

SEMANCO Energy Model is a quite large (592 concepts, 468 relationships, 3,459 axioms), formal ontology for smart cities that includes concepts derived from various sources (standards, sources related to urban planning and energy management, etc.) (see Figure 7-7). More specifically, it contains terms and properties that describe regions, cities, neighborhoods and buildings, energy consumption and CO_2 emission indicators, as well as climatic and socio-economic factors that affect energy consumption. It seeks to address the issue of heterogeneous data integration (SEMANCO Project, n.d.; Nemirovski et al., 2013).

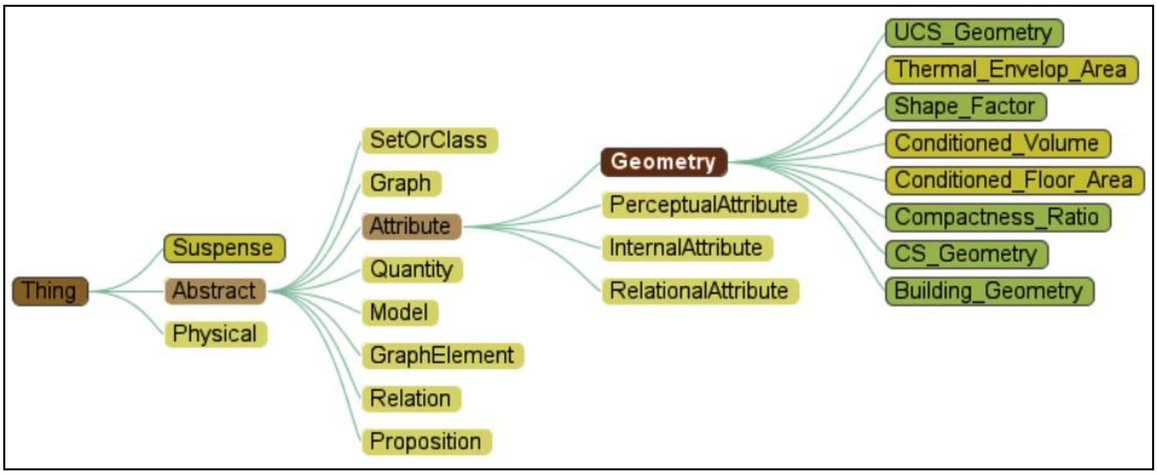

Figure 7-7: Part of SEMANCO Ontology (Source: Nemirovski & Sicilia, 2013)

Following a modular approach during the ontological design process, SEMANCO ontology is developed using parts of the top-level Suggested Upper Merged Ontology (henceforth SUMO). In this way, every concept contained in the SEMANCO ontology is subsumed by at least one concept of SUMO; while SUMO's fundamental relationships and axioms remain valid in the SEMANCO ontology (Nemirovski & Sicilia, 2013). The final selection of SUMO is based on a comparative analysis of four additional top-level ontologies (Descriptive Ontology for Linguistic and Cognitive Engineering – DOLCE, PROTo ONtology – PROTON, General Formal Ontology – GFO and Basic Formal Ontology – BFO). SUMO is ultimately chosen because it is quite simple and therefore easy to grasp, it exhibits great applicability in cases of reasoning and inference; but also comprises the appropriate number of concepts, related to the domain of interest (urban planning in particular) (Nemirovski & Sicilia, 2013).

7.1.7. City Geography Markup Language (CityGML) Ontology

CityGML ontology is an international open standardized data model introduced by the Open Geospatial Consortium (OGC) and contributes to the semantic modelling of cities and landscapes in three dimensions (3D). It covers the geometric, topological and semantic aspects of the three-dimensional modelling in five different levels of detail (LoD) (Figure 7-8) (Gröger & Plümer, 2012). The ontology includes concepts such as buildings, roads, public spaces, terrain, vegetation, etc., and thus it is broadly used in urban planning and architectural design. Although CityGML standardizes concepts and relationships pertinent to the geospatial knowledge as well as the semantics regarding the nature of objects and spaces within urban environments, this is implemented in a rather simplistic way as regards the interoperability of heterogeneous smart city data (Howell, 2017).

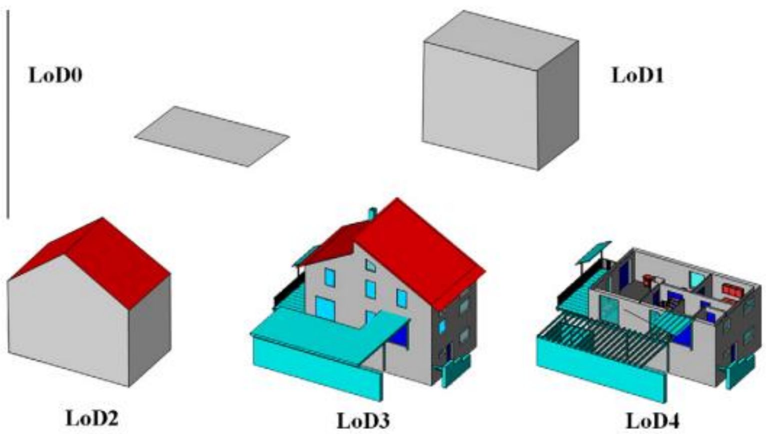

Figure 7-8: The Five Levels of Detail of CityGML Ontology (Source: Gröger & Plümer, 2012)

7.1.8. British Standards Institution's Ontology

The British Standards Institution (BSI) proposed in 2014 a top-level smart city ontology which includes 27 concepts to describe the entities typically met in cities' data (Figure 7-9). It aims at facilitating discussions among decision makers and experts, who design and develop systems and services for urban functions in order to come up with and deliver efficient and commonly accepted smart urban strategies. Additionally, decision makers are encouraged to adopt and implement this conceptual model, so as to promote interoperability of data generated, used and managed across all urban domains (British Standards Institution [BSI], 2014b).

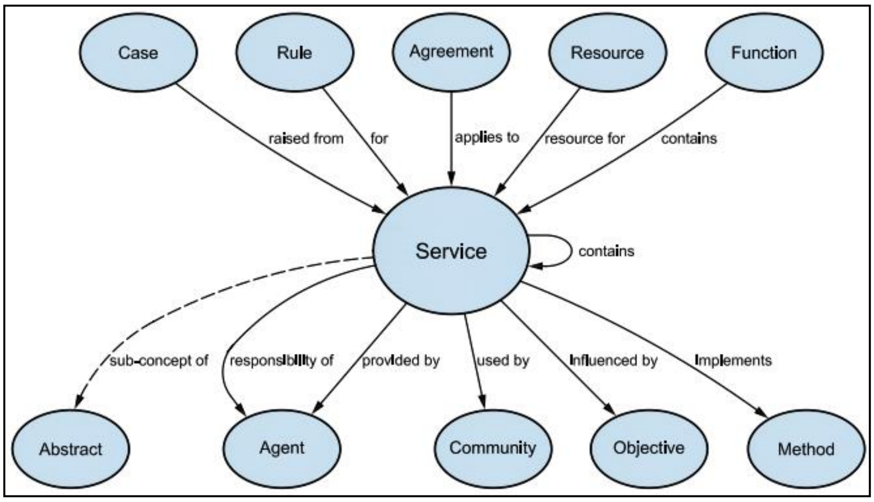

Figure 7-9: Sub-Classes of the Service Class of the BSI Concept Model (Source: BSI, 2014b)

Moreover, the ontology is developed alongside the *Smart Cities Vocabulary* (BSI, 2014a), which comprises an expanded list of commonly approved terms and their definitions, in order for them to be properly used in the development of smart strategies, applications, services, etc. Although the particular effort constitutes an important step in the conceptual representation of the smart city as a whole rather than sectorally, it is distinguished by its very limited conceptual depth (Howell, 2017).

7.1.9. Smart City Ontology (SCO)

SCO is developed by the URENIO research team of the Aristotle University of Thessaloniki and attempts to represent the field of smart cities holistically rather than fragmentarily. Its primary goal is to elucidate the limited effectiveness of smart applications in various sectors (mainly in transportation and energy).

During the construction process of the SCO, all the fundamental entities that form a smart city as well as the relationships among them are taken into account, in order to produce a coherent and comprehensible ontology. Starting from the concept's definitions – i.e., what the smart city term actually implies – the researchers gathered and studied the most widespread and broadly used ones and ended up with three essential smart city building blocks (Komninos et al., 2015):

- *City Block*: focuses on the city, its citizens and activities. More specifically, it includes all city resources, such as local communities, citizens, visitors, productive activities, services and infrastructure.
- *Knowledge and Innovation Block*: regards knowledge, intelligence and innovation. It incorporates processes and regulations for knowledge creation and strengthening of partnerships in the fields of technology and innovation (e.g., information collection and management, communication and networking).
- *Smart Systems and Technologies Block*: refers to smart systems and technologies that are widely applied in urban environments and comprises broadband networks, telecommunications, sustainable technologies, digital applications and Web services.

The above building blocks reflect both the elements met in the various smart city definitions and the fundamental dimensions of intelligence (human, collective, artificial) that are present in the different layers / spaces of a smart city (physical, social and digital space) (Komninos, 2006, 2008; Komninos et al., 2015).

Apart from static entities, the ontology also incorporates some dynamic aspects appearing during the operation and functioning of urban systems. Based on that, ten super-classes are defined (see also Figure 7-10) (Komninos et al., 2015):

- Classes of *spaces* that form any modern city (physical, social and digital space).
- Classes of *urban functions* (related to citizens, knowledge and innovation).
- Classes of *city type* (challenges, city type and planning), which determine the character of a city.
- A class referring to a city's *human capital* (residents, visitors, migrants, etc.).

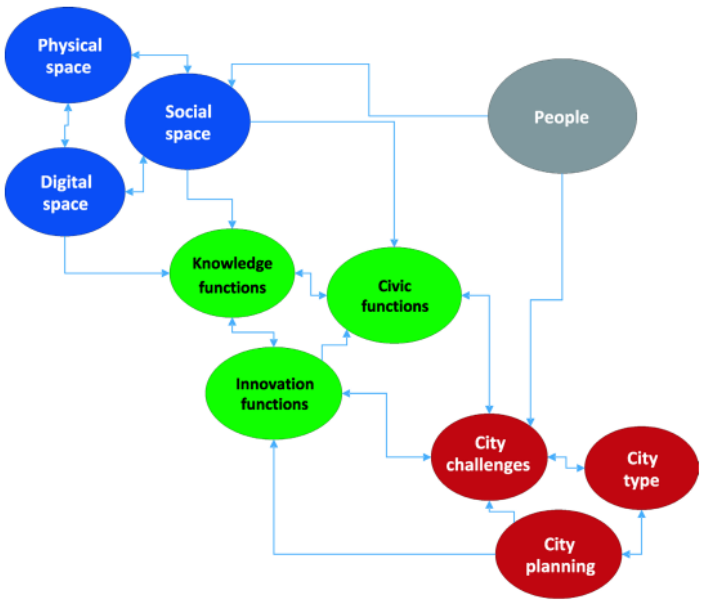

Figure 7-10: Super-Classes of the Smart City Ontology (SCO) (Source: Komninos et al., 2015)

The first version of the SCO (SCO 1.0) contains 10 super-classes, 422 classes, 708 entities, 62 relationships, 190 properties and 27 instances (Figure 7-11).

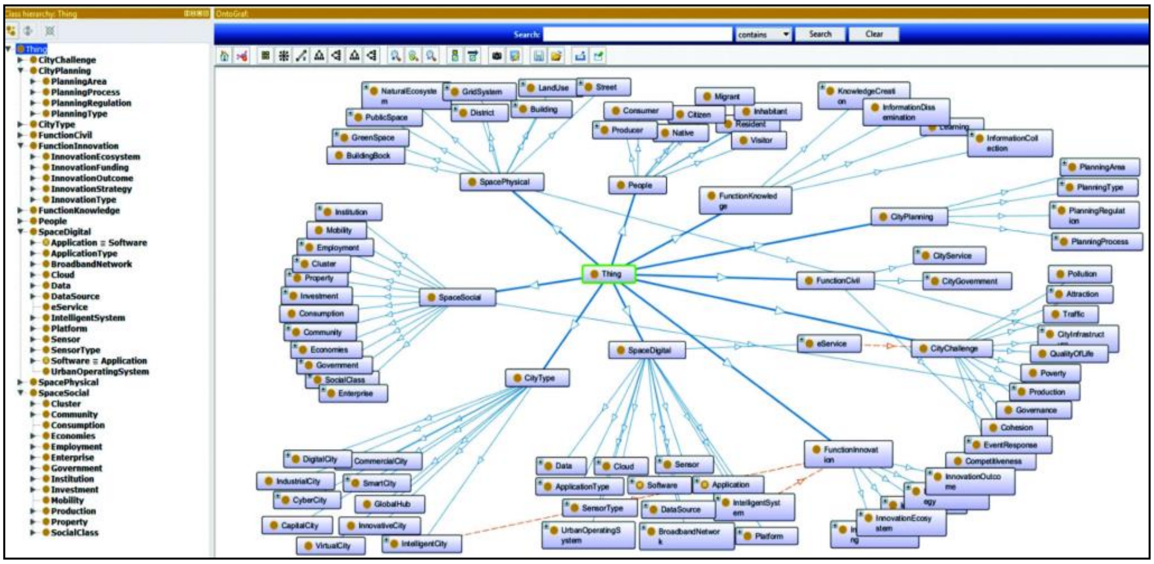

Figure 7-11: Smart City Ontology 1.0 (Source: Komninos et al., 2015)

In 2020, URENIO research team releases the second version of the SCO (SCO 2.0). Although the updated ontology includes many of the initial entities (classes, object and data properties), it significantly differs from the first version, since the goal of its development has changed (better understanding of the smart city concept and identification of its main components and functions in SCO 2.0 vs. assessment of smart city applications and services in SCO 1.0). Also, the Basic Formal Ontology (BFO) is used as a top-level ontology in order to guide the design and construction process of the SCO 2.0 (Komninos et al., 2021). Its contributors envisage to prepare the ground and establish a solid framework for more extensive work to be carried out in the field of smart city ontologies, which, in turn, will lead to the production of an integrated, holistic and interdisciplinary smart city ontology from the research community.

With regard to the building blocks of SCO 2.0, it should be mentioned that its entities are falling under three major categories / hubs: the *community hub* contains entities which describe the city and its elements; the *data and e-service innovation hub* focuses on information, knowledge and innovation; and the *smart city planning hub* consists of entities associated with planning, governance, urban challenges, etc. (Figure 7-12).

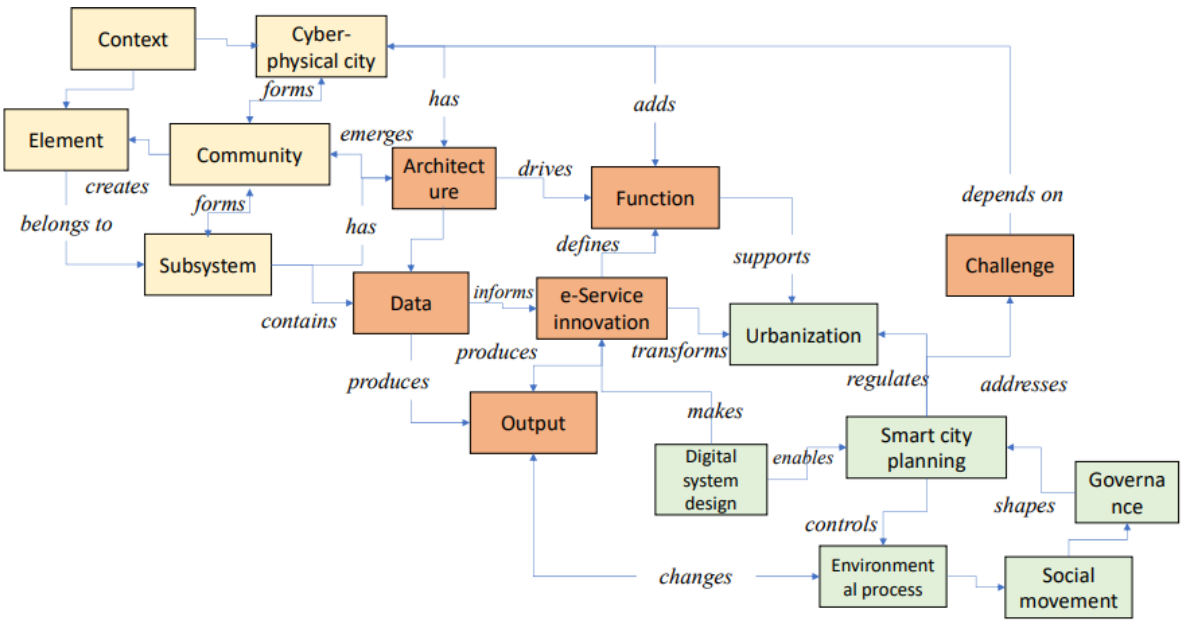

Figure 7-12: Super-Classes of Smart City Ontology 2.0 and their In-Between Relations (Source: Komninos et al., 2021)

Overall, the updated ontology contains 918 classes, 66 object properties, 197 data properties and 27 individuals. In comparison with SCO 1.0, the main alterations in the structure of the ontology focus on the increased number of: (i) entities; (ii) layers of the hierarchy; and (iii) 1st level classes (super-classes) that define its structure and relationships (23 vs. 10) (Komninos et al., 2021).

7.1.10. ISO 37120 Indicator Identifier Ontology

ISO 37120 Indicator Identifier Ontology comprises classes for each individual indicator defined by ISO 37120 (2014) on *Sustainable Development of Communities – Indicators for City Services and Quality of Life* (100 indicators for measuring a city's performance in services and quality of life) (BARTOC.org, 2019; Fox, n.d.). The ontology contains 17 super-classes of indicators (economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunications and innovation, transportation, urban planning, waste water, water and sanitation), with each one of them being specialized in sub-classes that correspond to specific indices, as these have been defined by the respective standard (Figure 7-13).

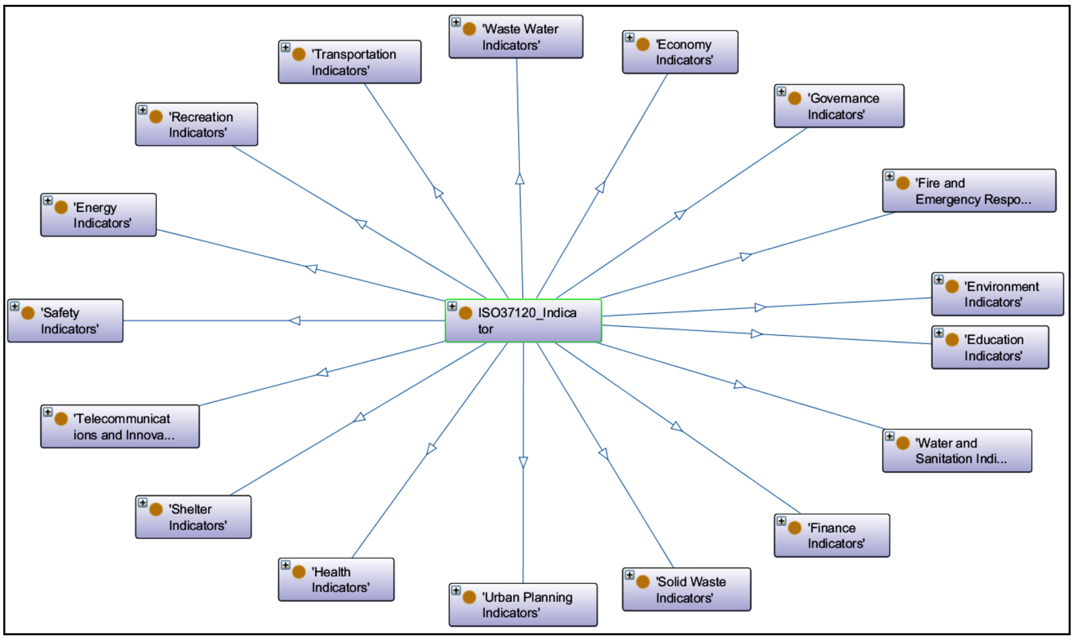

Figure 7-13: Super-Classes of the ISO 37120 Indicator Identifier Ontology (Source of OWL Code: Fox, n.d.)

7.1.11. Additional Endeavors

In May 2017, the International Organization for Standardization (ISO), in cooperation with the International Electrotechnical Commission (IEC), published the *Smart City Concept Model – Guidance for Establishing a Model for Data Interoperability* (ISO & IEC, 2017). It is about a conceptual model for smart cities that attempts to shape an interoperability layer among the various urban sub-systems by establishing a generic framework of concepts and relationships that can be used to describe data stemming from any sector (Schirn, 2022). Its creators intend to render it an essential medium / tool for sharing ideas, information, solutions, successful practices, etc. In addition, decision makers are encouraged to explore the data reuse as a revolutionary and innovative way for systems and services' future direction.

Finally, it is worth mentioning two important online ontology repositories, where users can find and download ontologies related to different smart city sectors (transport, energy, building infrastructure, urban planning, sensor networks, etc.). These repositories are:

- smartcity.linkeddata.es: http://smartcity.linkeddata.es/index.html.
- Smart City Artifacts – A Collection of Artifacts Related to Smart City Projects: http://opensensingcity.emse.fr/scans/applications.

7.2. Discussion and Conclusions

The above analysis leads to the conclusion that although ontologies' diffusion to the field of smart cities is still at an early stage, with quite limited applied work and documentation available, this research domain appears to be gaining momentum, as evidenced by the growing (over time) remarkable efforts undertaken until now. These efforts seek to approach the multifarious notion of smart city from different directions, serving thus diverse goals and perspectives. However, it is observed that the majority of the smart city sectors / sub-systems are not yet adequately or sufficiently modelled (Panagiotopoulou, 2018).

The explored ontologies exhibit different levels of *formality*, ranging from informal hierarchies including only concepts to more formal ontologies that comprise concepts' definitions and various types of relationships among them; and *generality*, extending from general, high-level concepts to specific ones for modelling a particular city (Panagiotopoulou, 2018).

The overarching goal of ontologies in the field of smart cities and smart urban planning, as well as the purpose of their development seems to be twofold for the time being (Otero-Cerdeira et al., 2014):

- Firstly, to facilitate the combination / correlation of heterogeneous data in order to synthesize useful information for the creation of integrated knowledge bases. To this end, they provide a framework for attempting to comprehend what is covered by the different information sources.
- Secondly, ontologies have proven their reliability in describing the meaning of concepts and therefore they act as effective means for bridging semantic gaps. Ensuring interoperability is a critical point that needs to be addressed in order to secure the success of a project.

Moreover, Uceda-Sosa et al. (2012) argue that if a city's ontology is *complete* and *authoritative*, then it substantially streamlines the development of applications that require integrated access to city data sources and fosters smart solutions' *replicability*.

Apart from their abovementioned dual role, some additional benefits brought by the development and use of ontologies in (smart) urban planning worth to be stressed (Durán-Muñoz & Bautista-Zambrana, 2013):

- *Explicit organizing and modelling of specialized knowledge*: ontologies have the capacity to specify the meaning of a domain's underlying conceptualization and thus to represent the fundamental elements of that domain (León-Araúz et al., 2013).
- *Possibility of selecting the desired level of granularity*: users can focus on either more general or more specific content, according to their needs.
- *Systematicity in information retrieval*: ontologies offer the possibility to categorize and retrieve information in a structured, cohesive and organized manner.
- *Provision of systematic, well-documented and coherent definitions*.
- *Representation of the multidimensional nature of urban entities*: multidimensionality refers to the categorization of a concept in more than one way within a conceptual model (Bowker, 1997; Kageura, 1997). In the context of ontological representations, multidimensionality is expressed either by the mixing and co-existence of hierarchical and meronymic relations in the same ontological structure; or through the attachment of various types of characteristics (all being at the same hierarchical level) to an entity.
- *Multilinguality*.

Based on the previous remarks, it becomes apparent that the inspected ontologies aspire to restore semantic interoperability by assisting in organizing and integrating heterogeneous data and by offering a shared understanding of the city's basic components; while they usually focus on modelling particular urban sub-systems (e.g., transport, energy, health, safety). What seems to be almost entirely missing from the majority of them is the exploration and representation of cities' *external environment* (Panagiotopoulou, 2018). This term refers to all those external factors / conditions / parameters that may radically affect an area's future trajectory and their thorough analysis constitutes a critical and integral stage of any planning process. One of the most illustrative examples of such factors is the phenomenon of climate change. Climate change may have a radical impact on a place's physiognomy, without that place being able to affect the phenomenon whatsoever. Clearly, very few of the studied ontologies aim at supporting purely smart planning endeavors (Panagiotopoulou, 2018), – i.e., planning *"approaches devoted to planning the "smart" part of the city to best integrate technological innovation with the specific urban peculiarities and historical and cultural value"* (De Nicola & Villani, 2021, p. 24 of 40) – and this partially justifies the external environment's notable absence observed in these current frameworks. This remark is in total alignment with the notion that, an ontology's *scope* and *domain of interest*, determine, to a great extent, its structure, concepts, relationships, attributes, etc. (Noy & McGuiness, 2001).

Focusing exclusively on the realm of the *planning practice* – the cornerstone of the present Dissertation – it should be mentioned that smart city ontologies have been hailed as an innovative, radical and, in many cases, efficient solution to several urban problems, from traffic management and energy conservation, to smart buildings and active participatory planning platforms. Nonetheless, many of these ontologies have been heavily criticized for substantial inefficiencies, that may potentially hinder their significance and usefulness in urban planning. The most important weaknesses met in the international literature are the following:

- *Lack of standardization*: refers to the absence of a common vocabulary and conceptual framework for representing and sharing data about cities and their vital sub-systems (energy, transportation, buildings, public spaces, etc.). Without standardized ontologies, various urban stakeholders may use different terminology (or may attach different meanings to the same terms) and data formats, thereby causing great difficulties in integrating and comparing heterogeneous data. Such a situation may considerably restrict the potential of adopting data-driven approaches to improve urban planning and management (Panagiotopoulou, 2018).

- *Limited interoperability*: it is often said that although ontologies are marketed as indispensable interoperability tools, they are often non-interoperable (Karray, 2021). The same holds true for smart city ontologies due to vital differences detected in the processes of ontology design, development, and representation. This can lead to siloed data that cannot be easily shared and utilized by other systems, abrogating thus ontologies' primary role.
- *Weakness in capturing and representing the complex nature of urban environments*: cities are continuously evolving perplexed systems (Hirst et al., 2012; ISO & IEC JTC 1, 2015; Gardner, 2016) and it is this dynamic and complicated character that constantly poses new obstacles to the perception and modelling of the urban reality. On top of that, most of the times, multiple levels of abstraction (granularity) should be considered, from physical infrastructure and parts thereof to the social and economic systems of the city. Moreover, Fonseca et al. (2000) have diligently studied how urban ontologies can be used for geospatial purposes. They have come across to a plethora of impediments and ambiguities regarding urban space such as: cities' abstract boundaries, intense complexity inherent in urban sub-systems and functions, too little knowledge available beyond human perception, etc.
- *Defiance of existing knowledge – too many ontologies*: Karray (2021) points out the issue of numerous ontologies that have been developed from scratch (60%) to model a domain of interest, instead of reusing existing ontologies and build new knowledge upon them. This causes – inter alia – a great degree of cacophony and disorientation.
- *Dearth of common methodology*: Karray (2021) also highlights that approximately 50% of ontologies are constructed in ad hoc ways and do not follow a particular and scientifically sound methodology.
- *Replicability concerns*: despite some common ground, cities are unique in their core. They have their own extraordinary characteristics, specificities and

priorities. Therefore, an ontology that may work well in one city may not be quite applicable in another.

- *Challenges in ontology maintenance*: maintaining a smart city ontology constitutes an important technical aspect that must be taken into account during its design and development procedure, but a really tricky issue at the same time. As urban landscapes evolve and new data, entities and relationships emerge, ontologies need to be periodically corrected and updated in order to remain accurate and relevant (Valarakos et al., 2006). This, in turn, requires a significant amount of effort and resources, which can be a barrier to the effective use of smart city ontologies in urban planning.
- *Limited stakeholder engagement*: the process of constructing smart city ontologies may not always involve adequate and representative stakeholder engagement. This can result in final outcomes that do not reflect the needs and perspectives of the community as a whole, leading thus to reduced or even unsuccessful implementation of the developed ontologies (Panagiotopoulou, 2018; Panagiotopoulou et al., 2019).
- *Poor documentation*: constitutes a significant barrier to comprehending and using an ontology. Developers should provide clear and extensive documentation of the whole design and construction procedure; include indicative examples and use cases; and actively seek feedback from the target user community to improve their ontology over time.
- *Privacy and security issues*: data collection and sharing within a smart urban ecosystem may raise serious questions about how that data is being used and who has access to it. Additionally, an ontology's limited *'waterproofness'* could render it extremely vulnerable to cyber-attacks.
- *Data quality issues*: ontologies' efficacy relies primarily on high-quality data. However, data quality can be a massive challenge in smart city projects due to the large number and wide spectrum of sources involved. Questionable data quality may potentially lead to inaccurate or incomplete – and thus unreliable – ontologies, a fact which significantly narrows their scope and reduces their usefulness.
- *Urban ontologies not developed by urban planners*: the development of urban ontologies requires collaboration across various disciplines. It is deemed to be

a ‘meeting point’, where numerous scientific streams converge and work in harmony in order to shed light on every different aspect of a city. However, several urban ontologies have been almost exclusively structured – for their most part – by knowledge engineering experts, rather than planners. Quite frequently, the result is a technically sound product, but void of the planning perspective / view. Planners’ restricted engagement may be the source of serious negative consequences such as: lack of alignment with the urban planning goals and objectives, deficient consideration of social, environmental, political, cultural, etc. aspects of the city, limited usability and applicability of ontologies and so on (Panagiotopoulou, 2018).

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Part 1 Contextual Background

Part 2 Bibliographic Review on Smart Cities

Part 3 Construction of an Integrated Indicator Framework for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 4 Bibliographic Review on Semantics & Ontologies

Part 5 Development of an Ontology for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 6 Conclusions & Future Research

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CHAPTER 8: BUILDING AN ONTOLOGICAL REPRESENTATION FOR SMART, SUSTAINABLE, RESILIENT, AND INCLUSIVE CITIES – THE S2RIC ONTOLOGY (S2RICO)

Synopsis*: Despite the remarkable interest in smart cities, noticed during the last decade, a consistent comprehension of the concept is not yet fully established. Various definitions have been occasionally introduced, ranging from exclusively technology-oriented perceptions that treat ICTs as dominant key drivers; to broader and more integrated views, which keep a certain balance between ICTs and aspects of society, economy, governance and participation for meeting urban sustainability objectives. This definitional polyphony has raised severe semantic ambiguity and interoperability issues. Empirical evidence witnesses the prevalence of technology-pushed smart city initiatives, but also their failure to meet expectations in several urban domains. It also unveils that when planning 'smart', the relevance of ICTs and their applications should be in alignment with spatial and other urban peculiarities and sub-systems' interactions, implying the necessity to get a deep insight into the city's ontology. Moreover, modern urban planning approaches should incorporate concerns related to sustainability, resilience and inclusiveness; and provide powerful tools for gauging the performance of crafted strategies and launched initiatives. In such a context, the present chapter, the last piece of the puzzle of this Dissertation, describes the journey towards the development of an ontological representation of the smart cities' realm, as captured and perceived by the planning scope. The proposed ontology will attempt to outline smart cities' main key drivers and interrelationships; elucidate – to the best possible degree – the smart city concept; integrate contemporary planning dimensions; and embed a unified global indicator framework that will guide cities towards identifying appropriate city- and citizen-specific indicators for carrying out relevant assessments and implementing sound policies.*

8.1. Setting the Ontological Context

The severe *definitional polyphony* (Panagiotopoulou et al., 2019) that accompanies the smart city term (see chapter 2 for extensive analysis) has rendered it an extremely equivocal, confusing and contentious concept; judging by the heated debates on its meaning, the absence of a commonly established and accepted definition and the arising interoperability issues. Moreover, experience and knowledge gained so far through various smart city examples highlight the immense prevalence of purely technology-pushed strategies and initiatives; and the limited performance of such approaches in many urban aspects. This entails the need for delineating the different notions, uses, and applications of the term through the underlying concepts and the interrelationships among them; or, in other words, getting a better understanding of a city's *ontology*, as a first step, and bridging this ontology with the ontology of technology or various smart applications afterwards (Komninos et al., 2015).

Actually, many recent studies (Poveda-Villalón et al., 2014; Komninos et al., 2015; Abid et al., 2016; Rani et al., 2016; etc.) claim that ontologies and ontology-based technologies can find widespread application and use in the field of smart cities, while they have gradually begun to penetrate this scientific area and have become a new and promising (in terms of prospects and results) research topic. An ontology, defined as *"a formal, explicit specification of a shared conceptualization"* (Studer et al., 1998, p. 184), i.e., a formal description / representation of knowledge of a specific scientific domain, provides the essential concepts to be modelled, as well as their in-between relationships. Ontologies have been used in various fields such as medicine, biology, law, engineering, robotics, artificial intelligence, geography, etc. They are particularly useful in applications that require a common understanding among different actors (semantic Web, information extraction, retrieval, integration, etc.).

In light of the above remarks, the present chapter endeavors to explore, analyse and formalize the semantics of the smart city concept via the development of a new conceptual model, that aspires to:

- Describe the basic building blocks / key drivers / fundamental concepts of the smart city (classes of the ontology), based on the findings, empirical evidence, and proposals of the available international literature.

- Delineate the direct relationships between the ontology's fundamental classes in order to grasp the dynamics of their interactions.
- Integrate the unified, multidimensional, global indicator framework, structured in chapter 5, into the new ontology; thereby embedding the dimensions of smartness, sustainability, resilience and inclusiveness into the new conceptual model; and, finally, providing a useful planning tool for performance assessment and benchmarking purposes.

More specifically, the contemporary urban challenges and threats that have given birth to the smart city paradigm, explored in chapter 1; the rigorous conceptual analysis of the smart city term that takes place in chapter 2; the various aspects of the technological dimension, thoroughly delineated in chapter 3; the plethora of smart applications deployed in successful smart city examples, described in chapter 4; the global, integrated and multidimensional indicator framework for smart, sustainable, resilient and inclusive cities, constructed in chapter 5; the basic theoretical background on semantics and ontologies established in chapter 6; as well as the demarcation of the smart city ontologies realm, in order to find out what is already out there and identify critical opportunities and weaknesses, provided in chapter 7; serve as valuable input to the new ontological scheme (Figure 8-1).

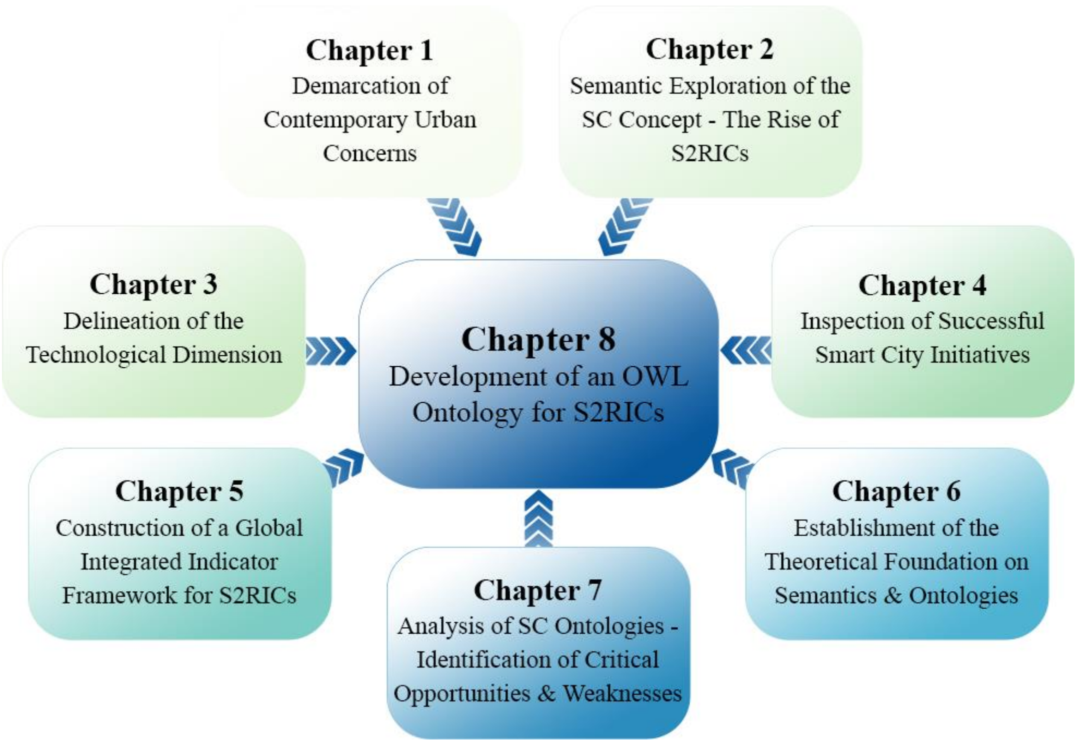

Figure 8-1: Basic Input to the Proposed Ontology (Source: Own Elaboration)

The *scope* of this effort is to boost planning and policy-making endeavors towards smartening up contemporary urban environments. The proposed ontology aims at incorporating the heterogeneous aspects and challenges that pertain to modern cities; and fostering a common formal language and understanding among the different actors involved. It is expected to support urban planning and more informed policy decisions [type of (spatial) interventions, focus sectors, smart applications that should be deployed, etc.] by feeding relative decision-making processes with the necessary organized knowledge on a specific domain, rendering thus the whole planning procedure more integrated, innovative, efficient, as well as citizen- and city-oriented.

8.2. Motivation

The most significant factors that have guided the development of a new ontology for smart, sustainable, resilient, and inclusive cities (henceforth S2RICO), are divided into two broad categories, on the basis of how imperatively they necessitate the structuring of this conceptual model (Figure 8-2).

Figure 8-2: Reasons behind the Development of the S2RICO (Source: Own Elaboration)

According to Figure 8-2, the most pressing factors (primary factors) that have driven the building of the S2RICO are shaded in purple colour and form a small circle that surrounds the S2RICO concept. These factors are pertinent to the intense *definitional pluralism* and *conceptual vagueness* that characterize the smart city term, which, in turn, have instigated serious *semantic interoperability* gaps. Moreover, the absence of a clear view of what smart cities actually are (constituents and their interrelations), and how smartness is practically translated when it comes to real urban environments, has induced severe confusion to policy makers, planners, urban stakeholders, and municipal authorities, leading thus to failed or partially successful smart initiatives.

The factors that are conducive to the S2RICO development, but are less pressing and have a broader scope compared to the primary ones (secondary factors), are shaded in blue color and form a bigger circle that surrounds the S2RICO concept and the primary factors as well. These focus on the need to encompass contemporary urban planning concerns (related to sustainability, resilience, and inclusiveness); and urban challenges and threats – with most of them delineating cities' external environment to a great extend – that are absent or their presence is very limited in most existing smart city ontologies.

Lastly, the structuring of a unified indicator framework – founded on cities' imperative need to measure their performance in terms of smartness, sustainability, resilience, and inclusiveness – that will guide them towards selecting the most suitable metrics, but will also secure consistency among indicators developed by various standardization bodies, completes the set of secondary factors that have led to the construction of the S2RICO.

8.3. Building the Smart, Sustainable, Resilient and Inclusive Cities Ontology (S2RICO)

The particular section provides a succinct description of the construction process of the ontological scheme for smart, sustainable, resilient and inclusive cities (S2RICs). In general lines, the purpose of this ontology is the *semantic exploration* of the smart city term through the identification of its fundamental concepts (classes); the delineation of their in-between direct relationships (object properties); and the integration of a unified global indicator framework. The latter intends to embed contemporary urban planning concerns / dimensions (sustainability, resilience, and inclusiveness) into the smart city discourse; provide a certain guidance to planners and policy makers towards navigating into this framework and select proper indicators for assessing urban sustainability achievements; and serve as a benchmarking tool.

As already stressed in chapter 6, ontologies are built and utilized to capture knowledge about a particular field of interest. To do so, they describe the concepts that comprise the field (its structural elements), but also the relationships among them.

Uceda-Sosa et al. (2012), claim that *"not all ontologies are created equal"* (slide 5/30). In practice, several ontological schemata are developed to serve various purposes (scope) and are used in combination with inference engines and rules (Table 8-1).

Table 8-1: Categories of Ontological Schemata (Source: Adapted from Uceda-Sosa et al., 2012)

		Purpose	Instances	Inferencing	Examples
Normative Schema	**As a Deductive System**	Development of a Deductive System (Axioms & Deductive Rules)	Part of the Knowledge Base	Defined by Rules	Expert Systems Optimization Planning ***S2RICO***
	As a Data Blueprint	Constraint of a Domain	Must Conform to the Normative Schema Determined by the Ontology	Subsumption Class Inferencing	Biomedical and Life Sciences (FMA, Radlex)
	As a Data Classifier	Classification of Open Data	Unknown Formats	Subsumption Class Inferencing	Tag Ontologies (MOAT, Echarte, SCOT, NAO, etc.)
	As a Data Integrator	Integration of Pre-Defined Model to Existing Data Sources	Instances are Mapped – No Constraint Enforcement	Subsumption Class Inferencing Entity Inferencing	SCRIBE
Integrative Schema – Dependent on Instances	**As a Data Mapping Vocabulary**	Mapping to / from Existing Data Sources	Mined Instances Determine the Ontology / Schema	Subsumption Class Inferencing	D2RQ

Pursuant to Table 8-1, ontologies are developed to operate either as data mapping vocabularies, data integrators, data classifiers, data blueprints; or as deductive systems. The case of S2RICO falls into the last category, since it constitutes a deductive system that makes inferences on the basis of defined constraints (axioms and rules) and offers an instantiated knowledge base. Simply put, S2RICO is used to represent knowledge in a structured way, and logical rules are then applied to make deductions from that knowledge.

The most recent development in standard ontology languages is Ontology Web Language 2 (OWL2 from now on), proposed by the World Wide Web Consortium (W3C). OWL 2 is a logic-based ontology language, which includes classes, properties, individuals (instances) and data values in order to represent rich and perplexed knowledge about a domain. It can be subjected to reasoning either to verify an ontology's consistency, or to render implicit knowledge explicit (World Wide Web Consortium [W3C], 2012).

The structuring of the S2RICO (OWL-based ontology) is implemented by use of the Protégé 5.5.0 software. Protégé is a free, open-source editor for developing, visualizing, and maintaining ontologies, while it supports numerous reasoners (validation of ontological consistency and inference of new information) and several additional knowledge management tools (plugins).

Reasoners are automated computational tools designed to analyse and infer logical consequences and relationships within a given ontology. More particularly, they utilize a set of logical rules and inference mechanisms to derive implicit knowledge from the explicit statements and relationships encoded in the ontology (Dentler et al., 2011; Sequeda, 2013; DeBellis, 2021). By employing various reasoning techniques, such as deduction, classification, and inference, they are able to (Dentler et al., 2011; Sequeda, 2013): identify implicit facts that may not be directly defined in the ontology; investigate class satisfiability (check out whether it is possible for a class to have instances without provoking consistency errors); classify entities (determine the IS-A relationships between classes which is especially useful in cases of multiple inheritance); validate and verify ontologies by detecting logical inconsistencies and contradictions, ensuring thus the integrity and reliability of the knowledge representation scheme; conduct instance checking; and support advanced querying capabilities (complex queries that involve logical relationships and constraints). This way, reasoners enable access to relevant information based on logical inferencing, and consequently, enhance the efficacy of knowledge retrieval and decision-making processes.

Protégé 5.5.0. has several built-in reasoners, but many others are available as plugins. For the implementation of the of the S2RICO, the Pellet reasoner is used. Pellet is a high-performance reasoning engine, designed to work with OWL ontologies and presents a series of impressive advantages, such as *scalability* (ability to handle ontologies with thousands or millions of concepts, properties, and individuals), *expressive reasoning*, *rule-based reasoning* [extension of reasoning capabilities by supporting rule-based reasoning using Sematic Web Rule Language (SWRL)], *modularity and extensibility*, *compatibility and interoperability*, *active user community and rich documentation* (Sirin et al., 2007).

8.3.1. Steps of Ontological Development

Various methodologies for ontology development have been proposed (Ushold & King, 1995; Gruninger & Fox, 1995; Mizoguchi et al., 1995; López et al., 1999; Staab et al., 2001; etc.), but the prevailing view is that ultimately there is no right or wrong way to model a domain. Conversely, there are always multiple, viable ways to structure an ontological representation; but the final outcome mostly depends on the intent and expectations of the creator (Noy & McGuinness, 2001). Ontology's *domain* and *scope* are two decisive factors that guide the selection of the most suitable methodological approach. Moreover, ontology development is an *iterative* process, in the sense that its constant revision – throughout its entire lifecycle – is rather unavoidable. Finally, concepts incorporated in an ontology must be close to objects (physical or logical) and relationships, that are valid for a certain domain. Simply put, ending up with the reasons the ontology will be used for, and how general or detailed (depth of the tree structure) it will be, lead to the various modelling decisions (Noy & McGuinness, 2001).

Lacking a standardized and strict way of building an ontology, the steps of ontological development followed in this case correspond to some general and empirical stages of ontological design and implementation that each methodology ought to incorporate, as these are articulated by Noy and McGuinness (2001):

- Determination of the *domain* and *scope* of the ontology.
- Reuse of *existing ontologies*.
- Enumeration of *important terms* of the domain.
- Definition of *classes* and *class hierarchy*.
- Establishment of *relationships* among classes.
- Attribution of *properties* and their respective *values* to classes.
- Addition of *instances*.

Determination of the domain and scope of the ontology

Noy and McGuinness (2001) suggest that the construction of an ontological scheme should begin by defining its *domain of interest* and *scope*. To do so, the following basic questions should be taken into very serious consideration:

- Which domain of interest will the ontology cover?
- What are the reasons behind its construction?
- To what types of questions will the ontology provide answers?
- To whom is the ontology addressed and who will maintain it?

In the context of the Dissertation, the field of *smart cities* – seen from the *planning point of view* – has been defined as the *domain of interest* of the proposed ontology. The *scope* of the S2RICO focuses on: acquiring a *deep insight* into the smart urban environments, as these are delineated by the available literature; addressing the severe problem of *definitional impreciseness* of the smart city term – which has caused great semantic ambiguity and polysemy issues and, therefore, dearth of semantic interoperability – by establishing an integrated conceptual basis; coping with the lack of a *commonly shared indicator framework* that reflects the contemporary urban stresses and developmental goals (sustainability, resilience, inclusiveness) by incorporating a relevant, unified, global indicator framework into the new scheme; delivering a *cognitive tool* for aiding planners and policy makers in grasping smart cities' fundamentals and the interrelations among them; developing a *navigation system* that will guide users towards selecting the most appropriate indicators for measuring the performance – in terms of smartness, sustainability, resilience, and inclusiveness – of various urban sectors; and offering a *benchmarking* instrument.

Reuse of existing ontologies

The use of existing ontologies or controlled vocabularies is a common but not a compulsory step of the ontological development process, since it is possible that some of them may cover the domain of interest as a whole, partially, or they may model related domains (Noy & McGuiness, 2001). Therefore, it is wise to investigate whether these can be used as the ground for developing a more target-oriented ontology. Ontology reuse involves the development of a new ontology *"through maximizing the adoption of pre-used ontologies or ontology components"* (Lonsdale et al., 2010, p. 318); and exhibits several advantages, such as improving the quality of the developed ontology, facilitating mapping among input ontologies, and enabling ontology update (Lonsdale et al., 2010).

It should be noted that none of the existing ontologies has been selected to participate in the building process of the S2RICO at this very early stage. However, reuse of current ontological representations is anticipated to occur during the revision phase of the initial scheme.

Enumeration of important terms in the ontology

The particular step refers to the identification and gathering of all those terms that are deemed to be essential for describing the ontology's domain of interest; and may refer to concepts, relationships, or properties, without taking into account any semantic equivalence or overlapping at this stage.

In this respect, based on the thorough exploration and analysis of the profusion of smart and/or smart and sustainable cities' definitions (see chapter 2), all the fundamental components of these terms, their in-between relations and several of their attributes are collected and used as valuable input. In addition, the global indicator frameworks, inspected in chapter 5, provide an indispensable pool of concepts that will populate the proposed ontology.

At this point it should be stressed that numerous terms, pertinent to contemporary, urban opportunities and threats, emerged from a *participatory procedure* that took place in the context of the 4th Euro-Mediterranean Conference, which was held in Athens in October 2020. Part of the conference was dedicated to a stimulating dialogue among the scientific, entrepreneurial and policy-making communities, on the topics raised by the EU "Green Deal" and especially the "Mission for Climate-Neutral and Smart Cities". The whole process intended to identify the opportunities and challenges associated with the downscaling of the Green Deal as well as the Climate-Neutral and Smart Cities' priorities and targets to the regional and city level. In order to detect and prioritize the *key issues* and *barriers* with regard to the implementation of the above strategies; and use the obtained information to enrich the ontology, a *questionnaire* was structured and sent to 284 persons in total. Respondents were given one month to fill in the questionnaire and, finally, 81 answers were received (28% of the initial sample of recipients).

In the complementary part of the questionnaire, respondents were requested to express their perception on contemporary cities by use of *three keywords* that largely reflect both positive and negative challenges, currently evolving or expected to affect future urban developmental trails in a medium to longer term. Based on the received answers, a *word cloud* (Figure 8-3) that presents the strong points but also the vulnerabilities of modern cities, as these grasped by the respondents, is produced. Most of these terms are added in the S2RICO and more specifically into the `UrbanChallenge` super-class (see next step of the ontological development process for further information).

Figure 8-3: Cloud of Terms Regarding Contemporary Urban Opportunities, Challenges and Threats (Source: Own Elaboration)

Finally, it is worth mentioning that although the spatial reference of the questionnaire focuses on the Mediterranean Region, most of the obtained keywords are kept and added in the ontology, since these represent global challenges and threats, but with diversified degree of intensity compared to the Mediterranean.

Definition of classes and class hierarchy

This is the initial phase of organizing the terms gathered during the former step (enumeration of important terms in the ontology). Particular attention should be paid to their proper classification, in order to end up with hierarchical structures that efficiently describe the domain of discourse and serve the scope of the ontology. Terms which represent entities characterized by independent existence, are selected as classes. These classes are used to denote all entities included in a concept and are associated with other classes through hierarchical (IS-A) relationships (Figure 8-4).

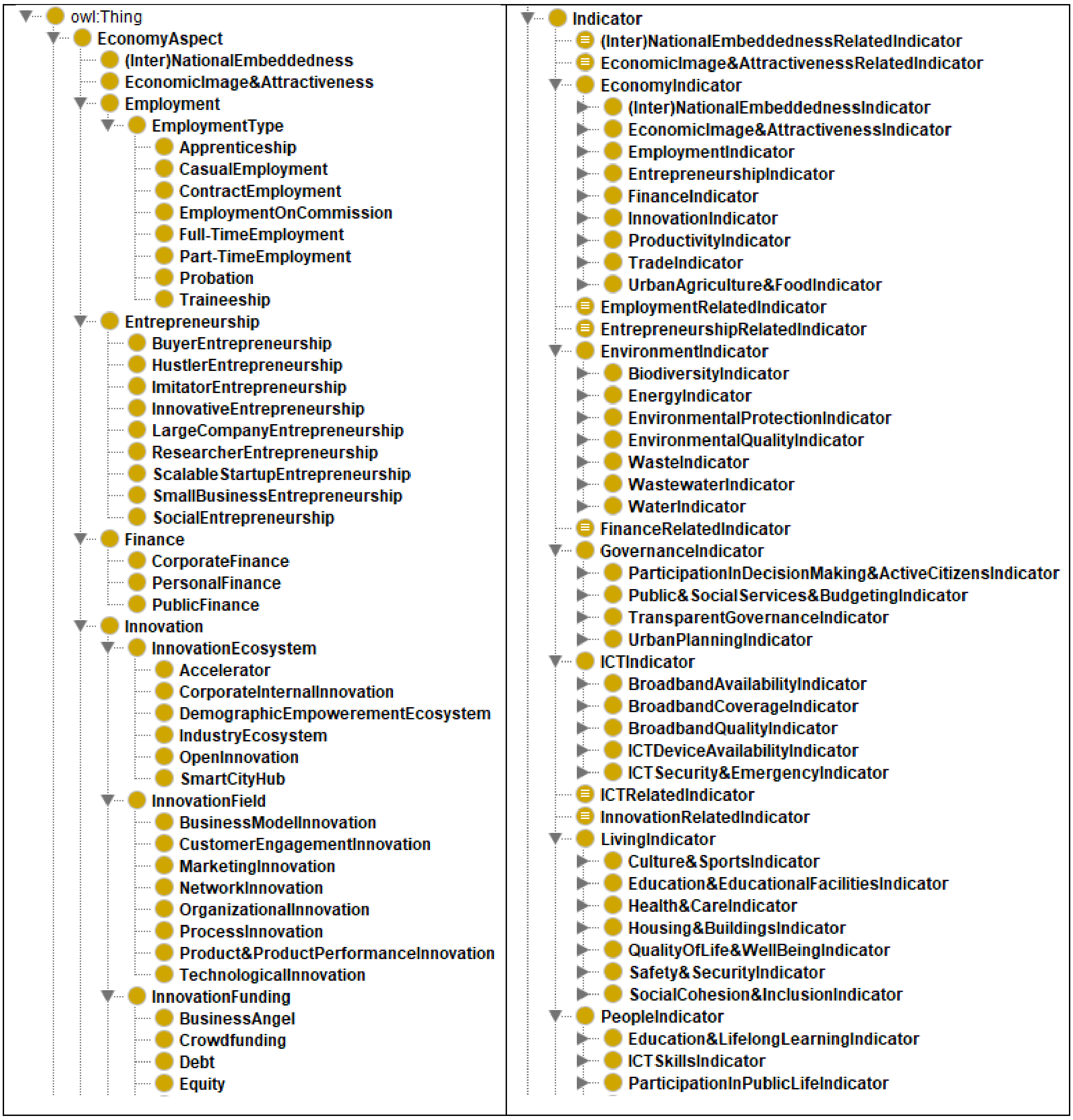

Figure 8-4: Indicative Segments of the Hierarchical Structure of the S2RICO (Source: Own Elaboration)

Considering the very nature of the collected terms, but also the various proposed taxonomies and classifications emerging from the available international literature, nine super-classes, that describe cities' main physical, digital / technological, social, institutional and functional aspects, are defined (see Figure 8-5). Six of them (EconomyAspect, EnvironmentAspect, PeopleAspect, LivingAspect, TransportAspect, and GovernanceAspect) are equivalent to the six fundamental characteristics of Giffinger et al. (2007). The seventh class (UrbanChallenge) includes concepts related to contemporary urban challenges, with the majority of them delineating the external decision environment. The eighth class (Indicator) contains all the indicators that form the integrated global indicator framework, whose construction process is thoroughly analysed in chapter 5; while the ninth class (TechnologyAspect) reflects cities' digital skin, which permeates every urban facet (Figure 8-5), with particular focus on ICT infrastructure, online services, data, and applications.

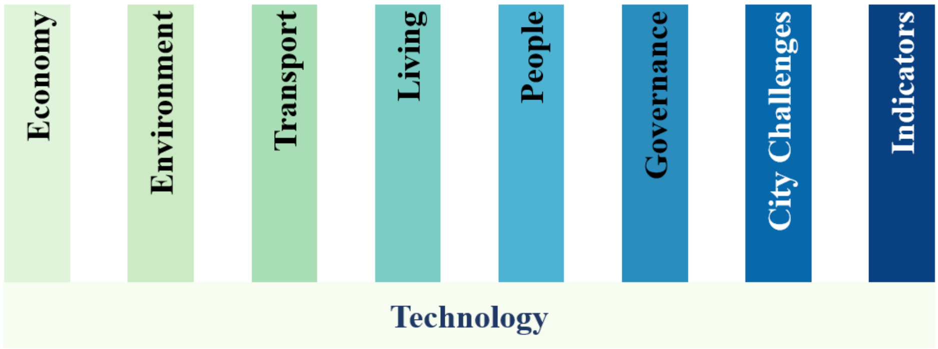

Figure 8-5: Super-Classes of the S2RICO and the Cross-Cutting Nature of Technology (Source: Own Elaboration)

The nine super-classes of the S2RICO are in alignment with the three smart city dimensions (see Figure 2-7 in chapter 2). The TechnologyAspect class describes the hard dimension; the EconomyAspect, EnvironmentAspect, PeopleAspect, LivingAspect and Transport&MobilityAspect classes demarcate the human (urban socio-economic) dimension; while the UrbanChallenge, Indicator, and GovernanceAspect classes represent the institutional dimension. Moreover, all of them consist of concepts that fall into the three different types of spaces – *physical, social, and digital* – that any modern city is composed of.

It is highlighted that these super-classes incorporate both *static* and *dynamic* facets of contemporary urban environments. Static facets refer to cities' entities that continue to exist through time (e.g., country, person, building, road, bridge); whereas dynamic facets focus on the operation and functions of urban systems and allude to processes of any kind (e.g., operation of city services, emergency response, innovation, learning and knowledge processes). These types of entities actually reflect the continuant and occurrent entities that are met in top-level ontologies.

`Continuants` represent entities that exist in time while maintaining their identity, i.e., entities that are grasped as complete concepts at any point in time. On the contrary, `occurrents` describe entities which happen, unfold or develop through time, i.e., entities that only a part of them can be perceived by someone at a given moment in time (e.g., an earthquake event or a hurricane). Grenon and Smith (2004) and Smith and Grenon (2004) point out that occurrents are events in which continuants are involved. Moreover, it is noted that both continuants and occurrents extend to space and time, while their distinction allows for the classification of real-world entities, such as objects, processes, events, and states (Kougias et al., 2015).

The final hierarchical structure (first and second level classes) of the S2RICO is presented in Figure 8-6.

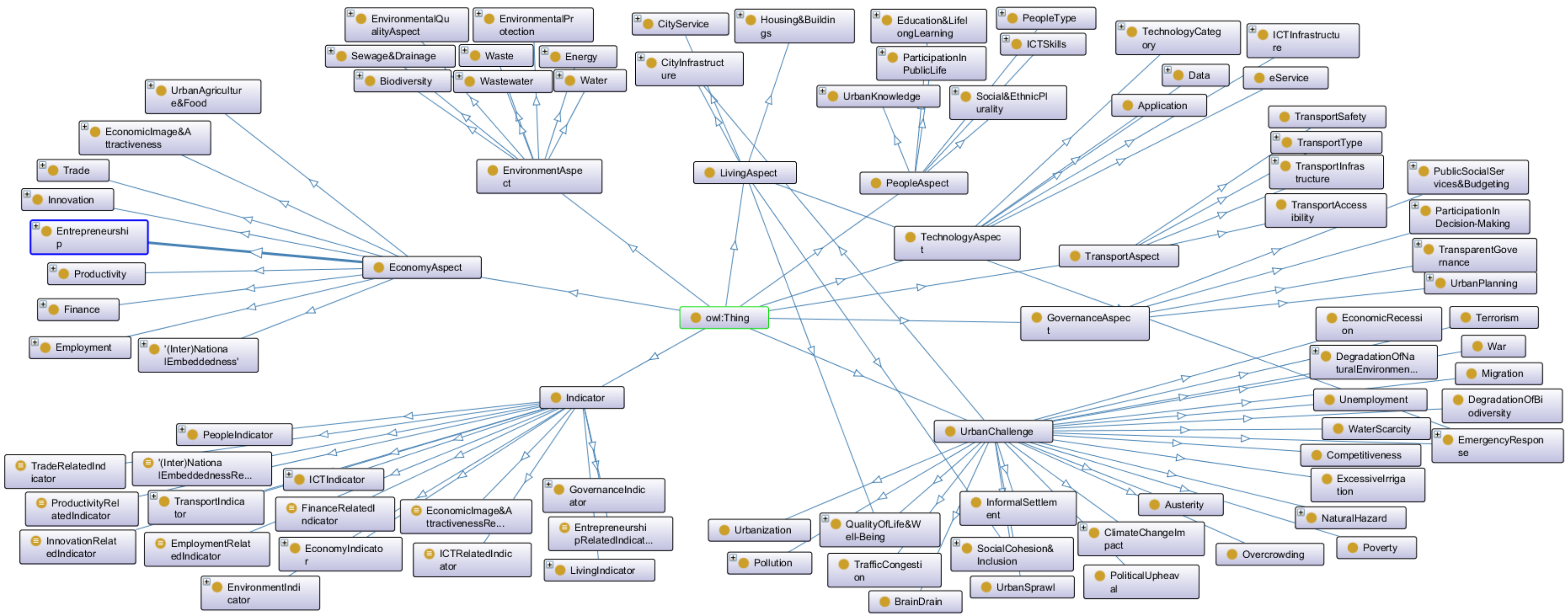

Figure 8-6: Basic Hierarchical Structure (First and Second Level) of the S2RICO (Source: Own Elaboration)

Establishment of relationships between classes

Apart from the hierarchical relationships that have already been established in the former step, there are other types of relationships that connect the classes to each other; e.g., *has part, contributes to, affects, provokes, increases, activates*. These should be described and defined as well, so as to form a full picture of the interactions and interrelationships between the concepts. The significance of getting a deep insight into the relations developed between the elements of a smart city is beautifully summarized in the words of Kanter and Litow (2009), who state that:

> A smarter city should be viewed as an organic whole – as a network, as a linked system. In a smarter city, attention is paid to the connections and not just to the parts. Civic improvement stems from improved interfaces and integration. (p. 2)

However, bearing in mind cities' extreme complex nature and the fact that an attempt to capture all the relations between the S2RICO classes would cause great confusion due to their excessive number – not to mention that such an effort would be completely vain, since all urban sub-systems are somehow interrelated directly or indirectly – it was decided that the direct relations between the indicators (sub-classes of the `Indicator` super-class) and the basic thematic categories / classes of the S2RICO will be mainly modelled.

The delineation of these relations is accomplished with the help of a matrix that contains all the indicators of the proposed integrated global indicator framework and the fundamental concepts (basic classes of the ontology) that describe contemporary urban environments. To illustrate in a simple and comprehensible way how the various indicators address their thematic linkages (their interactions with the principal urban elements), Table 8-2 presents an overview of their potential to measure progress towards smartness, sustainability, resilience, and inclusiveness across the basic classes of the ontology.

According to Table 8-2, the classes to which the indicators primarily apply are shaded in black and grey. Black indicates a very clear, strong, direct relationship; while grey signifies a clear, direct, but less intense link, compared to the black colour.

Table 8-2: Indicative Indicators for Water and their Relations with S2RICO's Classes (Source: Own Elaboration)

Indicators	Innovation	Entrepreneurship	Finance	Employment	Economic Image & Attractiveness	Productivity	Trade	(Inter)national Embeddedness	Urban Agriculture & Food	Transport & Mobility	Technology	Environmental Quality	Environmental Protection & Awareness	Waste	Wastewater	Biodiversity	Water	Sewage / Drainage	Energy	Lifelong Learning, Training & Level of Qualification	Social & Ethnic Plurality	Participation in Public Life	ICT Skills	Culture & Sports	Health & Care	Safety & Security	Housing & Buildings	Education	Social Cohesion & Inclusion	Quality of Life & Well-Being	Participation in Decision Making / Active Citizens	Public Social Services & Budgeting	Urban Planning	Transparent Governance
17.1 Total water consumption per capita																																		
17.2 Freshwater consumption																																		
17.3 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources																																		
17.4 Total domestic water consumption per capita																																		
17.5 Compliance rate of drinking water quality																																		
17.6 Proportion of households with water saving installations																																		
17.7 Efficient use of water (use per GDP) – Water productivity																																		
17.8 Change in water-use efficiency over time																																		

Indicators	Innovation	Entrepreneurship	Finance	Employment	Economic Image & Attractiveness	Productivity	Trade	(Inter)national Embeddedness	Urban Agriculture & Food	Transport & Mobility	Technology	Environmental Quality	Environmental Protection & Awareness	Waste	Wastewater	Biodiversity	Water	Sewage / Drainage	Energy	Lifelong Learning, Training & Level of Qualification	Social & Ethnic Plurality	Participation in Public Life	ICT Skills	Culture & Sports	Health & Care	Safety & Security	Housing & Buildings	Education	Social Cohesion & Inclusion	Quality of Life & Well-Being	Participation in Decision Making / Active Citizens	Public Social Services & Budgeting	Urban Planning	Transparent Governance
17.9 Percentage of water loss in the water distribution system																																		
17.10 Average annual hours of water service interruptions per household																																		
17.11 Availability of smart water meters																																		
17.12 Percentage of the city's water distribution network monitored by a smart water system																																		
17.13 Percentage of drinking water tracked by real-time, water quality monitoring station																																		
17.14 Environmental water quality monitored by ICT																																		
17.15 City freshwater sources monitored using ICT																																		
17.16 Availability of visualised real-time																																		

Indicators	Innovation	Entrepreneurship	Finance	Employment	Economic Image & Attractiveness	Productivity	Trade	(Inter)national Embeddedness	Urban Agriculture & Food	Transport & Mobility	Technology	Environmental Quality	Environmental Protection & Awareness	Waste	Wastewater	Biodiversity	Water	Sewage / Drainage	Energy	Lifelong Learning, Training & Level of Qualification	Social & Ethnic Plurality	Participation in Public Life	ICT Skills	Culture & Sports	Health & Care	Safety & Security	Housing & Buildings	Education	Social Cohesion & Inclusion	Quality of Life & Well-Being	Participation in Decision Making / Active Citizens	Public Social Services & Budgeting	Urban Planning	Transparent Governance
information regarding water use																																		
17.17 Number of different sources providing at least 5% of total water supply capacity																																		
17.18 How many years ahead does the city's water plan look (e.g., does it analyse the city's 10 year + needs?)																																		
17.19 Percentage of city population that can be supplied potable water by alternative methods for 72 hours during disruption																																		

For example, the indicator "17.4: Total domestic water consumption per capita" has very strong primary links to water infrastructure and quality of life and well-being (black shaded relations). However, this indicator is also useful for determining citizens' awareness of water consumption; the level of training they have received on household water consumption practices; issues of social cohesion and inclusion regarding water accessibility; and the impact of pertinent regulations and crafted strategies in water consumption behaviours and patterns. Therefore, the environmental protection & awareness, lifelong learning, training & level of qualification, social cohesion & inclusion and urban planning themes are shaded in grey.

In OWL, relationships between classes or individuals are represented by the so-called *object properties*. In the case of the S2RICO and the modelling of the relations between the indicators and other classes of the ontology, two inverse[6] object properties are defined: `isStronglyAssociatedWith` and *`isRelatedTo`* (Figure 8-7). The first one reflects strong, direct relationships of the constructed matrix, shaded in black colour; while the second describes direct but weaker relations, shaded in grey colour.

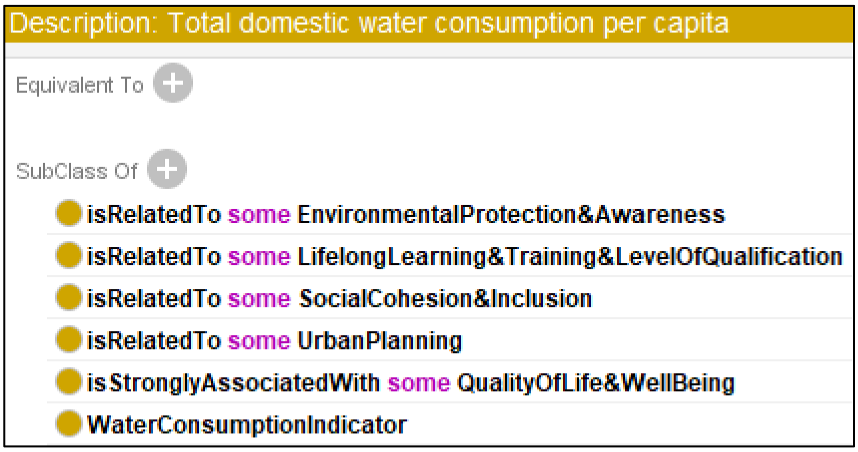

Figure 8-7: Definition of Relationships between the "Total Domestic Water Consumption per Capita" Indicator and Other Classes of the S2RICO (Source: Own Elaboration)

It should be stressed that the use of `isStronglyAssociatedWith` and `isRelatedTo` relations is accompanied with the necessary *quantifier existential restrictions*. Quantifier restrictions entail that a property must have some or all values of a particular class. Existential restrictions represent classes of individuals that participate in at least one

6 If a property links class A to class B, then its inverse property links class B to class A. For example, the object property `PizzaTopping hasIngredient Peperoni` has inverse property `Peperoni isIngredientOf PizzaTopping`. In general lines, inverse object properties imply a couple of `hasProperty`- and `isPropertyOf`-type relations.

relation along a specified property. For example, the restriction `isRelatedTo some UrbanPlanning` (see Figure 8-7) is an existential restriction, which restricts the `isRelatedTo` object property to the `UrbanPlanning` realm. In other words, this restriction describes the class of all the individuals that have at least one `isRelatedTo` relationship to an individual that is a member of the `UrbanPlanning` class.

Indicatively, the defined non-hierarchical relationships between the "Total domestic water consumption per capita" indicator and other classes of the S2RICO are graphically represented in Figure 8-8 with the help of the 'OntoGraf' tab of the Protégé software.

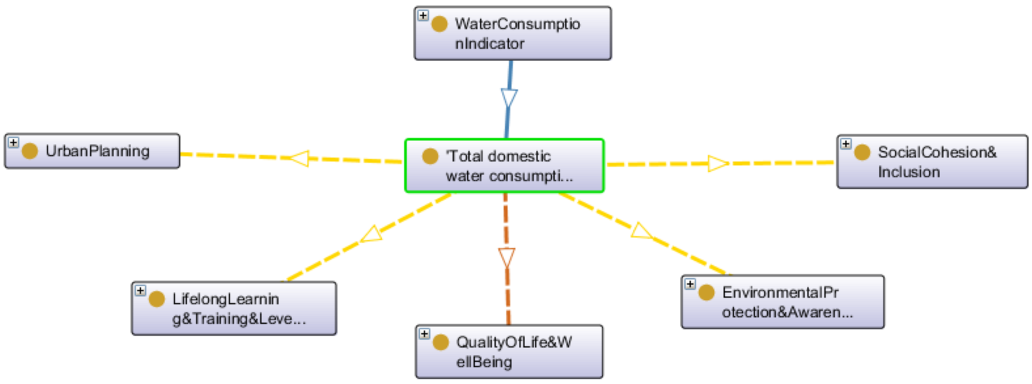

Figure 8-8: Graphical Representation of the Non-Hierarchical Relationships between the "Total Domestic Water Consumption per Capita" Indicator and Other Classes of the S2RICO (Source: Own Elaboration)

Finally, the position of the "Total domestic water consumption per capita" indicator in the S2RICO hierarchical structure is presented in Figure 8-9.

Additionally, it should be noted that apart from the `isStronglyAssociatedWith` and `isRelatedTo` relations, the S2RICO ontology includes many more object properties that connect the classes and the individuals to each other, such as (see also Figure 8-10): `hasPart`, `isPartOf`, `hasInput`, `hasOutput`, `hasValue`, `activates`, `creates`, `contains`, `increases`, `affects`, `causes`, `facilitates`, `funds`, `emergesFrom`, etc.

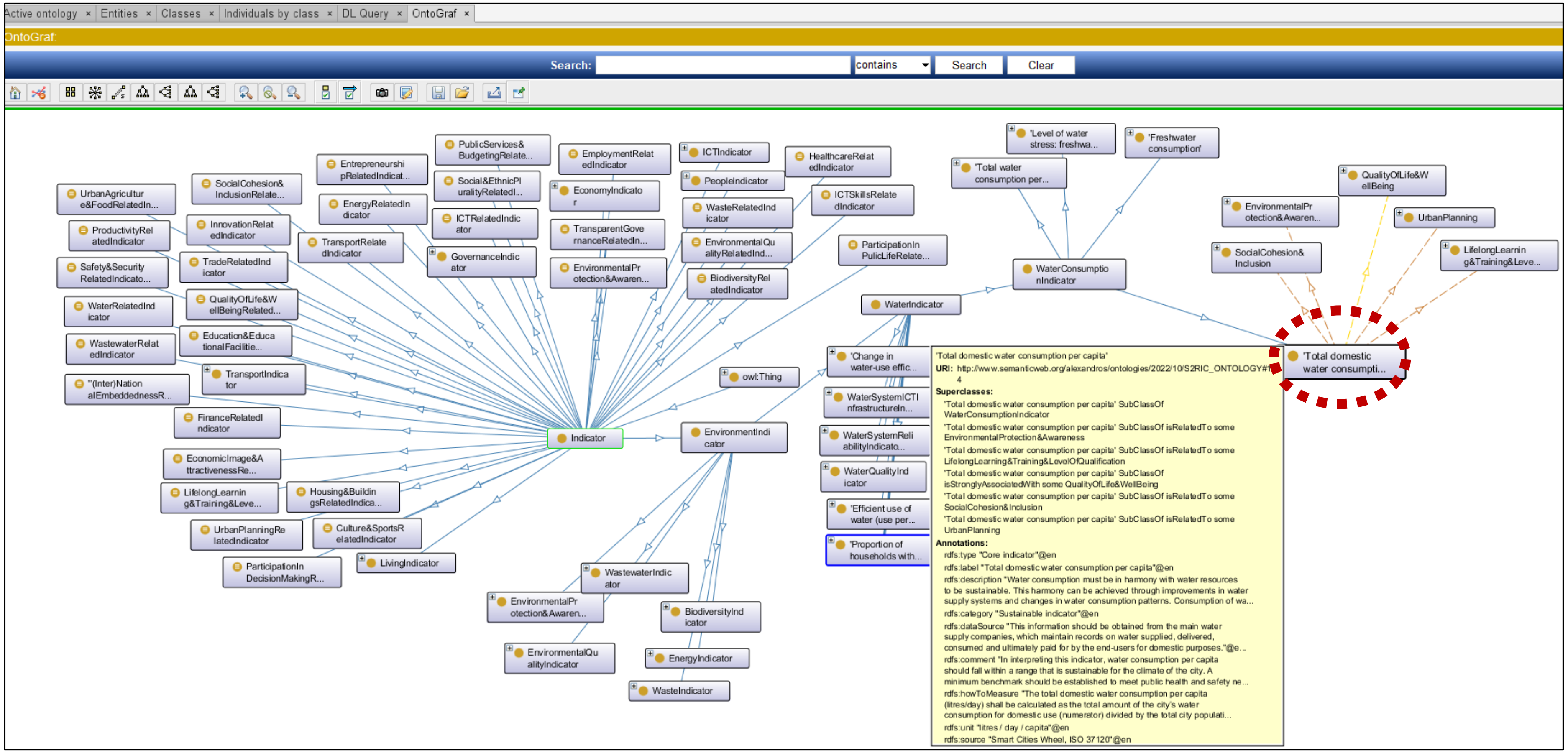

Figure 8-9: The Position of the "Total Domestic Water Consumption per Capita" Indicator into the S2RICO Hierarchical Scheme (Source: Own Elaboration)

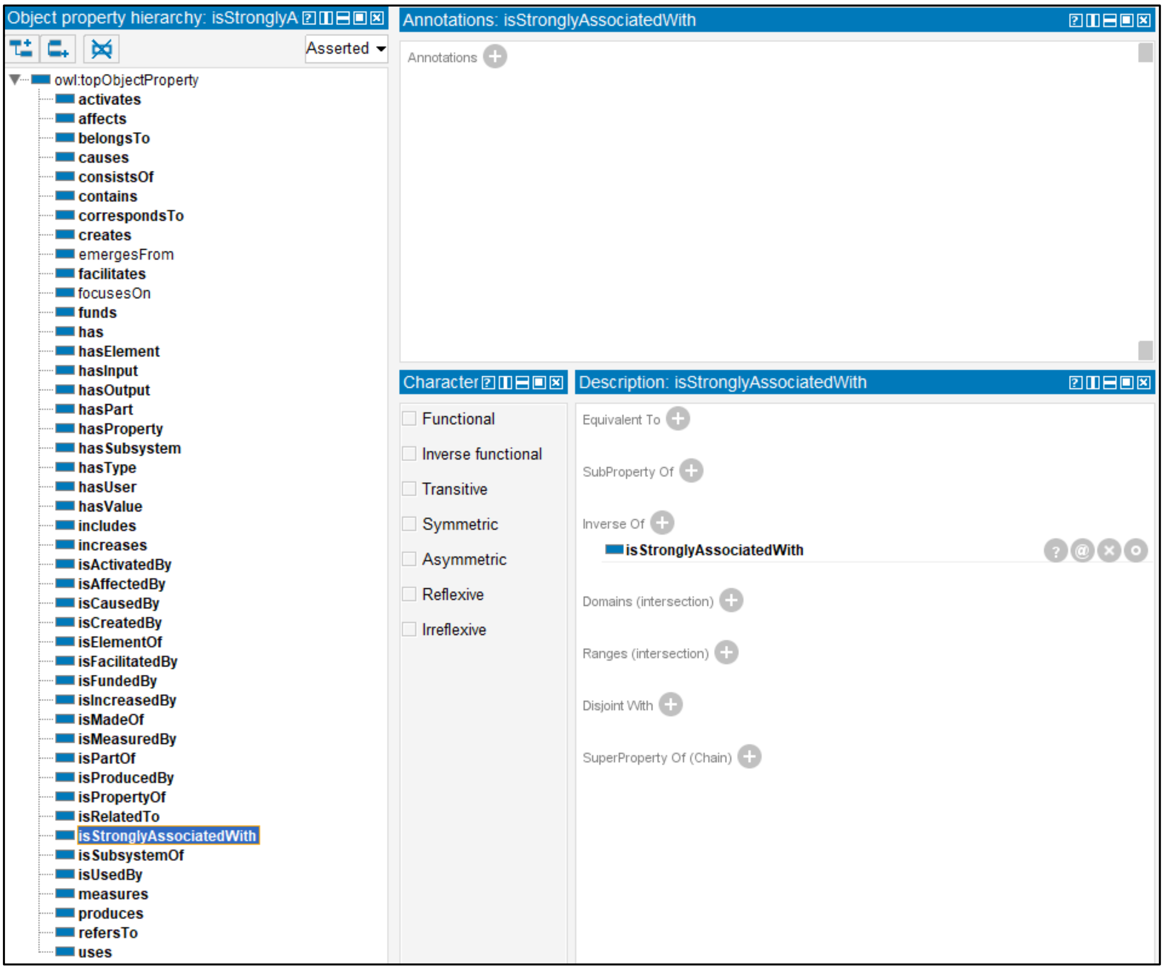

Figure 8-10: Object Properties of the S2RICO (Source: Own Elaboration)

Attribution of properties and their respective values to classes

Aside from the object properties whose range and domain correspond to classes, there are also properties – henceforth *data properties* – whose range is defined as a simple datatype (e.g., string, integer, float, date). For example, the range of the population attribute is integer. The distinction between object and datatype properties in OWL is similar to the distinction between an association and an attribute in the Unified Modeling Language (UML), or the distinction between relations and attributes in Entity-Relationship (E-R) modelling (DeBellis, 2021).

In the context of the S2RICO, important data properties that assign values to classes and instances are related to population metrics, building, green, and population densities, energy consumption metrics, environmental metrics, hospitality and culture metrics, etc. (see Figure 8-11). Most of them refer to well established indicators, proposed by international organizations (e.g., ISO), or indicators that are taken into account for the creation of the Innovation Cities™ Index (2thinknow, n.d.).

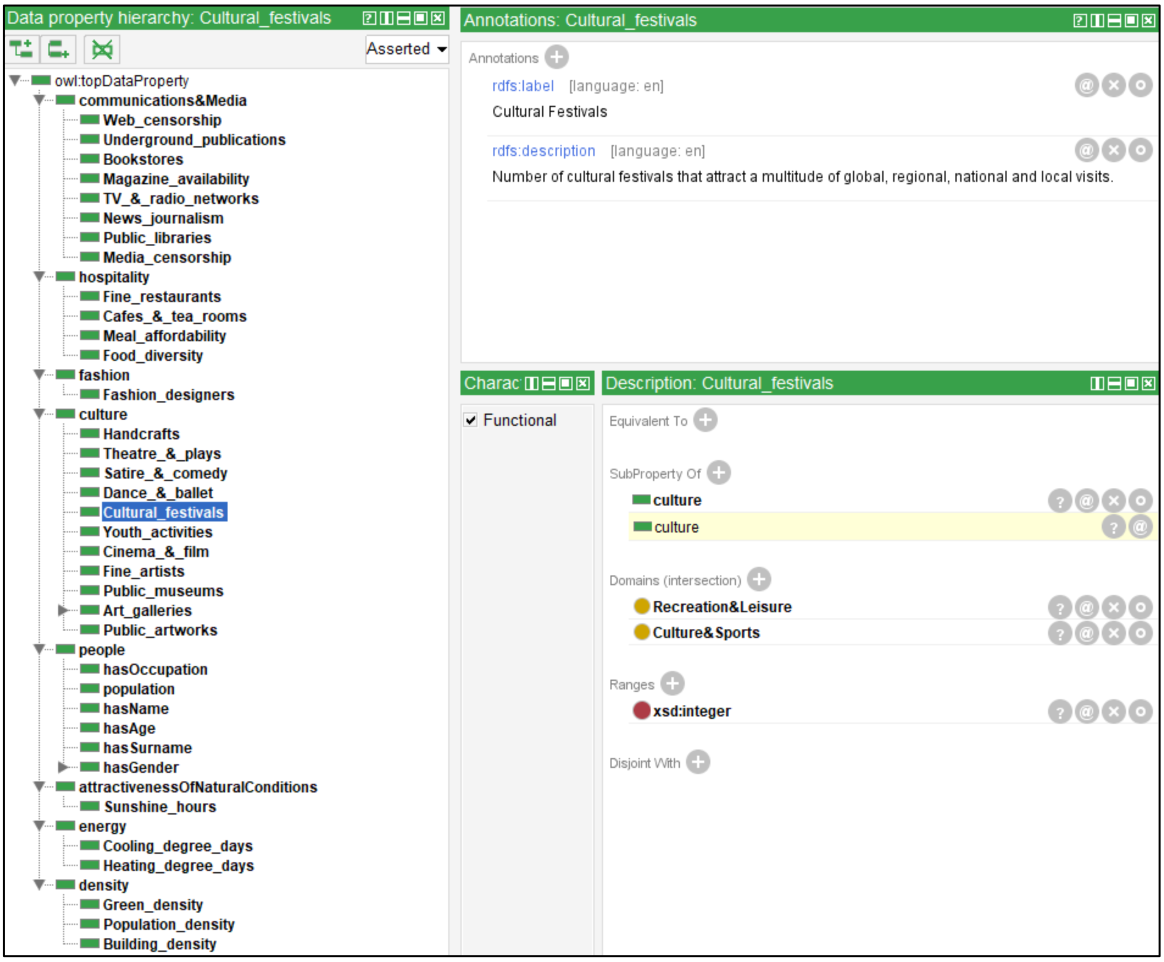

Figure 8-11: Data Properties of the S2RICO (Source: Own Elaboration)

It is worth noting that in most of the explored smart city ontologies (see chapter 7), included indicators (if any) are defined as data properties and not as classes, contrary to the case of the S2RICO. It could be argued that since indicators' range is a simple datatype and not a concept (class), these should be declared as data properties in an ontological schema. This is a very interesting observation, considering that terms with exactly the same meaning can be defined as classes within a specific hierarchy or as properties within another.

Whether a term will be ultimately defined as class, property of a class or value of a property of a class, has been a topic of intense discussion between Noy and McGuiness (2001), who point out that this largely depends on: (i) the purpose an ontology is developed for; (ii) the significance of the term to the domain of interest; and (iii) if declaring this term as a property of a class (or value of a property) will cause any changes to the relationships of this class with other classes. Noy and McGuiness (2001) also stress that if a certain distinction is quite important for the domain of interest and objects with different values of this distinction are considered to be of different types (as in case of embedded indicators), then a new class should be created for the given distinction.

Lastly, another reason for deciding to define indicators as classes has to do with the very nature of data properties. More specifically, data properties are less powerful than OWL objects, since many of object properties' capabilities, such as having an inverse property or being transitive, are not available for data properties (DeBellis, 2021); thereby considerably limiting – inter alia – ontologies' inference mechanisms.

Addition of instances

The S2RICO is populated with the smart projects and applications of the successful smart city examples that are thoroughly described in chapter 4, such as Singapore's *contactless fare payment* initiative, launched to upgrade the ticketing system of public transport (Figure 8-12).

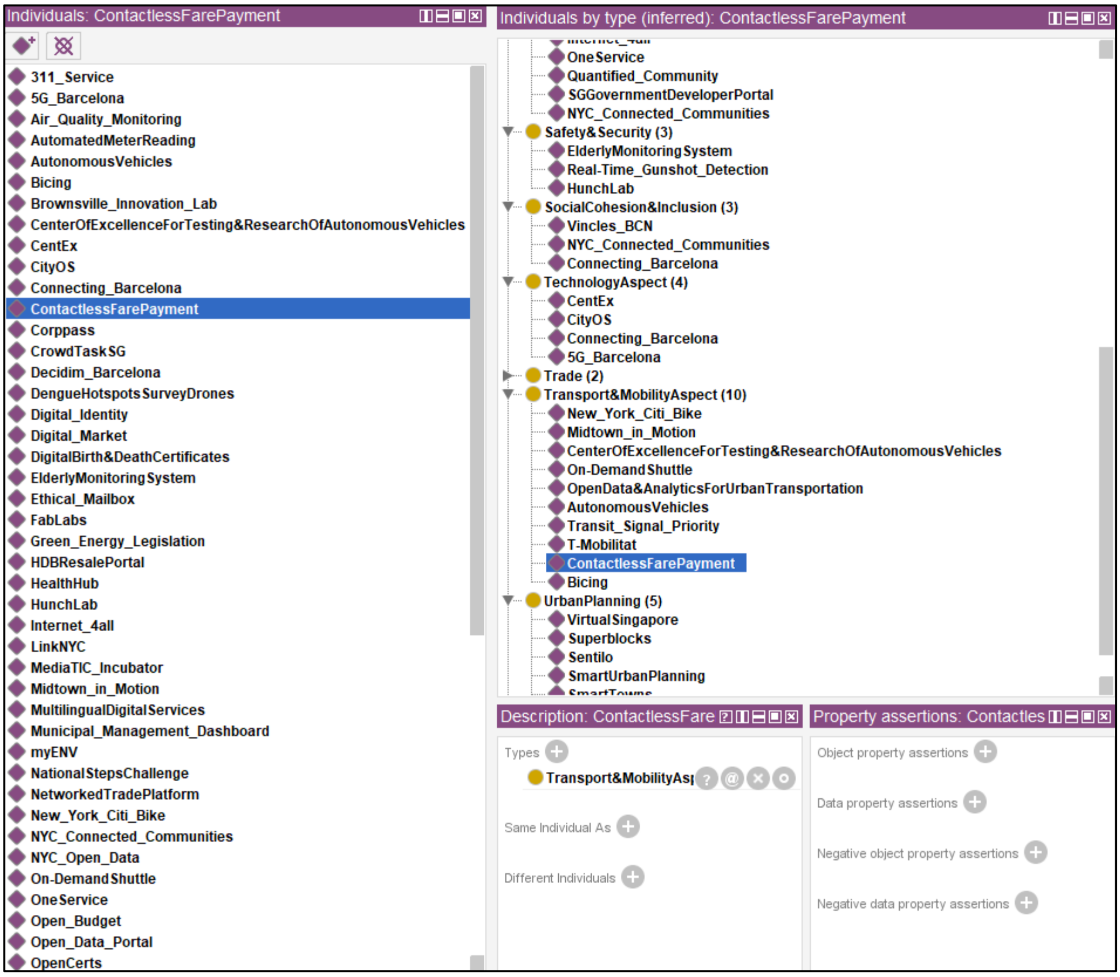

Figure 8-12: Indicative Instances of the S2RICO (Source: Own Elaboration)

Creation of defined classes – Automatic Reasoning

All of the S2RICO classes, described so far, are *primitive classes*, i.e., they use only *necessary* (but not sufficient) axioms that apply to all of their instances (if something is a member of class A then it is necessary to fulfil these conditions). However, in order to take full advantage of the capabilities offered by ontologies, it is possible to create *defined classes*, i.e., classes determined by both necessary and sufficient conditions, which help to render implicit knowledge explicit. Therefore, when the reasoner encounters an individual that satisfies all the conditions of a specific defined class, it will deduce that it is an instance of that class. Moreover, the reasoner uses the necessary and sufficient conditions of a defined class to change the class hierarchy (e.g., to infer that a class A is a sub-class of class B, as in the case of S2RICO) (DeBellis, 2021).

Focusing on the S2RICO, numerous defined classes (33 so far) are created with the help of Description Logic (DL) axioms, so as to make inferences on the incorporated indicators, on the basis of the object properties that have been established in previous step (see "Establishment of relationships between classes"). To be more specific, the defined classes are used to automatically classify all the indicators that are related to particular concepts of the ontology. For example, Figure 8-13 presents the automatic classification of all the indicators that are linked to the water concept (both infrastructure and management). Apart from the indicators that have been defined as sub-classes of the `Water` class during the S2RICO development phase, the automatic reasoning finds all the other indicators that have `isRelatedTo some Water` or `isStronglyAssociatedWith some Water` relations, with the assistance of the `WaterRelatedIndicator` defined class (see Figure 8-13).

In closing, the S2RICO contains:

- 1,032 classes (the multitude of classes is due to the large number of indicators, included in the ontology);
- 46 object properties;
- 50 data properties;
- 68 individuals; and
- 9 annotation properties.

The S2RICO file as well as the matrix that contains all the relationships between the indicators and the classes of the ontology are accessible trough the link:

https://drive.google.com/drive/folders/1rSywDqdWNPZQ0Tg9Z9x11ewqBp6LIdQT?usp=sharing.

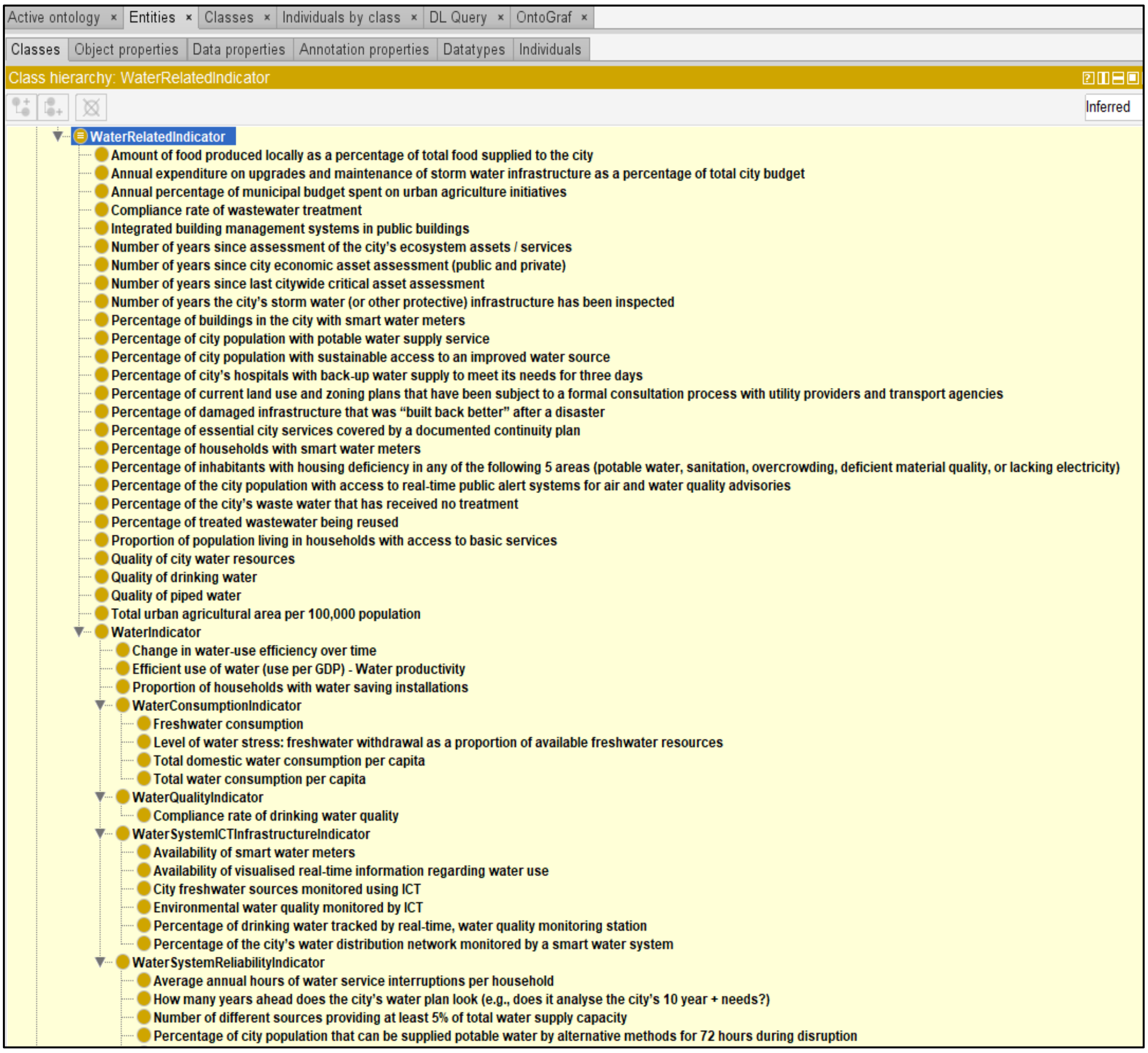

Figure 8-13: Automatic Reasoning by Use of Defined Classes (Source: Own Elaboration)

Indicative use case examples

To better grasp the usefulness of the S2RICO in the planning process, the following simplified examples are described. Firstly, suppose that a municipality wishes to craft and implement a strategic plan for the development of a new city district / neighbourhood. In this respect, planners are assigned the task of designing and organizing the physical layout of the new area as well as analysing and evaluating different aspects of urban development with the help of the S2RICO. Based on S2RICO's powerful reasoning capabilities, users can take advantage of the defined logical rules to infer relationships and assess the indicators. Moreover, they can query the ontology in order to gain insights into specific critical facets of the city (e.g., resource management, energy efficiency, transportation accessibility, social inclusiveness). Therefore, the reasoning process supports the detection of potential issues, interdependencies, and trade-offs between different indicators and urban development aspects. In such a context, planners identify:

- *Sustainability indicators* to ensure environmentally responsible development, such as designation of areas for renewable energy installations (solar panels, wind turbines); proper spatial distribution of spaces for recycling facilities and waste management systems; integration of green spaces, parks, and urban farming areas for improved air quality and community well-being; implementation of building codes and standards for energy-efficient construction.
- *Smart indicators* to shape an intelligent and interconnected environment, such as deployment of IoT infrastructure for real-time monitoring and optimal resource management; deployment of sensor networks to collect data on traffic flows, air quality and noise levels; availability of Wi-Fi in public areas; allocation of spaces for smart parking systems, electric vehicle charging stations, and bike-sharing stations; construction of smart buildings with energy management systems and efficacious digital connectivity.
- *Resilience indicators* to ensure the district's ability to withstand and recover from adverse events, such as detection of suitable locations for emergency services (e.g., fire stations, hospitals, and police stations); incorporation of resilient infrastructure (robust transportation networks, redundant utility systems, etc.); establishment of evacuation routes and safe zones to address potential natural disasters; design of adaptable and flexible public spaces that can be repurposed during emergencies; launch of community-based disaster preparedness programs.
- *Inclusiveness indicators* to create a diverse, accessible and participatory urban environment, such as appropriate dispersion of spaces for affordable housing units and mixed-income developments; provision of easy access to public transportation, particularly for underserved areas; integration of community spaces (community centers, libraries, cultural hubs, etc.) to foster social cohesion; structuring of universally accessible infrastructure (e.g., deployment

of ramps, elevators, tactile paving); promotion of community engagement platforms.

Once the developmental plan is implemented, the S2RICO may contribute to the continuous monitoring and evaluation of the plan's performance. This involves collecting data from various sensors, surveys, and other feedback mechanisms to assess the district's sustainability, smartness, resilience, and inclusiveness. The data can be analysed and used to refine the various stages of the planning process for future iterations or improvements.

The second example is less general and focuses on the energy sector and how this is holistically treated in the context of a planning exercise. By use of the S2RICO, planners can identify: (i) energy-related sustainability indicators, such as renewable energy production, energy consumption, greenhouse gas emissions, etc.; (ii) energy-related smartness indicators that involve the use of advanced technologies like smart grids, smart meters, demand response systems, and energy management platforms to optimize energy consumption and improve operational efficacy; (iii) energy-related resilience indicators that encompass the ability of the energy infrastructure to resist and recover from natural disasters (e.g., energy storage capacity, integration of distributed energy resources); and (iv) energy-related inclusiveness indicators that focus on equitable access to energy services, affordability, energy poverty reduction, and community engagement in energy decision-making processes.

By leveraging ontology reasoning, planners and policy makers can explore the relationships between the embedded indicators and various dimensions of the energy sector. From this perspective, they are able to:

- Evaluate the relationships between sustainability indicators and energy infrastructure elements. For instance, they can determine the renewable energy potential of a particular location based on indicators like solar irradiance, wind speed, and land availability for solar panels or wind turbines.
- Analyse the resilience indicators in relation to energy infrastructure. They can assess the vulnerability of energy assets to natural hazards and map out strategies to boost resilience, such as incorporation of backup power systems or design of redundant energy networks.
- Understand how smartness indicators relate to energy infrastructure; promoting thus the integration of smart meters and advanced grid technologies to enable

real-time monitoring, data analytics, and demand response programs for optimizing energy consumption.

- Detect which inclusiveness indicators are associated with the energy sector. Planners can analyse the accessibility of energy services in different areas and identify areas of energy poverty or lack of affordable energy options. This information can feed related policies to ensure equitable access to energy resources for all residents.

Moreover, through the powerful inference mechanisms of S2RICO, planners have the ability to include additional indicators into their plans – which, although directly related to energy, they do not directly measure a particular aspect of it – to assess cities' energy performance or to propose specific energy-related interventions (Figure 8-14). For example, the average commuting time, the city area by real-time interactive street maps as a percentage of the city's total land area, the use of public transport, the presence of demand-based pricing, the percentage of hospitals with back-up electricity supply, the percentage of essential city services covered by a documented continuity plan, the percentage of city land area covered by tree canopy or the O_3 (ozone) concentration, are all indicators somehow associated with the energy sector and should be considered during the planning process as well.

In conclusion, by incorporating ontology reasoning into the planning procedure, decision makers can gain valuable insights into how different indicators are related to specific elements of the energy sector in smart cities. This integrated understanding helps in formulating evidence-based policies, designing efficient energy systems, and promoting sustainable, smart, resilient, and inclusive energy practices within the city.

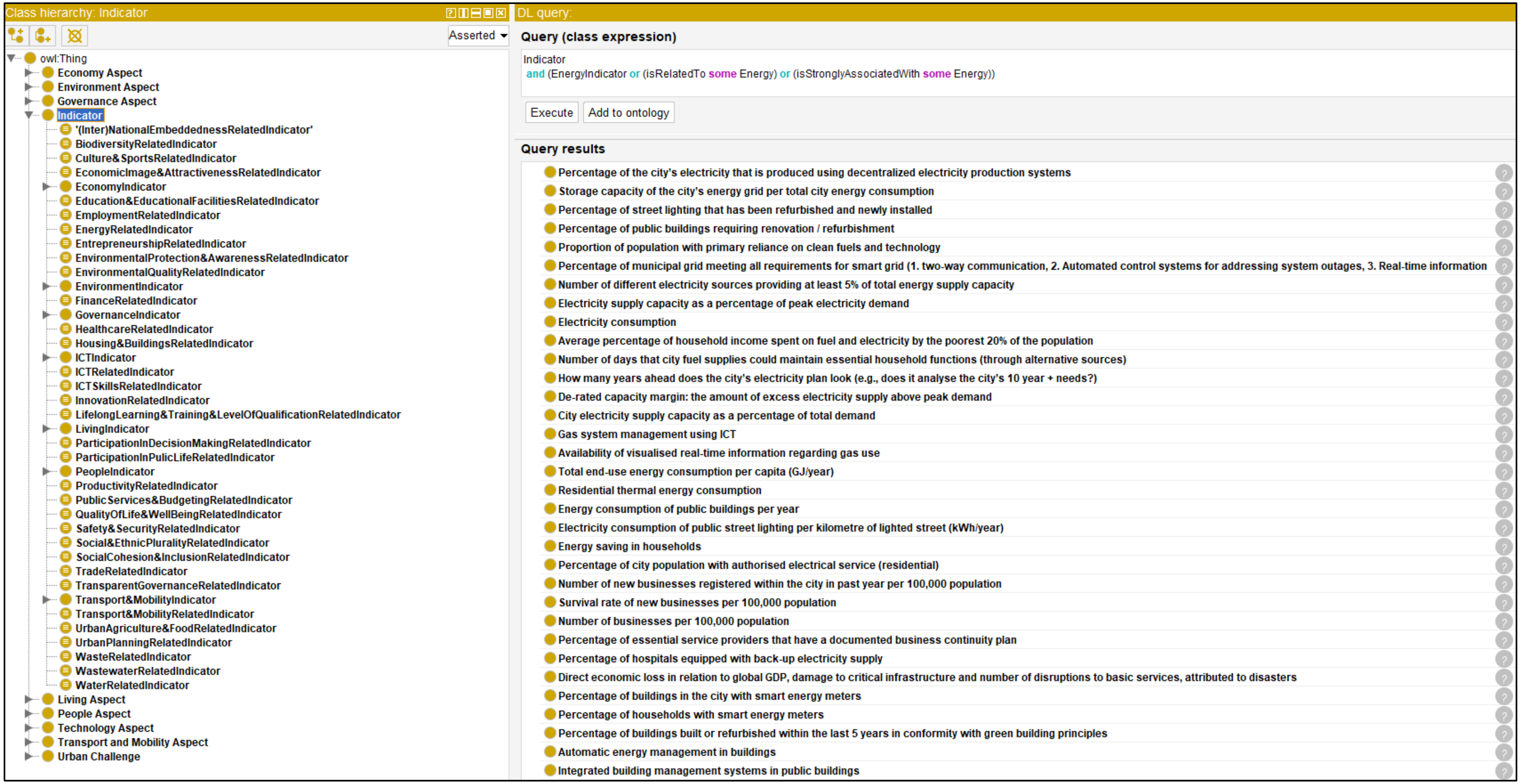

Figure 8-14: Use of DL Queries to Detect Indicators Related to the Energy Sector (Source: Own Elaboration)

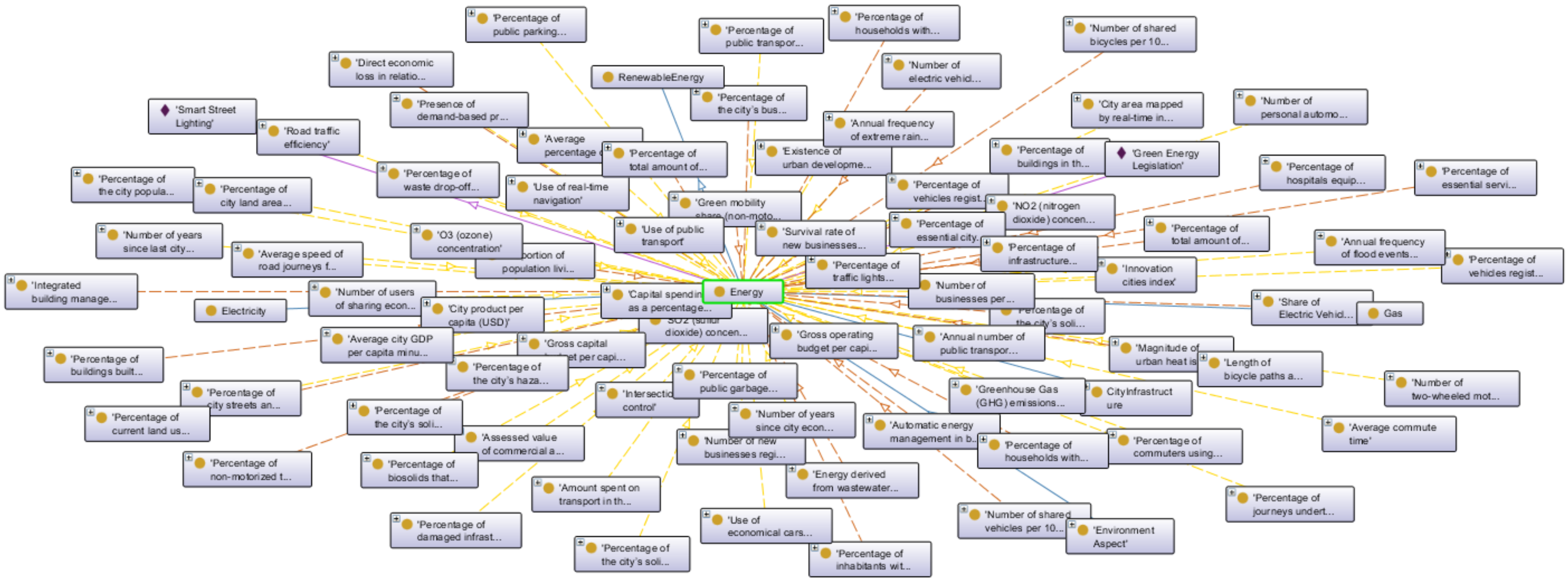

Figure 8-15: Visualization of the Indicators Related to the Energy Sector (Source: Own Elaboration)

8.4. Discussion and Conclusions

Smart cities are taking the world by storm as the global population continues to rampantly grow and urbanization becomes more prevalent. These urban environments are designed to leverage state-of-the-art technologies so as to upgrade quality of life, boost environmental sustainability, and drive economic prosperity. However, serious emerging obstructions, such as the great ambiguity inherent in the smart city concept; the consequent limited comprehension of the term's meaning; and the huge interoperability gap, provoked by the intense definitional impreciseness, call for the development of a conceptual model that will try to address the abovementioned issues.

In this respect, ontologies – as formal representations of a particular domain of interest – can be deployed to model the various facets of the smart city concept, and finally lead to a shared understanding (development of a common vocabulary) of the term; a critical factor that will allow urban stakeholders to communicate effectively and collaborate in order to map out and launch successful smart city initiatives.

Seeking to satisfy this need, S2RICO is developed as a systematic endeavor to form a shared conceptualization of the smart city as a system of systems and their interrelationships; thereby contributing to the deep understanding of the concept, dealing with semantic vagueness, and restoring semantic interoperability. The embedment of a unified, global indicator framework into the ontological scheme is anticipated to offer a common framework to support collaboration both between urban stakeholders and various standardization bodies; help cities assess their overall progress towards becoming smarter, more sustainable, more resilient, and more inclusive (Stratigea et al., 2017; Panagiotopoulou et al., 2020); assist municipal authorities in grasping the numerous, perplexed and interrelating dimensions, factors, and domains of smart cities and guide them towards putting together a set of appropriate standards and requirements to secure the success of their projects; and provide consistency among indicators developed by various standardization bodies (International Organization for Standardization & International Electrotechnical Commission Joint Technical Committee [ISO & IEC JTC 1], 2015).

The development of a smart city ontology and S2RICO in particular, entails a series of substantial benefits for all urban actors. First and foremost, a conceptual representation of the smart city domain may restore *semantic interoperability* among heterogeneous systems. Contemporary cities are inundated with numerous different systems, services, and applications that utilize (produce and/or provide) data of various formats and structures. By establishing a common conceptual basis, it is possible to secure effective and seamless communication among systems; avoiding thus data 'silos' and ensuring stakeholders' accessibility to the information they need to make reasoned decisions.

S2RICO can decisively contribute to the *comprehensive understanding* of the complex interactions within smart cities by providing a well-structured framework of concepts, relations, and attributes. Therefore, urban planners are supported towards crafting related strategies and policies in a more holistic manner.

Moreover, the deployment of S2RICO might reveal new opportunities for *innovation* and *collaboration*. A shared understanding of cities' different components can probably uncover critical areas where novel technologies or radical methodological approaches could be applied to improve efficiency, productivity, sustainability, or quality of life. This, in turn, gives birth to opportunities for collaboration among various stakeholders, including governmental agencies, private sector organizations, and academic institutions.

Constructing and adopting the S2RICO may, also, help to improve the *transparency* and *accountability* of urban functions. Having a common vocabulary to describe cities' constituents at their disposal and getting a deep insight into their interconnections, allow interested parties to shape a more transparent and comprehensive view of how the city operates. Citizens and other stakeholders can better understand how decisions are made and how resources are distributed, a fact that contributes to the building of the necessary trust and boosts support for city initiatives.

Ultimately, S2RICO may assist in guaranteeing the *equitable allocation* of urban resources. A crystal-clear view of the urban sub-systems and their in-between interactions can guide urban planners and municipal authorities towards identifying areas where disparities or inequities in access to services or resources are detected. Therefore, stakeholders are encouraged to work together to address these issues and secure that all residents reap the benefits of smart city initiatives. In addition, by leveraging incorporated indicators, planners and decision makers can prioritize investments, distribute budgets effectively, and target interventions where they will have the most significant impact.

The incorporation of an extended *indicator framework* into the S2RICO, and the determination of the relations between the indicators and the fundamental elements of smart cities provide a powerful tool for data integration, analysis, and decision making, and can help organizations (public or private) unlock the full value of their data. More specifically, encompassing indicators into the S2RICO unveils a series of significant opportunities, such as:

- *Enhancement of data analysis*: an ontology with embedded indicators can facilitate data analysis by establishing a structured framework for organizing and querying data. Through ontologies, it becomes possible to perform complex queries, infer hierarchies and relationships, and generate insights that might not be feasible with traditional approaches of data analysis.
- *Support of data discovery and exploration*: ontologies that include numerous indicators allow users to discover and explore data based on concepts and indicators pertinent to the domain of interest; making it thus easier to identify patterns, trends, and insights.
- *Improvement of data quality and reliability*: adding indicators to an ontology ensures consistent and accurate data collection; and secures data quality by providing clear definitions, semantic relationships, and contextual information. Therefore, ambiguity errors and inconsistencies in data collection, analysis, and reporting are greatly reduced; while data quality and reliability are considerably enhanced, leading to more perceptive data for decision-making purposes.
- *Fostering of data-driven decision making*: indicator-oriented ontological representations are able to support data-driven and evidence-based decision making by forming a common framework for comprehending and analysing data, i.e., a standardized set of indicators and a shared understanding of their meaning, contributing thus to the overall improvement of the effectiveness and efficiency of decision-making processes (comparison and assessment of different options more efficaciously). Such an approach empowers decision makers to make informed choices, detect trends and patterns, and monitor progress towards smart, sustainable, resilient, and inclusive urban development.
- *Boost of transparency and accountability*: by providing a clear definition of each indicator and the methodology used to calculate it, it becomes possible to validate and verify the data, and ensure that the decisions are based on sound

evidence, strengthening in this way transparency and accountability of decision-making.

- *Facilitation of data integration and interoperability*: ontologies offer a common vocabulary and a shared understanding of domain concepts and relations, which allows smooth data exchange and integration across different systems and organizations. An ontology populated with a well-established, commonly accepted, standardized set of indicators, offers a powerful tool that can be used consistently across different applications, and data sources, rendering combination and comparison of heterogeneous data much easier.
- *Contribution to long-term smartness, sustainability, resilience, and inclusiveness*: S2RICO can possibly allow the constant monitoring and assessment of key smartness, sustainability, resilience, and inclusiveness metrics. Such a state contributes to long-term planning; ensures that urban development strategies align with environmental, economic, and social goals; and aids in the identification of areas that require interventions or improvements to enhance the overall sustainability of the city.

Ultimately, the construction of a smart city ontology from scratch uncovers some critical points that every developer should consider. More specifically:

- *Standardization is essential*: the creation of a smart city ontology requires standardization of involved terms and concepts. It is crucial to establish a common language and framework to secure interoperability and effective communication between different smart city systems and stakeholders.
- *Collaboration is the key*: smart city ontology development is a complex task that requires collaboration among various stakeholders, including government bodies, urban planners, technology providers, and citizens. Their collective expertise and input are necessary to capture the diverse aspects of a smart city and shape a comprehensive ontological representation.
- *Flexibility and scalability are vital*: a smart city ontology should be designed with flexibility and scalability in mind. As technologies evolve and new applications emerge, the ontology should be able to adapt and incorporate new concepts and relationships without significant disruptions to the existing framework.

- *Continuous refinement and updates*: a smart city ontology is not a one-time task, but rather an ongoing process that needs to be continuously updated and refined to reflect changes in technology, urban infrastructure, citizen demands, and evolving city dynamics. Regular feedback and input from stakeholders can help secure its relevance and accuracy over time.

Lastly, despite the abovementioned considerations, S2RICO may potentially become a valuable tool in urban planners' arsenal for efficaciously implementing integrated, interoperable, participatory planning exercises that take into account cities' multidimensional nature and complex interactions. Moreover, it acts as a bridge between the smart city domain and performance assessment of various urban sectors, by providing a unified, global indicator framework, and demarcating the relations of every indicator with cities' fundamental concepts. By utilizing this tool, planners can envisage and create smarter, more liveable, and sustainable urban environments for the benefit of their residents and future generations.

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Part 1 Contextual Background

Part 2 Bibliographic Review on Smart Cities

Part 3 Construction of an Integrated Indicator Framework for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 4 Bibliographic Review on Semantics & Ontologies

Part 5 Development of an Ontology for Smart, Sustainable, Resilient & Inclusive Cities (S2RICs)

Part 6 Conclusions & Future Research

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CHAPTER 9: CONCLUSIONS AND CRITICAL CONSIDERATIONS FOR FUTURE RESEARCH

The European Commission (2011) envisages tomorrow's cities as highly inclusive places where environmental sustainability, social equity, affordable housing, and universal access to infrastructure and social services prevail. They are also grasped as incubators of democracy, open dialogue and powerful engines of economic growth.

However, cities nowadays are far from such a vision, which actually represents a goal to be attained within the broader context of sustainable urban development. Indeed, modern cities are confronted with enormous threats that jeopardize their developmental trajectories towards desirable future states. Sustainable urban development, although at the forefront for several decades now, continues to be a sought-after planning goal, and a 'moving target' as well, in light of the extremely pressing challenges, with urbanization being the protagonist and the dominant trend of the 21st century (Suzuki et al., 2010).

Today, policy makers and planners, in their effort to map out efficacious sustainable strategies and related planning interventions, are immensely supported by radical technological advancements and the new possibilities these offer for economic prosperity, organizational efficiency, social justice, equity and cohesion, and upgraded quality of life. ICTs have substantially improved the interaction potential among various urban actors (decision- and policy-making bodies, academia, organizations and institutions, business community, citizens, etc.) by eliminating time and space barriers and by providing access to distributed knowledge and information, as well as to a wide spectrum of applications and tools that facilitate network and synergies' creation both locally and internationally. In such a context, deeply marked by the technological factor and its phenomenal possibilities, the concept of smart cities comes to the surface as a new tech-oriented planning paradigm, capable of supporting the pursuit of sustainable urban development through the boost of competitiveness, well-being, and social inclusion.

Despite its promising nature, the review of the available literature unveils a tremendous polyphony concerning the meaning attributed to the *smart city term*, an intricate state that reflects the different perceptions of various scientific groups, and the serious dearth of consensus on that matter. At the same time, a huge gap in defining and finally embracing a shared smart city definition is detected. The lack of a holistic comprehension and documentation of the term, has, in many cases, failed to meet the high expectations placed on the smart city notion, as evidenced by real examples and the divergence between anticipated outcomes and those ultimately achieved through the deployment of relevant technological applications (Komninos et al., 2015). In this regard, the building of a smart city ontology, which constitutes a formal knowledge representation of the smart city domain, can bridge this conceptual gap.

Through the development of a *new smart city ontology* (S2RICO), it is possible to outline all of its fundamental constituents and specify the relationships developed among them. This is a very critical step for comprehending perplexed urban systems and thus crafting effective strategies and delivering sufficient and to the point solutions. Furthermore, the construction of an ontological scheme for smart cities fosters (Panagiotopoulou, 2018; Panagiotopoulou et al., 2019):

- Proper organization and reuse of existing knowledge on a certain field of interest.
- Deep understanding of the complexities and interdependencies among the social, economic, environmental, cultural, technical, and spatial aspects of a smart city.
- Restoration of semantic interoperability.
- Breaking down of knowledge silos that adopt the 'one size fits all' rationale. This is deemed to be a pivotal parameter for managing urban issues, as it highlights the necessity to integrate spatial and other information and incorporate interdisciplinary approaches in the study of urban ecosystems, strengthening thus – inter alia – the applicability and relevance of the ontology to real-world urban contexts.
- The ability to expand / enrich this ontology with new concepts, relationships, properties or even new ontologies (or parts thereof).

Moreover, the exploration of smart cities – always from the planning point of view – has revealed the need to move beyond conventional approaches that often neglect the interconnectedness of various aspects of urban life and embrace more integrative paths. By developing an ontology that captures *smart cities' complexity and interdependencies*, this research offers a valuable tool to policymakers, planners, and stakeholders for assessing and guiding the development of urban environments that are not only technologically advanced but also sustainable, resilient, and inclusive.

Undoubtedly, different urban environments entail a series of distinct peculiarities, different local visions, needs and requirements, as well as different starting points regarding sustainability, and therefore diversified goals, objectives and respective policy packages for their fulfillment (Stratigea & Panagiotopoulou, 2015). Any efforts to bring the smart city 'developmental scenario' to life must, inter alia, consider citizens' needs and aspirations and the specific characteristics and issues of every single urban ecosystem in order for appropriate decisions on the infrastructure to be made and relevant digital applications to be implemented (Stratigea, 2012; Stratigea & Panagiotopoulou, 2015). In other words, all the endeavors and initiatives for realizing the concept of smart cities should be oriented towards solving urban problems, so that the entire process of application development in each specific urban environment becomes a distinct case study where problems are assessed and, based on them, the most suitable technological applications are chosen. Therefore, there is not a unique perfect *smart city strategy* that can be applied to all urban environments in order to achieve sustainable urban development. This argument is further justified by the fact that current city examples demonstrate significant variations in terms of technological maturity and infrastructure, smart applications, geographic and geopolitical contexts within which smart applications are developed (Stratigea et al., 2017; Panagiotopoulou et al., 2020).

Apart from the definitional impreciseness of the smart city term, but closely related to it, the assessment of *cities' performance* in terms of contemporary critical urban goals, i.e., smartness, sustainability, resilience, and inclusiveness remains a fuzzy issue. This is mainly justified by the vagueness inherent in the definitions of both smart and sustainable urban development; while empirical evidence on the impact of smart applications on cities' functions and sustainability, resilience and inclusiveness gains is rather limited (Komninos et al., 2015). Based on the aforementioned, the role of *indicators* as tools for assessing cities' performance is highly appreciated and has been broadly adopted by plentiful case studies. Numerous global, but also national / local indicator systems, have been developed so far, in an effort to support planners and decision makers to assess urban performance. However, very often, involved indicators lack standardization, consistency, comparability through time and space, and sufficient endorsement.

Taking these critical obstacles into account, the elaboration on several globally-initiated and recently developed indicator frameworks and the establishment of a new, integrated one by complementing different indicator sets and views reflected by these frameworks, is attempted. Moreover, general but insightful guidelines on the steps that should be followed so as to navigate into the new framework and select proper indicators for assessing urban sustainability, smartness, resilience and inclusiveness achievements, are provided.

One of the *innovative features* of the Dissertation is the embedment of the unified indicator framework into the S2RICO, which is anticipated to set a common ground for the collaboration both between urban stakeholders and standardization bodies; aid cities in evaluating their overall progress in respect to smartness, sustainability, resilience, and inclusiveness (Stratigea et al., 2017; Panagiotopoulou et al., 2020); facilitate evidence-based decision making; guide urban development strategies and policies that are responsive to the evolving needs and aspirations of urban communities; help responsible authorities to gain a deep insight into smart cities' various, perplexed and interrelating dimensions, factors, characteristics, and domains and guide them towards assembling a set of suitable standards and requirements to guarantee the success of their projects; and provide consistency among indicators developed by different standardization bodies (International Organization for Standardization & International Electrotechnical Commission Joint Technical Committee [ISO & IEC JTC 1], 2015). Such a multidimensional approach recognizes the interplay between technological advancements, environmental sustainability, social equity, economic vitality, and effective governance, thereby fostering a more nuanced understanding of urban development. In general lines, this integrated ontological scheme provides a comprehensive and holistic framework for evaluating the multiple dimensions of urban environments.

Despite the potential benefits of the building and utilization of the S2RICO (see chapter 8 for extensive details), several *critical considerations* for future research should be taken into account. First and foremost, the degree of subjectivity. Subjectivity may manifest in different ways during the ontology construction process, with the trickiest one referring to the selection of concepts and relationships to be included, which may be influenced by personal biases or views of the developer or the domain expert. This can result in an ontology that does not incorporate a representative variety of perspectives, or is biased towards a particular aspect. One approach to coping with subjectivity concerns during the S2RICO revision phase is to commit multiple stakeholders to the process. In this way, the ontology's multifaceted character is secured; reducing thus the risk of bias and limiting potential inconsistencies.

In close connection to the former remark, the conduct of extensive participatory workshops is deemed to be absolutely necessary throughout the revision / update phase of the S2RICO. Stakeholders' engagement plays a crucial role, as it ensures that the ontology reflects accurately the domain of interest and meets the needs of the intended users. By involving various actors in the S2RICO update procedure, it is possible to:

- Secure the relevance of the domain to be modelled, since stakeholders are an indispensable source of domain knowledge, experience, and expertise. Their engagement guarantees the accurate representation of the concepts, relationships, properties, and terminology used to describe the field of interest.
- Improve ontology usability, as stakeholders may provide valuable feedback on ontology's content and functioning (e.g., issues related to its structure, terminology, and user interface), which can be used to refine the ontology and render it more user-friendly.
- Broaden ontology adoption. Engaged stakeholders are more likely to use and promote the ontology within their organization or community.
- Boost ontology quality. Broad participation will probably lead to more rapid detection of ontological errors, inconsistencies, or gaps. Moreover, involved parties can give feedback on the ontology's completeness, accuracy, and relevance, which, in turn, contributes to its enrichment and refinement.

Future research of the S2RICO predicts the enrichment of the ontological scheme with more concepts, relations, properties, and instances that derive from the international literature and empirical findings. Additionally, broadly accepted and used, fully documented, lightweight ontologies and vocabularies are expected to enrich the S2RICO, such as the Dublin Core (DC) ontology, an RDF-S vocabulary for describing generic metadata; and the Friend of a Friend (FOAF) ontology, a dictionary of properties and classes that describes persons, their activities, and their relations to other people and objects.

Ultimately, another significant issue for future research revolves around linking the S2RICO to a top-level ontology. In general lines, the root node of a domain ontology should be associated (or defined) with terms that are included in a top-level ontology, in order to render the management of scientific information, incorporated in the former, more efficient in the long term. Such a process will ensure that the ontology is structured using the architecture of a top-level scheme, shared among various other ontologies (many ontologies that have a common architecture) (Arp et al., 2015).

Top-level ontologies serve as semantic bridges that facilitate semantic integration (problem-solving of semantic heterogeneity) of domain ontologies and guide the development of new ontological representations. For this reason, they focus on standardizing general and abstract concepts that are not related to a specific domain, but apply to all domains and can, therefore, be easily reused by them. In other words, they provide a common ontological background for domain ontologies (Hoehndorf, 2010; Schmidt et al., 2016).

In addition, top-level ontologies are deemed to be a means of verifying associated domain ontologies, since the former impose constraints on their classes (in the form of axioms) that are inherited by the latter. This is particularly helpful throughout the construction phase of a new ontology that seeks to achieve semantic interoperability with another existing one. During the process of creating a new ontology, top-level ontologies contribute to the verification of basic ontological constraints. They can also be used to verify the compatibility of a new ontology with others that are associated with the same upper-level ontological scheme. Therefore, they provide high-quality compatibility and reliability checks for domain ontologies and their semantic integration (Hoehndorf, 2010). Moreover, given the multitude of current domain ontologies, their correlation with a top-level one is extremely useful, as it is important to reuse the well-documented knowledge of top-level ontologies along with domain ontologies in order to reduce modelling time; limit the problem of heterogeneity in knowledge representation; and cope with complexity of ontological modelling (Schmidt et al., 2016).

Based on the literature review, the most appropriate top-level ontologies that could ‘host’ S2RICO, are:

- Basic Formal Ontology (BFO) – small, genuine, top-level ontology designed to support information retrieval, analysis and integration; and used by more than 250 ontology-oriented endeavors globally (Basic Formal Ontology [BFO], 2020).
- General Formal Ontology (GFO) – upper ontology that includes elaborations of categories, such as objects, processes, time, space, properties, relations, roles, functions, facts, and situations (Onto-Med, n.d.).

- Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) – foundational ontology that provides general categories and relations that can be reused in different application scenarios (Borgo et al., 2022).
- Suggested Upper Merged Ontology (SUMO) – upper ontology designed for a variety of computer information processing systems. SUMO, together with its domain ontologies, forms the largest formal public ontology currently in place; and is used for research and applications in search, linguistics and reasoning (Ontology Portal, 2023).

Despite the possible weaknesses of the S2RICO, this can become an indispensable instrument for the optimal implementation of integrated, participatory planning processes that consider modern cities' multidimensional nature and complex interactions. By properly leveraging the possibilities of this tool, planners and policy makers can shape smarter, more livable, and sustainable urban environments.

It is important to acknowledge that ontology development is not a static endeavor but rather an iterative process that requires ongoing refinement and adaptation. As cities continue to evolve and face new challenges, the ontology must remain dynamic, accommodating emerging trends, technologies, and priorities. Regular updates and revisions, informed by research developments, stakeholders' engagement, and best practices will ensure its relevance and longevity as a practical tool for planning and the assessment of smart cities.

In closing, the integration of performance assessments of smart, sustainable, resilient, and inclusive cities into the planning process through the construction of a new ontological representation constitutes a good starting point for shaping holistic, effective, and successful urban development strategies. This Dissertation has attempted to demonstrate the importance of a comprehensive and multidimensional approach that considers the interdependencies between various urban aspects by leveraging the power of technology, data, and knowledge.

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ANNEX I – SMART CITY DEFINITIONS

Table I-1: Smart City Definitions (Source: ITU, 2014a)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
1	Academic	A smart city is a city well performing in a forward-looking way in smart economy, smart people, smart governance, smart mobility, smart environment and smart living, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens.	Economic growth, transport, mobility, environment, standard of living, governance	Giffinger et al. (2007)
2	Academic	We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.	ICT, high quality of life, natural resource management, participatory governance, transport infrastructure, communication infrastructure, economic growth, sustainability	Caragliu et al. (2011)
3	Academic	The rudiments of what constitutes a smart city which we define as a city in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies.	Traditional infrastructure, ICT, integrated infrastructure, coordinated infrastructure, digital technology	Batty et al. (2012)
4	Academic	Instead of striving for physical growth, a city's success today should be measured by how wisely it uses energy, water, and other resources, how well it maintains a high quality of life for its people, and how smart it is in building prosperity on a sustainable foundation. In short, cities have to become much smarter about how they use the existing capacities and resources.	Wise use of resources, quality of life, sustainability	Dixon (2012)
5	Academic	The Cellular City Compact, diverse, walk able and attractive cities are a luxury, but they should not be. The City Science Initiative at the MIT Media Lab is exploring technologies to help develop cities that facilitate the creation of desirable urban features, such as shared electric vehicles, adaptable living environments, and flexible work spaces. Our goal is to design urban cells that are compact enough to be walk able and foster casual interactions, without sacrificing connectivity to their larger urban surroundings. These cells must be sufficiently autonomous and provide resiliency, consistent functionality, and elegant urban design. Most importantly, the cellular city must be highly adaptable so it can respond dynamically to changes in the structure of its economic and social activities.	Urban, technology, desirable features, shared electric vehicles, adaptable living environments, flexible work places, compact urban cells, elegant design, connected, autonomous adaptable dynamic	Massachusetts Institute of Technology (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
6	Academic	Tracing the genealogy of the word smart in the label smart city can contribute to an understanding of how the term smart is being loaded. In marketing language, smartness is centered on a user perspective. Because of the need for appeal to a broader base of community members, smart serves better than the more elitist term intelligent. Smart is more user-friendly than intelligent, which is limited to having a quick mind and being responsive to feedback. Smart city is required to adapt itself to the user needs and to provide customized interfaces.	User perspective, user friendly, responsive, adaptability	Nam & Pardo (2011)
7	Government	A city that monitors and integrates conditions of all of its critical infrastructures including roads, bridges, tunnels, rails, subways, airports, sea-ports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens.	Integrated infrastructure, resource optimization, preventive maintenance, monitors security, and maximizes services	Hall et al. (2000)
8	Academic	The term "smart city" is not used in a holistic way but with reference to various aspects which range from ICT districts to smart inhabitants in terms of their educational level. In addition, the term often refers to the relation between city government and citizens (e.g., good governance or smart governance). There is often a strong reference to the use of modern technology in everyday urban life, which includes innovative transport systems, infrastructures and logistics as well as green and efficient energy systems. Additional 'soft factors' connected to urban life for a Smart City include: participation, security/safety, cultural heritage. In conclusion, the literature review reveals the following main dimensions (or clusters of aspects): smart governance (related to participation); smart human capital (related to people); smart environment (related to natural resources); smart living (related to the quality of life) and smart economy (related to competitiveness).	Living, governance, economy, infrastructure, ICT, citizens, transport, energy, urban life	Lombardi (2011)
9	Academic	The 'eco-cities' theme does not stand alone but is situated in a complex array of relevant variations of sustainable development, sustainable urban development, sustainable communities, bioregionalism, community economic development, appropriate technology, social ecology, green movement.	Ecology, technology, communities.	Roseland (1997)
10	Academic	A sustainable city is one in which its people and businesses continuously endeavor to improve their natural, built and cultural environments at neighbourhood and regional levels, whilst working in ways which always support the goal of global sustainable development.	Business, natural environment, built environment, cultural environment.	Haughton et al. (1994)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
11	Academic	We say that a sustainable city is one in which the community has agreed on a set of sustainability principles and has further agreed to pursue their attainment. These principles should provide the citizenry with a good quality of life, in a liveable city, with affordable education, health care, housing, and transportation.	Quality of life, lovable city, education, health care, housing	Munier (2007)
12	Academic	A sustainable city can broadly be defined as one that has put in place action plans and policies that aim to ensure adequate resource availability and (re)utilization, social comfort and equity and economic development, and prosperity for future generations.	Policies, resource availability, social comfort, economic development, future generations.	Jingzhu (2011a)
13	Academic	A sustainable city is one that relates its use of resources and its generation and disposal of wastes to the limits imposed on such activities by the planet and its organisms.	Resources, waste, planet and organisms.	Jingzhu (2011b)
14	Academic	The basic feature of a sustainable city can be characterized as: facilitating economical uses of resources by technological and environmental improvements, targeting economic development, wealth building, social progress, and ecological security, maintaining a balance among resources, environment, information, interflow of material of the inner-outer urban system, meeting a city's future needs based on a correct assessment, and satisfying the present needs of urban development.	Technology, economic development, wealth, social progress, resources, information, urban development.	Jingzhu (2011c)
15	Academic	Improving the quality of life in a city, including ecological, cultural, political, institutional, social, and economic components without leaving a burden on future generations.	Ecological, cultural, political, institutional, social and economic	Jingzhu (2011d)
16	Academic	World Watch Institute considered that a city moving toward sustainability should improve public health and well-being, lower its environmental impacts, increase recycling its materials, and use energy with growing efficiency.	Public health, materials, recycle, energy efficiency	Jingzhu (2011e)
17	Academic	A sustainable city is one that can provide and ensure sustainable welfare for its residents with the capacity of maintaining and improving its ecosystem services.	Residents, ecosystem services, welfare	Jingzhu (2011f)
18	Academic	The urban ecosystem service can be generally defined as processes and conditions offered for people's survival and development by cities as social-economic-natural complex ecosystems.	People, survival, development, social, economic, natural	Jingzhu (2011g)
19	Academic	A smart city is referred to as the safe, secure, environmentally green, and efficient urban centre of the future with advanced infrastructures such as sensors, electronics, and networks to stimulate sustainable economic growth and a high quality of life.	Safe, secure, environment, green, efficient, urban, future, infrastructure, sensor, electronics, networks, sustainability, economy, quality of life	Schaffers et al. (2012a)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
20	Academic	Major aspects highlighted in this paper balance different economic and social demands as well as the needs implied in urban development, while also encompassing peripheral and less developed cities.	Economic, social, urban development	Schaffers et al. (2012b)
21	Academic	A smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable greener city, a competitive and innovative commerce and an increase in the quality of life with a straightforward administration and maintenance system of the city.	Advanced, high-tech, information, sustainability, green, competitive, innovation, commerce, quality of life, administration, maintenance	Schaffers et al. (2012c)
22	Academic	A "smart city" is a city well performing in a forward-looking way in the six characteristics (smart economy, smart people, smart governance, smart mobility, smart environment, smart living) built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens.	Citizens, economy, people, governance, mobility, environment, living	Chourabi et al. (2012a)
23	Academic	A city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city.	Interconnected IT, social, business infrastructure	Chourabi et al. (2012b)
24	Academic	A city striving to make itself "smarter" (more efficient, sustainable, equitable, and liveable)	Efficient, sustainable, equitable, liveable, standard of living	Chourabi et al. (2012c)
25	Academic	Based on the exploration of a wide and extensive array of literature from various disciplinary areas, we identify eight critical factors of smart city initiatives: management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment.	Technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment	Chourabi et al. (2012d)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
26	Academic	In general terms, we can define a “smart city” as a public administrative service or authority that delivers (or aims to deliver) a set of new generation services and infrastructure, based on information and communication technologies. Defining a new generation service is nevertheless a bit more complex and broader as the systems and services provided by smart cities should be easy to use, efficient, responsive, open and sustainable for the environment. The “smart city” concept brings together all the characteristics associated with organizational change, technological, economic and social development of a modern city. Moreover, smart city services and infrastructures entail the characteristics of engaging and interacting with the citizen that makes use of them. Another central element is the adaptive nature of services, ICT systems, infrastructures, buildings that comprehend the smart city concept. They acknowledge their initial status via a set of indicators and adapt their response according to the external changes that affect them. In doing so, they intelligently adapt to the external variables and demands that they are subject to, thus offering an always customized, more efficient and adaptive response.	Technology, economic, social development, ICT, infrastructure, buildings	González et al. (2011)
27	Corporate	Hitachi's vision for the “smart sustainable city” seeks to achieve concern for the global environment and lifestyle safety and convenience through the coordination of infrastructure. Smart sustainable cities realized through the coordination of infrastructures consist of two infrastructure layers that support consumers' lifestyles together with the urban management infrastructure that links these together using IT.	Coordinated infrastructure, lifestyle safety, lifestyle convenience, urban infrastructure, IT	Hitachi (2014)
28	Corporate	A smarter city uses technology to transform its core systems and optimize finite resources. At the highest levels of maturity, a smarter city is a knowledge-based system that provides real-time insights to stakeholders, as well as enabling decision-makers to proactively manage the city's subsystems. Effective information management is at the heart of this capability, and integration and analytics are the key enablers.	Technology, transform, optimize finite resources, real-time information, decision-making information, information management, integration, analytics.	IBM (2013)
29	Corporate	Five (5) steps to make a city smart: 1. Vision: setting the goal and the roadmap to get there; 2. Solutions: bringing in the technology to improve the efficiency of the urban systems; 3. Integration: combining information and operations for overall city efficiency; 4. Innovation: building each city's specific business model; 5. Collaboration: driving collaboration between global players and local stakeholders.	Urban systems, efficiency, technology, integration, innovation, efficiency.	Schneider Electric (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
30	Corporate	A "smart sustainable city" is one in which the seams and structures of the various urban systems are made clear, simple, responsive and even malleable via contemporary technology and design. Citizens are not only engaged and informed in the relationship between their activities, their neighbourhoods, and the wider urban ecosystems, but are actively encouraged to see the city itself as something they can collectively tune in, such that it is efficient, interactive, engaging, adaptive and flexible, as opposed to the inflexible, mono-functional and monolithic structures of many 20th century cities.	Urban system optimization, technology and design, informed citizens, citizen contribution, efficiency, interactive, adaptive, flexible.	ARUP (2011)
31	Corporate	Infrastructure, operations and people. What makes a city? The answer, of course, is all three. A city is an interconnected system of systems. A dynamic work in progress, with progress as its watchword. A tripod that relies on strong support for and among each of its pillars, to become a smarter city for all.	Interconnected systems, progress, infrastructure, operations, and people.	IBM (2014)
32	Corporate	A city's attractiveness is directly related to its ability to offer the basic services that support growth opportunities, build economic value and create competitive differentiation. Potential inhabitants, of both the commercial and residential variety, are a discriminating lot, and they are looking for cities that operate efficiently and purposefully. They are looking for smarter cities. In particular, we are seeing the most advanced cities focus on three areas of expertise: • Leveraging information to make better decisions. • Anticipating and resolving problems proactively. • Coordinating resources to operate more efficiently. Forward-thinking cities are not waiting for better economic times to take action. They are focused on staying competitive, maximizing the resources at their disposal and laying the groundwork for transformation. They are redefining what it means to be a smarter city.	Growth, economy, competitive differentiation, efficiency, purpose.	IBM (2012)
33	Corporate	Replacing the actual city infrastructures is often unrealistic in terms of cost and time. However, with recent advances in technology, we can infuse our existing infrastructures with new intelligence. By this, we mean digitizing and connecting our systems, so they can sense, analyse and integrate data, and respond intelligently to the needs of their jurisdictions. In short, we can revitalize them so they can become smarter and more efficient. In the process, cities can grow and sustain quality of life for their inhabitants.	Technology, connecting systems, analyse data, integrate data, responsive, efficient, growth, quality of life, sustainability.	IBM-India Needs Smart Cities (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
34	Corporate	The "smart sustainable city" concept is really a framework for a specific vision of modern urban development. It recognizes the growing importance of information and communication technologies (ICTs) as drivers of economic competitiveness, environmental sustainability, and general liveability. By leveraging ICT as a core element of their development, the smart sustainable cities of the future will foster economic growth, improve the lifestyle of citizens, create opportunities for urban development and renewal, support eco-sustainability initiatives, improve the political and representative process, and provide access to advanced financial services. The right ICT infrastructure will affect the way each city will be created and evolved. It will enable smart sustainable cities to include vastly enhanced sustainable areas, such as smart buildings, smart infrastructures (water, energy, heat, and transportation) and smart services (e-substitutes and e-services for travel, health, education, and entertainment), which drastically change the urban experience for city dwellers and travellers.	ICT, economy, environment, sustainability, quality of life, development, renewal, citizen representation, financial services, smart buildings, smart infrastructure, water, energy, heat, transportation, e-services.	Alcatel Lucent (2011)
35	Corporate	The most effective definition of a smart sustainable city is a community that is efficient, liveable, and sustainable, and these three elements go hand-in-hand. Traditionally, water, gas, electricity, transportation, emergency response, buildings, hospitals, and public services systems of a city are separate and operate in silos independent of each other. A truly efficient city requires not only that the performance of each system is optimized but also that these systems are managed in an integrated way to better prioritize investment and maximize value. An efficient city also starts a community on the path to become competitive for talent, investment, and jobs by becoming more liveable. A city must work to become a pleasant place to live, work, and play. It must appeal to residents, commuters, and visitors alike. It must be socially inclusive, creating opportunities for all of its residents. It must provide innovative, meaningful services to its constituents. Liveability plays a critical role in building the talent pool, the housing market, and in providing cultural events which can bring memorable experiences, international attention, and investment to the community. A sustainable community is one which reduces the environmental consequences of urban life and is often an output of efforts to make the city more efficient and liveable. Cities are the largest contributors of carbon emissions; the highways, public spaces, and buildings we rely on to live, work, and play emit the bulk of each city's emissions. Implementing efficient, cleaner, and sustainable operations in all of these areas is critical to minimizing a city's environmental footprint.	Efficient, quality of life, sustainability, integrated, services, natural resources, resource optimization, talent, investment, jobs, socially inclusive, innovative, low carbon, efficiency, regeneration.	Aoun-Schneider Electric (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
		Cities must also look at other methods of achieving sustainability, including resource efficiency, regenerating aging districts, ensuring robustness of systems, and incorporating design and planning in harmony with their natural ecosystem, as opposed to simply living in them.		
36	Corporate	A smart sustainable city is typically defined as "an environmentally conscious city that uses information technology (IT) to utilize energy and other resources efficiently." In Hitachi's vision, a smart sustainable city is one that seeks to satisfy the desires and values of its residents, with the use of advanced IT to improve energy efficiency and concern for the global environment as prerequisites, and in so doing maintains a "well-balanced relationship between people and the Earth."	Environment, ICT, energy, resource management, efficiency, environment, values of citizens, desires of citizens.	Smart Cities: Hitachi (2014)
37	Corporate	A city has common capabilities and delivers a set of common services, as well – office and residential buildings, natural resource management, transportation, health and safety, waste management, education and culture, public administration and services. One important characteristic that distinguishes an intelligent city is the manner in which it delivers services using advanced technologies: an integration of a number of innovations including machine-to-machine communication enabled by telematics, sensors and RFID technologies, smart grid technologies to enable better energy production and delivery, intelligent software and services, and high-speed communications technologies that serve as a core network for all related city, citizen and business services.	Services, natural resource management, transportation, health, safety, waste management, education, culture, public administration, services, ICT, RFID, integrated, smart grid, energy, high speed communication.	Berton et al.Accenture (2014)
38	Corporate	The 'Smart Community' is a next-generation community in which the management and optimized control of various infrastructures such as electricity, water, transportation, logistics, medicine, and information are integrated. The 'Smart Community' will provide comprehensive solutions encompassing energy, water, and medical systems in order to realize a synergetic balance between environmental considerations and comfortable living.	Electricity, water, transportation, logistics, medicine, information, integrated, optimization, energy, comfortable living.	Takenaka-Toshiba (2012)
39	Corporate	We define a "smart sustainable city" as the city that uses information technology and communications to make both its critical infrastructure, its components and utilities offered more interactively, efficiently and where citizens are made more aware of them. It is a city committed to the environment, both environmentally and in terms of cultural and historical elements	ICT, infrastructure, utilities, interactive, efficient, aware, environment, culture, history	Telefónica (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
40	Corporate	A city that uses data, information and communication technologies strategically to: • provide more efficient, new or enhanced services to citizens, • monitor and track government's progress toward policy outcomes, including meeting climate change mitigation and adaptation goals, • manage and optimize the existing infrastructure, and plan for a new one more effectively, • reduce organizational silos and employ new levels of cross-sector collaboration, enable innovative business models for public and private sector service provision.	Quality of life, authority, development, citizens, infrastructure.	Arup, Accenture, Horizon, University of Nottingham (2014)
41	Corporate	The "smart city" concept includes digital city and wireless city. In a nutshell, a smart city describes the integrated management of information that creates value by applying advanced technologies to search, access, transfer, and process information. A smart city encompasses e-home, e-office, e-government, e-health, e-education and e-traffic.	ICTs, quality of life, health, employment.	Huawei (2014)
42	Corporate	A sustainable city is made up of three (3) main parameters to make sure that there is an overall development of energy, health care, buildings, transport, and water management in a city: • Environmental care – With right technologies, cities will become more environmentally friendly. • Competitiveness – With the right technologies, cities will help their local authorities and businesses to cut costs. • Quality of life – With the right technologies, cities will increase the quality of life for their residents.	Quality of life, technologies, authorities, buildings, transport, water.	Siemens (2014)
43	Corporate	As nations look to rebuild their aging infrastructures and at the same time take on the challenge of global climate change, Patel argues that resource usage needs to be at the heart of their thinking. We must also take a fundamental perspective in examining "available energy" in building and operating the infrastructure. Only if we use fewer resources to both build and run our infrastructures, he says, we will create cities that can thrive for generations to come. We can only build in that way, he suggests, if we seamlessly integrate IT into the physical infrastructure to provision the resources – power, water, waste, etc. – at a city scale based on the need.	Infrastructure, energy, IT, power, water, waste.	Patel,-Hewlett Packard (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
44	Corporate	One manifestation of the Oracle iGovernment vision is Oracle's Solutions for Smart Cities, which will address the ever increasing need to provide businesses and citizens with transparent, efficient and intelligent engagement with their local authority/administration – through any channel – for any purpose, from information requests and government programme enrolment, to incident reporting or scheduling inspections, to complete online start-up of a local business. Development, implementation and refinement of such a multichannel, single point-of-contact platform to all government organizations lays the foundation for a range of additional capabilities from business recruitment and retention to self-selecting, interest- and knowledge-based communities amongst citizens to improved management of civil contingencies and emergency disaster planning.	Authority, information, business, development, citizens, disaster.	Oracle (2014)
45	Corporate	A future where clean, efficient and decentralized energy will power a smart electricity grid to deliver power efficiently to millions of homes; a world not suffering from water scarcity where waste is seen as a resource; where citizens' mobility and health care needs are all taken care of by efficient and comprehensive systems; and where they can live in sustainable cities with green spaces, clean air and a high quality of life.	Efficient, decentralized, energy, electricity, water, waste, green spaces, clean air and quality of life.	Dunlop (2012)
46	Corporate	Urbanization, rapid population growth and shortages of resources are placing a new strain on city systems. So how can cities fuel economic growth whilst improving environment and social conditions? What must they do to raise service quality despite finite resources, and ever-growing demand? How can they work more effectively across the public sector, and with the private and 3rd sectors to transform outcomes? Smart technologies help city administrations tap into public information and create not just smarter, but more sustainable cities.	Fuel economy, technology, administrations, sustainable.	Capgemini (2014)
47	Corporate	"Smart Cities" are an effective response to today's needs which have become crucial. Thanks to the rapid, pressing trends seen throughout the world. In our view, the "smart city" is an urban model that minimizes efforts around "low level" needs and effectively satisfies "higher level" needs to guarantee an elevated quality of life while optimizing resources and areas for sustainability.	Quality of life, optimization, resources, sustainability.	ABB Group (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
48	Corporate	It takes more to build a smart city than simply using ICT to link and manage social infrastructure. Providing new values and services that residents truly need is also essential. Generating the knowledge to arrive at solutions by continuing to closely examine local issues, while putting this information into the equation when analysing the enormous amount of data from smartphones, various sensors, metres, and other devices, is a crucial task. Achieving it requires that Fujitsu put ICT to work to establish a sustainable social value cycle and create new innovations.	Knowledge, solutions, sensors, data, ICT, innovations, infrastructure.	Fujitsu (2014)
49	Corporate	The IBM vision for a smarter city uses technology to bring cities forward so that they can accomplish these types of objectives: – Quality of life for its citizens and visitors, – A well-managed city works to create an optimal urban environment for its citizens, visitors, and industries by focusing on urban design, energy and water management, and an efficient and easy-to-use transportation system. These cities provide better performing and reliable city services that enable simplified and integrated access to services. – A healthy and safe city addresses the health and safety of residents and visitors through innovations in local health care networks, disease management and prevention, social services, food safety, public safety, and individual information privacy. – A sustainable city implements concrete measures toward sustainability through, for example, reduced consumption of energy and water and reduced emissions of CO_2. Possible measures that can make a city sustainable include urban planning principles for mixed land use, architecture and construction principles for buildings, and methods to use rainwater instead of treated water. – A city with good governance strives to improve the quality and efficiency of city services. It mandates transparency and accountability at all levels of the government. It provides the means to listen, understand, and respond to the needs of its citizens and businesses.	Quality of life, water and energy consumption, networks, information.	Kehoe-IBM (2011a)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
		– A city that incorporates culture and events attracts visitors and keeps citizens interested in the city through investments in arts, culture, and tourism. These investments are a great way to draw attention to the city and a way to establish the city as a world-class location to live in. – A city focused on its citizens looks to address their needs by providing information and access to city services in a convenient and easy-to-use manner. When done rightly, both the citizens and the city government can benefit. This mechanism gives the citizens access to the information and services when needed and gives the city a means to share important information and obtain input from its citizens in a timely manner.		
50	Corporate	Business growth and development, building the city's economy: – A city of digital innovation focuses on using strategic investments in connectivity and communications (for example, wireless broadband either broadcast or through hotspots). It attracts cutting edge businesses in the industrial and high-tech fields and builds human and intellectual capital. – A city of commerce establishes itself as a local, regional, or national centre of commerce and economic development. It builds local expertise in a specific industry and the infrastructure and services to support continued growth and to remain competitive. – A city attracting and keeping skilled workers promotes itself as being a desirable place to locate to or to grow up and stay in.	Digital, commerce, building the city's economy, cost effective.	Kehoe-IBM (2011b)
		This ability to maintain skilled workers is accomplished by anticipating and accommodating shifts in business needs, skills, local population, and demographics to offer economic opportunities. – A city with free-flowing traffic identifies and manages congestion actively. This demand is accomplished by making various forms of transport (such as road, air, rail, and bus) cost effective and efficient.		
51	Corporate	IBM defines a smarter city as one that makes optimal use of all the interconnected information available today to better understand and control its operations and optimize the use of limited resources.	Information, operations, resources, optimize.	IBM Smarter City Assessment Tool (2009)
52	Corporate	Smart cities: Innovative urban developments that leverage ICT for the management of natural energy consumption at the community level and other technologies to balance environmental stewardship with comfortable living.	Innovation, urban, ICT, energy, community, technology, environment, living.	Fujitsu (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
53	Corporate – Derived from video	Cities are a complex and dynamic system. According to SAP, there are eight (8) fundamental factors that determine what defines a sustainable city: • Smart economy – Long-term prosperity, innovation, entrepreneurs, and social business models. • Good government – High performance. • Open society. • Resilience and sustainability – being clean and green. • Global attractiveness. • Human and social capital. • World-class financial expertise. • Excellent infrastructure – physical and soft infrastructure (technology, research and knowledge).	Smart economy, good government, open society, global attractiveness, human and social capital, infrastructure, knowledge, technology.	SAP (2014)
54	Corporate definition derived	Smart is a combination of collaborative leadership, policy and legal, customer insight, budget and performance management, service orientation and technology.	Leadership, policy, customer, service orientation, technology.	Colclough-Capgemini (2011)
55	Corporate CSR	In a broader definition, a city can be considered as "smart" when its investment in human and social capital and in communications infrastructure actively promotes sustainable economic development and a high quality of life, including the wise management of natural resources through participatory government.	Human capital, social capital, communication, economic growth, economic development, sustainability, quality of life, natural resource management, participatory government.	Hirst-European Investment Bank (2012)
56	Corporation	A smart city is a city that meets its challenges through the strategic application of ICT goods network and services to provide services to citizens or to manage its infrastructure. A sustainable city is a city that meets the needs of the present without compromising the ability of future generations to meet their own needs.	ICTs, citizens, environment, social, economic growth.	Lovehagen-Ericsson (2013)
57	Government/ International organization	Traditionally, a "smart sustainable city" has been defined as a city that uses information and communication technology to make both its critical infrastructure, its components and utilities more interactive, efficient, making citizens more aware of them.	ICT, interactive critical infrastructure, interconnectivity, efficiency, awareness.	Azkuna (2012a)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
58	Government/ International organization	In preparing this report, we used the smart sustainable city model, which identifies the presence and convergence of six areas: economy, mobility, environment, citizenship, quality of life, and, finally, management. A city can be defined as smart when it displays a positive performance in these six areas, and when it has been built based on a "smart" combination of elements (communication, infrastructure, economic development) and on purposeful and independent citizen activities (participation, education) that make sound management of natural resources through participatory governance.	Convergence, integration, economy, mobility, environment, citizenship, quality of life, communication, infrastructure, economic development, citizen participation, education, natural resource management, participatory governance.	Azkuna (2012b)
59	Government/ International organization	A type of city that uses new technologies to make them more liveable, functional, competitive and modern, the promotion of innovation and knowledge management, bringing together six (6) key fields of performance: economy, mobility, environment, citizenship, quality of life and, finally, management.	Liveable, technology, citizens, quality of life, management, economy.	Azkuna (2012c)
60	Government/ International organization	Smart sustainable cities combine diverse technologies to reduce their environmental impact and offer citizens better lives. This is not, however, simply a technical challenge. Organizational change in governments – and indeed society at large – is just as essential. Making a city smart is therefore a very multidisciplinary challenge, bringing together city officials, innovative suppliers, national and EU policymakers, academics and civil society.	Diverse technology, environment, quality of life, city officials, suppliers, policy makers, academics, civil society.	European Commission (2014)
61	Government/ International organization	A real smart city develops the city to reach the aim of improving the quality of life. It needs sound and innovative economic development as a means to reach this aim. Uses ICT as a tool with a great potential for ameliorating daily life, public services and the economy.	Quality of life, innovative, economic, ICT, public services.	Schweiker - Council of European Municipalities (2010)
62	Academic	Amsterdam Smart City uses innovative technology and the willingness to change behaviour related to energy consumption in order to tackle climate goals. Amsterdam Smart City is a universal approach for design and development of a sustainable, economically viable programme that will reduce the city's carbon footprint.	Smart city, innovative, technology, energy, economically, carbon footprint.	Lee et al. (2012)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
63	Government/ International organization	There are three major functions that "ICT Smart Town" is expected to contain. ICT to be used both in ordinary times and in times of disaster. ICT is used in order to contribute to self-sustaining town development in ordinary times, while it functions for disaster prevention and mitigation in times of disaster. Users, mainly local citizens, can participate in the Smart Town community using the ICT system through user-friendly and accessible interfaces such as mobile phones and TVs. New services resulting from the use of "Big Data", including the government-held (public) data, private sector data and real-time data, collected through sensors.	Disaster, citizens, smart town, community, interfaces, government, real-time data.	Japan Ministry of Internal Affairs and Communications (2013)
64	Government/ International organization	Smart cities should be regarded as systems of people interacting with and using flows of energy, materials, services and finance to catalyse sustainable economic development, resilience, and high quality of life; these flows and interactions become smart through making strategic use of information and communication infrastructure and services in a process of transparent urban planning and management that is responsive to the social and economic needs of society.	People, quality of life, energy, materials, sustainable, economic, urban planning, society.	European Commission (2013)
65	Government/ International organization	A "city" can be defined smart when systematic information and communication technologies and resource-saving technologies are used to work towards a post fossil society, to reduce resource consumption, enhance permanently citizens' quality of life and the competitiveness of local economy – thus improving the city's sustainability. The following areas are at least taken into account: energy, mobility, urban planning and governance. An elementary characteristic of a smart city is the integration and cross-linking of these areas in order to implement the targeted ecological and social aspects of urban society and a participatory approach.	Energy, mobility, urban planning, governance, integration, ecological, ICT.	Homeier-City of Vienna (2013)
66	Government/ International organization	Create a real shift in the balance of power between the use of information technology by business, government, communities and ordinary people who live in cities.	Power, information technology, business communications, government, people.	Deakin-European Commission (2014)
67	Corporate	A smart city offers its inhabitants a maximum of life quality by a minimum use of resources thanks to intelligent combination of different infrastructure systems (transport, energy communication, etc.) on different levels like buildings, areas, quarters and cities. «Intelligent» in this context does not automatically mean "IT". By similar performance, passive or self-regulating mechanisms is preferable to active regulated systems.	Quality of life, infrastructure systems, intelligence.	Horbaty-Energie Schweiz (2013)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
68	Academic	"...are territories with a high capacity for learning and innovation, which is built into the creativity of their population, their institutions of knowledge creation and their digital infrastructure for communication". .... [and are concerned] with people and the human capital side of the equation, rather than blindly believing that IT itself can automatically transform and improve cities.	Learning, innovation, creative people, knowledge institutions, communication infrastructure.	Hollands (2008)
69	Industry association	The Council defines a Smart Sustainable City as one that has digital technology embedded across all city functions.	ICT, integrated, city functions.	Smart Cities Council (2014)
70	Government/ International organization	"At its core a smart city is a welcoming, inclusive city, an open city. By being forthright with citizens, with clear accountability, integrity, and fair and honest measures of progress, cities get smarter".	Integrity, citizens.	Comstock-World Bank Blogs (2012)
71	Internet	A developed urban area that creates sustainable economic development and high quality of life by excelling in multiple key areas: economy, mobility, environment, people, living, and government. Excelling in these key areas can be done through strong human capital, social capital, and/or ICT infrastructure.	Economic growth, standard of living, quality of life, transport, mobility, environment, governance, human capital, social capital, ICT, urban area.	Business Dictionary (2014)
72	Corporate	Framing the "triple bottom line" of economy, environment, and social equity in one big picture. We are working to get our arms around a more sustainable future – a better way to connect people, homes, jobs and places – as a metro area and region, with more transportation choices. Frankly, it is a very tough challenge.	Metro, economy, environment and social equity, transportation, interconnecting people, home, jobs and places.	Ott-HBR Blog Network (2011)
73	ITU	A "smart sustainable city" is mainly based on the information and communication technologies. Through the transparent and full access to information, the extensive and secure transmission of information, the efficient and scientific utilization of information, SSC increases the urban operational and administrative efficiency, improves the urban public service level, forms the low-carbon urban ecological circle, and constructs a new formation of urban development.	ICT, information access, information utilization, operational efficiency, administrative efficiency, services, low carbon, urban development.	FG-SSC-0005 (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
74	ITU	Smart sustainable cities are well managed, integrated physical and digital infrastructures that provide optimal services in a reliable, cost effective, and sustainable manner while maintaining and improving the quality of life for its citizens. Key attributes of a smart sustainable city are mobility, sustainability, security, reliability, flexibility, technology, interoperability and scalability. Foundational aspects include economy, governance, society and environment with vertical infrastructures such as mobility, real estate and buildings, industrial and manufacturing, utilities -electricity and gas, waste, water and air management, safety and security, health care and education. All of these are woven into a single fabric with ICT infrastructure as a core.	Well managed, integrated, digital infrastructure, optimize services, sustainability, quality of life, mobility, security, reliability, flexibility, technology, interoperability, scalability, economy, governance, society, environment, real estate and buildings, industrial and manufacturing, utilities - electricity and gas, waste, water and air management, safety and security, health care and education, integrated, ICT.	FG-SSC-0013 (2014)
75	ITU/ Government	It is a city with a large, efficient and widespread technological network that fosters dialogue between citizens and everyday objects. It integrates the huge amount of information available to generate intelligence and improve daily life in a lifestyle that is increasingly "smart". It combines innovation with the environment, mobility and quality of life. It is a new phenomenon, complex and rapidly changing. Technological innovation moves in several directions (green buildings, smart mobility, e-health, e-government, etc.).	ICT, integrated, quality of life, innovation, environment, mobility, green buildings, health, environment governance.	FG-SSC-0014 (2013)
76	ITU	ICT spans across a number of application sectors that characterize the framework of smart sustainable cities. Among others, energy, buildings, transport and mobility, water and waste management.	ICT, sustainability, energy, buildings, transport, mobility, water management, waste management.	FG-SSC-0020 (2013)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
77	ITU	"A Smart Sustainable City has been defined as a 'knowledge', 'digital', and 'cyber' or 'eco' city; representing a concept open to a variety of interpretations, depending on the goals set out by a Smart Sustainable City's planners. We might refer to a Smart Sustainable City as an improvement on today's city both functionally and structurally, using information and communication technology (ICT) as an infrastructure. Looking at its functions as well as its purposes, a Smart Sustainable City can perhaps be defined as "a city that strategically utilizes many smart factors such as Information and Communication Technology to increase the city's sustainable growth and strengthen city functions, while guaranteeing citizens' happiness and wellness."	ICT, strategic resource utilization, sustainability, growth, services, citizen happiness, citizen wellness.	Hwang et al. (2013)
78	Magazine	Smart sustainable cities use information and communication technologies (ICT) to be more intelligent and efficient in the use of resources, resulting in cost and energy savings, improved service delivery and quality of life, and reduced environmental footprint –all supporting innovation and the low-carbon economy.	ICT, cost efficiency, energy efficiency, energy savings, quality of life, environment, improved service delivery, innovation, low carbon economy.	Cohen (2011)
79	Magazine	An eco-city is defined as a city in which citizens, business and government sustainably work, live and interact through delivery of integrated, low carbon products and services. The objective of this project is to build a new industrial community to maximize the welfare of the people and minimize carbon emission. The above vision can be achieved by integrating technology across water, waste, energy, transportation and safety infrastructure while taking measures like maximum utilization of renewable resources for electricity supply, minimum loss of natural resources and others.	Sustainably, integrated, low carbon products and services, maximize welfare, industrial community, integrated technology.	Manesar (2011)
80	User centric	"The use of Smart Computing technologies to make the critical infrastructure components and services of a city-which include city administration, education, healthcare, public safety, real estate, transportation, and utilities-more intelligent, interconnected, and efficient" (58).	Computing technologies, interconnected components, city administration, education, healthcare, public safety, real estate, transportation, utilities, efficiency.	Washburn et al. (2010)
81	User centric	A smart sustainable city is characterized by the integration of technology into a strategic approach to sustainability, citizen well-being, and economic development.	ICT, integrated, sustainability, citizen well-being, economic development.	Woods et al. (2013)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
82	User centric	The terms “smart” and “intelligent” have become part of the language of urbanization policy, referring to the clever use of IT to improve the productivity of a city's essential infrastructure and services and to reduce energy inputs and CO_2 outputs in response to global climate change.	ICT, infrastructure productivity, services, low carbon, environment.	Hodkinson, S. (2011)
83	User centric	A smart sustainable city is one that "uses information and communications technologies to make the critical infrastructure components and services of a city – administration, education, healthcare, public safety, real estate, transportation and utilities – more aware, interactive and efficient."	ICT, administration, education, health care, public safety, real estate, transportation, utilities, integrated, efficient, interactive.	Belissent (2010)
84	User centric	An urbanized area where multiple public and private sectors cooperate to achieve sustainable outcomes through the analysis of contextual information exchanged between them. The sectors could include hospitals or emergency services or finance and so on. The interaction between sector-specific and intra-sector information flows results in more resource-efficient cities that enable more sustainable citizen services and more knowledge transfer between sectors.	Information exchange, integrated, resource efficiency, services, sustainability.	Maio (2012)
85	User centric	Cities need to differentiate themselves to attract investment and productive residents, and this is coupled with constrained financial resources, fast-growing populations, and aging infrastructures, is driving investment in smart sustainable city solutions. Smart sustainable city solutions leverage ICT not only to deliver higher-quality citizen services more efficiently but also to effect behavioural change in government workers, city businesses, and citizens so that cities can develop more sustainably.	ICT, services, efficient, development and behavioural change in government workers, city businesses, and citizens.	IDC (2014)
86	User centric	It is precisely because of the importance of cities and the need to deepen knowledge of urban issues that we undertake the study. The effort to question and understand where cities are and where they are headed benefits all of us in a world urbanizing like never before. This includes the officials and policymakers setting the course, businesses invested in city well-being, and the citizens who build their lives in thousands of city neighbourhoods worldwide, rich or poor, picturesque or prosaic.	Policymakers, business, well-being, urbanizing.	Ernst & Young (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
87	User centric	Many cities are exploring the "Smart City" or "Intelligent Community" concept to improve efficiencies, optimize how they use largely finite resources and become better places to live and make business. They are deploying new information and communications technology to strengthen social and business services across different sectors and to build an intelligent digital nervous system supporting urban operations. By incorporating information and communications technology and strategically exploiting the vast amounts of data they generate, smart cities can make buildings more efficient, reduce energy consumption and waste, and make better use of renewable energy. They can manage traffic intelligently, monitor how infrastructure performs, provide better communications infrastructures, deliver services much more efficiently, and enhance citizens' access to government.	Social, business, efficient, renewable, monitor, infrastructure, citizens, government, ICT, energy consumption.	Craren et al. (2012a)
88	User centric	What makes a city tick? "Justice remains the appropriate name for certain social utilities which are vastly more important, and therefore more absolute and imperative, than any others," John Stuart Mill wrote in Utilitarianism in 1861. He added, "education and opinion, which have so vast a power over human character, should so use that power to establish in the mind of every individual an indissoluble association between his own happiness and the good of the whole." Many of those we spoke with this year in developing Cities of Opportunity agree. The foundations of healthy cities remain rule of law and safety and security today, as well as strong education to foster those qualities for future generations.	Justice, education, happiness, healthy, security, safety.	Craren et al. (2012b)
89	User centric	Smart city is characterized by the integration of technology into a strategic approach to sustainability, citizen well-being, and economic development. Smart city projects span several industry and operational silos: energy, water, transportation, buildings management, and government services. Most importantly, the smart city concept promotes new integrated approaches to city operations, leading to innovation in cross-functional technologies and solutions.	Technology, well-being, economic development, energy, water, transportation, buildings, government, innovation, technology.	Woods et al. (2013)
90	User centric	According to Deloitte the three market drivers of smart cities are smart water, smart energy and smart agriculture. Smart water is increasingly seen as a component of ambitious smart city programmes that address the myriad of problems created by mass urbanization. Smart energy – the race for more and more energy sources is driving an increase in unconventional oil and gas exploration – in turn driving significant water and wastewater issues. Smart agriculture – the challenge to feed a growing global population is stressing food systems in both the developed and developing world and requires novel agricultural solutions.	Solutions, water, agriculture, energy, population,	Haji (2013)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
91	User centric	The definition of sustainable development comprises five categories. Basic needs. Access to safe water, sufficient living space, adequate health care, and education are fundamental priorities for urban populations. Resource efficiency. A city's efficiency in such areas as the use of water and energy and the effective recycling of waste directly correlates to the quality of life of its citizens. Environmental cleanliness. Limiting exposure to harmful pollutants is fundamental to a city's liveability. Built environment. Equitable access to green space, public transportation, and dense, efficient buildings makes communities more liveable and efficient. Commitment to future sustainability. An increase in the number of employees and the level of financial resources devoted to sustainability suggests how committed city governments are to implementing national and local policies and standards.	Water, living space, health care, urban populations, energy, recycling, quality of life, pollutants, cleanliness, efficient, policies and standards.	Bouton et al. (2012)
92	Non-profit	A city "combining ICT and Web 2.0 technology with other organizational, design and planning efforts to de-materialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and liveability."	ICT, web 2.0, bureaucratic efficiency, city management, innovative solutions, sustainability, liveability, standard of living.	Toppeta (2010)
93	Conference	What makes a city smart? A non-vendor driven definition of a 'Smart Sustainable City' The closer a city behaves to the ethos of the Internet, the smarter it is. That means the city is a platform – an enabler for the people. So, empowering people is at the centre of the perfect storm. So, what does a Smart Sustainable City look like? A city can be defined as smart when investments in human and social capital and traditional (ex-transport) and modern (ex-ICT) communications infrastructure fuel sustainable economic development and a high quality of life with a wise management of natural resources through participatory governance.	People enabler, human capital, social capital, traditional communication, modern communication, ICT, economic development, quality of life, natural resource management, participatory governance.	Jaokar (2012)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
94	Others	Seven (7) important elements in most cases of a smart sustainable city (Source: Xi She): 1) sensible – sensor sensing the environment ,2) connectable – networking devices bringing the sensing information to the web, 3) accessible – the broader information of our environment is published on the web, and is accessible to the user on the web, (web), 4) ubiquitous – the user can access information through the web, but more importantly through the use of the mobile (mobile), 5) social – the user acquires the information, and publishes it through his social network (social network), 6) Sharing – sharing is not limited to data but also to the physical object, when some objects are in free status, people can get the notification and use it. (Web, mobile), 7) visibility/augmented – to retrofit the physical environment, make the hidden information seen not only through the mobile device by individuals but also with the naked eyes in a more border range like street signs.	Sensor monitoring, Internet connectivity, information availability, mobile, visible.	World Smart Capital (2012)
95	Industry	A smart city is a city that employs ICT infrastructures by sensing, transmitting and utilizing information in order to fulfil information sharing and service collaboration, further improve citizens' livelihood standards and their quality of life, increase urban operation efficiency and public service level, enhance the quality of economic development and industry competitive ability, and realize the scientific and sustainable development of the city.	Sensing, transmitting, ICT infrastructure, information, collaboration, quality of life, urban efficiency, economy, competitive, scientific, sustainable.	China Communication Standards Association (2014)
96	Government	Smart cities should be regarded as systems of people interacting with and using flows of energy, materials, services and finance to catalyse sustainable economic development, resilience, and high quality of life; these flows and interactions become smart through making strategic use of information and communication infrastructure and services in a process of transparent urban planning and management that is responsive to the social and economic needs of society.	Systems, people, energy, materials, services, finance, sustainable, economic, resilience, quality of life, ICT infrastructure, urban planning, responsive, social.	European Innovation Partnership on Smart Cities and Communities
97	Academic	Main features to be included in smart city administration: (i) Quality of life, (ii) Sustainable resource management, (iii) Cultural facilities, (iv) Health facilities, (v) Sustainable and innovative and safe transport systems, (vi) Environmental protection.	QoL, resources, sustainability, environment, health, transport, mobility.	Vienna University of Technology, University of Ljubljana, Delft University of Technology (2007)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
98	Academic	Eco-cities focus on: (i) entrepreneurship, (ii) environment, (iii) sustainable urban development.	Business, environment, sustainability.	Rapoport, E. (2014)
99	Academic	Smart cities should focus on: (i) improvement of urban living capacity, (ii) resource efficient development, (iii) low carbon economy, (iv) use of ICT to manage complex urban system.	Urban, resources, economy, people.	Alusi, A., Eccles, R. G., Edmondson, A. C., Zuzul, T. (2011)
100	Academic	Smart city triple helix: human and social relations connecting the intellectual capital, natural wealth and governance of their regional development.	People, intelligent, development, governance and administration, natural, resources.	Njikamp, Lombardi, P., Giordano, S., Caraglui, A., Del Bo, C., Deakin, M.
101	Academic/ Corporate	Key aspect of smart cities is a plan for efficient management of utilities enabled by technologies such as those entailing smart metering of the residential consumption of electricity, water or gas.	Technology, utilities, efficient, water, electricity.	Monedero, D. R., Bartoli, A., Hernandez-Saerrano, J., Forne, J., Soriano, M. (2013)
102	Academic	Features of smart cities involve the use of discrete future Internet technologies (RFID), improving e-governance, providing and environment for innovation.	ICT, technology, governance and administration.	Balloon, Pieter, Glidden, J., Kranas, P., Menychtas, A., Ruston, S., Van der Graaf, S. (2011)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
103	Academic	Typology of smart city functions: (i) Smart economy (competitiveness): innovative spirit, entrepreneurship, economic image, productivity. (ii) Smart mobility (transport and ICT): local accessibility, availability of ICT infrastructure, innovative and safe transport systems. (iii) Smart people (social and human capital): level of qualification, flexibility, creativity, participation in public life. (iv) Smart environment (natural resources): pollution control, environmental protection, sustainable resource management. (v) Smart governance (participation): decision-making, transparent governance, political strategies and perspectives. (vi) Smart living (quality of life): cultural activities, health conditions, housing quality, education facilities, touristic attractiveness, social cohesion.	Economy, business, competition, mobility, transport, social, people, capital, society, environment, sustainable, resources, natural, efficient, governance and administration, QoL, education, health, buildings.	Batty, M. Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., Ouzounis, G., Portugali, Y. (2012)
104	Academic	Smart cities should be centred around ecological modernization with an emphasis on business opportunities associated with a move to low carbon economy.	Environment, business, resources, efficient, economy.	Antrobus, D. (2011)
105	Academic	"Smarter cities" has the following four components: (i) the application of a wide range of electronic and digital technologies to communities and cities, (ii) the use of information technologies to transform life and work within a region, (iii) the embedding of such ICTs in the city, (iv) The territorialisation of such practices in a way that brings ICTs and people together so as to enhance innovation, learning, knowledge and problem solving that the technologies offer.	ICT, technology, QoL, community, public, innovations, society, intelligent.	Allwinkle, S., Cruickshank, P. (2011)
106	Academic	Urban dwellers should be provided with smart phones that provide advanced capabilities to connect to the Internet, determine the user's location as well as provide crowd-sourcing platforms.	Public, ICT, community, participatory, actively, accessible, mobility.	Benouret, K., Ramalingam, R. V., Charoy, F. (2013)
107	Academic	"A smart city is generally meant as a city capable of joining competitiveness and sustainability by integrating different dimensions of development and addressing infrastructural investments able to support economic as well as the quality of life of communities, a more careful management of natural resources, a greater transparency and participation to the decision-making process."	Sustainable, participatory, society, quality of life, integrate, resources, competitive, investment, economy, community, transparency, active, development.	Papa, R. (2013)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
108	Academic	Findings denote that smart cities should include the following dimensions: (i) Urban openness: making information visually available, participatory services to drive civic engagement. (ii) Service innovation: using ICTs to drive development in health, welfare, education, transportation, sectors, etc. (iii) Partnership formation: partnerships for building effective smart cities (central government, state government, private bodies, NGO involvement), direct vs indirect involvement, contracted/outsourcing development. (iv) Smart city integration: smart service access over multiple device platforms, app-based formatting of service information. (v) Smart city governance: Smart city teams involved with strategy, policy, and infrastructure and include ICT-based performance evaluation and feedback channels.	Accessible, participatory, ICT, governance and administration, investments, transport, business, health security and safety, urban, design, innovation.	Lee, J. H. Hancock, M. G., Hu, M. (2012)
109	Corporate	IBM Smarter Cities Initiative: " (a) is a long-term process aiming to transform city-based technologies and, in the process, help cities achieve their strategic vision; (b) recognizes that the needs and aspirations of each city may be very different; (c) requires partnerships (across many clients and with other delivery partners) to achieve the desired large-scale transformations; (d) is based heavily on dimensions from IBM's global Smarter Planet strategy of which there are many applications (smart education systems, cloud computing, risk assessments, ICT based platform for exchange of ideas etc.)."	Vision, solutions, design, management, business, education, ICT, technology.	Paroutis. S., Bennett, Heracleous, L. (2012)
110	Academic	"The basic concept of the Smart Cities initiative can be expressed as follows: the Smart Cities initiative seeks to improve urban performance by using data, information and IT to provide more efficient services to citizens to monitor and optimize existing infrastructure, to increase collaboration between economic actors and to encourage innovative business models in both public and private sectors".	Urban, ICT, innovation, people, economy, business, public, information, management, services.	Llacuna, M. L. M. Llinas, J. C., Frigola, J. M. (2014)
111	Academic	Five successful factors for a smart city: (i) broadband connectivity, (ii) knowledge workforce, (iii) digital inclusion, (iv) innovation, (v) marketing, (vi) advocacy.	ICT, education, technology, innovation, business, communication.	Kramers, A., Hojer, M., Lovehagen, N., Wangel, J. (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
112	Academic	"The concept of Smart City as a means to enhance the life quality of citizen has been gaining increasing importance in the agendas of policy makers". The main domains of a smart city include: (i) Employing ICT to deliver energy, enhance entrepreneurship and enable information exchange about consumption between providers and users with the aim of reducing costs and increasing reliability and transparency of energy supply systems. (ii) Public lighting, natural resources and water management. (iii) Waste management: Using innovations to manage waste generated by people, businesses and city services. This includes waste collection, disposal, recycling and recovery. (iv) Environment: Technology used to manage environmental resources and related infrastructure. This is done with the aim of improving sustainability. (v) Transport: Using sustainable public transportation based on environmentally friendly fuels and innovative propulsion systems. (vi) Healthcare: ICT applications and remote assistance to prevent and diagnose diseases. Improved access to health care systems. (vii) Public security: Use of ICT to assist with security issues like fire. ICTs may also be of help to the police department. (viii) Education and culture: Using ICTs to create opportunities for students and teachers, promote cultural events, manage tourism and hospitality. (ix) Public administration and governance: Promoting digitalized public administration, e-ballots and ICT-based transparency of government activities to enhance the empowerment of the inhabitants and involvement in administration.	Energy, economy, resources, management, water, environment, participatory, governance and administration, business, health security and safety, education, intelligent, ICT, innovation, natural, public, management, transport, utilities.	Neirotti, P., De Marco, A., Cagliano, A. C., Mangano, G., Scorrano, F. (2014)
113	Corporate	Smart cities are aimed at: addressing urbanization, facilitating economic growth, enhancing technological progress using ICTs, environmental sustainability.	Urban, ICT, environment, innovation, technology.	Naphade, M., Guruduth, B., Harrison, C., Jurij, P., Morris, R. (2014)

Ref. No.	Category	Definitions / Features	Key Concepts / Keywords	Source
114	Academic/International organization	Smart city establishments include: (i) Energy policy management, (ii) Healthcare governance, (iii) Financial policy management, (iv) Remote monitoring, (v) Complaint management, (vi) Intelligent buildings, (vii) Security systems based on ICT, (viii) IT configuration management databases.	Energy, health, security and safety, intelligent, ICT, management, buildings.	Asimakopoulou, E., Bessis, N. (2011)
115	Academic	"A city that monitors and integrates conditions of all the its critical infrastructures, including roads, bridges, tunnels, rails subways, airports, seaports, communications, water, power, even major buildings can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens."	Transport, energy, resources, society, integration.	Hall, R., E. (2000)
116	Academic	"A city striving to make itself smarter (more efficient, sustainable, equitable and livable)."	Sustainable, QoL, society, ICT, technology.	Nfuka, E., N., Rusu, L. (2010)

ANNEX II – EXPLORED INDICATOR FRAMEWORKS

Table II-1: Smart Cities – Ranking of European Medium-Sized Cities (Source: Giffinger et al., 2007)

Characteristic	Factor	Indicator	ICT-Related	Non ICT-Related
Smart Economy	Innovative spirit	R&D expenditure in % of GDP		✓
		Employment rate in knowledge-intensive sectors		✓
		Patent applications per inhabitant	✓	✓
	Entrepreneurship	Self-employment rate		✓
		New business registered		✓
	Economic image & trademarks	Importance as decision-making centre [headquarters (HQ), etc.]		✓
	Productivity	GDP per employed person		✓
	Flexibility of labor market	Unemployment rate		✓
		Proportion in part-time employment		✓
	International embeddedness	Companies with HQ in the city quoted on national stock market		✓
		Air transport of passengers		✓
		Air transport of freight		✓
Smart People	Level of qualification	Importance as knowledge centre (top research centres, top universities, etc.)		✓
		Population qualified at levels 5-6 of International Standard Classification of Education (ISCED)		✓
		Foreign language skills		✓
	Affinity to lifelong learning	Book loans per resident		✓
		Participation in lifelong learning in %		✓
		Participation in language courses		✓
	Social and ethnic plurality	Share of foreigners		✓
		Share of nationals born abroad		✓
	Flexibility	Perception of getting a new job		✓
	Creativity	Share of people working in creative industries		✓
	Cosmopolitanism / Open-mindedness	Voters turnout at European elections		✓
		Immigration-friendly environment (attitude towards immigration)		✓
		Knowledge about the EU		✓
	Participation in public life	Voters turnout at city elections		✓
		Participation in voluntary work		✓
Smart Governance	Participation in decision-making	City representatives per resident		✓
		Political activity of inhabitants		✓
		Importance of politics for inhabitants		✓

		Share of female city representatives		✓
	Public and social services	Expenditure of the municipal per resident in Prospective Payment System (PPS)		✓
		Share of children in day care		✓
		Satisfaction with quality of schools		✓
	Transparent governance	Satisfaction with transparency of bureaucracy		✓
		Satisfaction with fight against corruption		✓
Smart Mobility	**Local accessibility**	Public transport network per inhabitant		✓
		Satisfaction with access to public transport		✓
		Satisfaction with quality of public transport		✓
	(Inter-)national accessibility	International accessibility		✓
	Availability of ICT infrastructure	Computers in households	✓	
		Broadband Internet access in households	✓	
	Sustainable, innovative and safe transport systems	Green mobility share (non-motorized individual traffic)		✓
		Traffic safety		✓
		Use of economical cars		✓
Smart Environment	**Attractivity of natural conditions**	Sunshine hours		✓
		Green space share		✓
	Pollution	Summer smog (Ozone – O_3)		✓
		Particulate matter (PM)		✓
		Fatal chronic lower respiratory diseases per inhabitant		✓
	Environmental protection	Individual efforts on protecting nature		✓
		Opinion on nature protection		✓
	Sustainable resource management	Efficient use of water (use per GDP)		✓
		Efficient use of electricity (use per GDP)		✓
Smart Living	**Cultural facilities**	Cinema attendance per inhabitant		✓
		Museum visits per inhabitant		✓
		Theatre attendance per inhabitant		✓
	Health conditions	Life expectancy		✓
		Hospital beds per inhabitant		✓
		Doctors per inhabitant		✓
		Satisfaction with quality of health system		✓
	Individual safety	Crime rate		✓
		Death rate be assault		✓
		Satisfaction with personal safety		✓

	Housing quality	Share of housing fulfilling minimal standards		✓
		Average living area per inhabitant		✓
		Satisfaction with personal housing situation		✓
	Education facilities	Students per inhabitant		✓
		Satisfaction with access to educational system		✓
		Satisfaction with quality of educational system		✓
	Touristic attractivity	Importance as tourist location (overnights, sights)		✓
		Overnights per year per resident		✓
	Social cohesion	Perception on personal risk of poverty		✓
		Poverty rate		✓

Table II-2: The Smart Cities Wheel (Source: Cohen, 2014)

Dimension	Working Area	Indicator	Description	ICT-Related	Non ICT-Related
Smart Economy	Entrepreneurship and innovation	New startups	Number of new opportunity-based startups/year		✓
		R&D	Percentage of GDP invested in R&D in private sector		✓
		Employment levels	Percentage of persons in full-time employment		✓
		Innovation	Innovation cities index	✓	
	Productivity	Gross Regional Product (GRP) per capita	GRP per capita		✓
	Local and global connection	Exports	Percentage of GRP based on technology exports	✓	
		International events hold	Number of international congresses and fairs attendees		✓
Smart People	Inclusion	Internet-connected households	Percentage of Internet-connected households	✓	
		Smartphone penetration	Percentage of residents with smartphone access	✓	
		Civic engagement	Number of civic engagement activities offered by the municipality last year		✓
			Voter participation in last municipality elections (Percentage of eligible voters)		✓
	Education	Secondary education	Percentage of students completing secondary education		✓
		University graduates	Number of higher education degrees per 100,000 inhabitants		✓
	Creativity	Foreign-born immigrants	Percentage of population born in a foreign country		✓
		Urban living lab	Number of officially registered European Network of Living Labs (ENoLL) living labs		✓
		Creative industry jobs	Percentage of Labor Force (LF) engaged in creative industries		✓
Smart Governance	Online services	Online procedures	Percentage of government services that can be accessed by citizens via web or mobile phone	✓	
		Electronic benefits payment	Existence of electronic benefit payments (e.g., social security) to citizens	✓	
	Infrastructure	Wi-Fi coverage	Number of Wi-Fi hotspots per km^2	✓	
		Broadband coverage	Percentage of commercial and residential users with Internet download speeds of at least 2 Megabits/s	✓	
			Percentage of commercial and residential users with Internet download speeds of at least 1 Gigabit/s	✓	
		Sensor coverage	Number of infrastructure components with installed sensors. 1 point for each: traffic, public transit demand, parking, air quality, waste,	✓	

			H2O, public lighting		
		Integrated health and safety operations	Number of services integrated in a singular operations center leveraging real-time data. 1 point for each: ambulance, emergency/disaster response, fire, police, weather, transit, air quality	✓	
	Open government	Open data	Open data use	✓	
		Open apps	Number of mobile apps available based on open data	✓	
		Privacy	Existence of official citywide privacy policy to protect confidential citizen data	✓	
Smart Mobility	Efficient transport	Clean-energy transport	Kilometers of bicycle paths and lanes per 100,000 inhabitants		✓
			Number of shared bicycles per capita		✓
			Number of shared vehicles per capita		✓
			Number of Electric Vehicles (EV) charging stations within the city		✓
	Multi-modal access	Public transport	Annual number of public transport trips per capita		✓
			Percentage of non-motorized transport trips of total transport		✓
			Integrated fare system for public transport		✓
	Technology infrastructure	Smart cards	Percentage of total revenue from public transit obtained via unified smart card systems	✓	
		Access to real-time information	Presence of demand-based pricing (e.g., congestion pricing, variably priced toll lanes, variably priced parking spaces)	✓	
			Percentage of traffic lights connected to real-time traffic management system	✓	
			Number of public transit services that offer real-time information to the public: 1 point for each transit category up to 5 total points (bus, regional train, metro, rapid transit system [e.g., Bus Rapid Transit (BRT), tram], and sharing modes (e.g. bikesharing, carsharing)	✓	
			Availability of multi-modal transit app with at least three services integrated	✓	
Smart Environment	Smart buildings	Sustainability certified buildings	Number of Leadership in Energy and Environmental Design (LEED) or Building Research Establishment Environmental Assessment Method (BREEAM) sustainability certified buildings in the city		✓
			Percentage of commercial and industrial buildings with smart meters	✓	
			Percentage of commercial buildings with a building automation system	✓	

		Smart homes	Percentage of homes (multi-family and single-family) with smart meters	✓	
	Resources management	Energy	Percentage of total energy derived from renewable sources		✓
			Total residential energy use per capita (in kWh/yr)		✓
			Percentage of municipal grid meeting all of following requirements for smart grid (1. Two-way communication; 2. Automated control systems for addressing system outages; 3. Real-time information for customers; 4. Permits distributed generation; 5. Supports net metering)	✓	
		Carbon footprint	Greenhouse gas (GHG) emissions measured in tones per capita		✓
		Air quality	Fine Particular matter 2.5 concentration (µg/m^3)		✓
		Waste generation	Percentage of city's solid waste that is recycled		✓
			Total collected municipal solid waste city per capita (in Kg)		✓
		Water consumption	Percentage of commercial buildings with smart water meters	✓	
			Total water consumption per capita (liters/day)		✓
	Sustainable urban planning	Climate resilience planning	Does your city have a public climate resilience strategy/plan in place?		✓
		Density	Population weighted density (average densities of the separate census tracts that make up a metro)		✓
		Green space per capita	Green areas per 100,000 (in m^2)		✓
Smart Living	Culture and well-being	Life conditions	Percentage of inhabitants with housing deficiency in any of the following five areas: potable water, sanitation, overcrowding, deficient material quality or lacking electricity		✓
		Gini index	Gini coefficient of inequality		✓
		Quality of life ranking	Mercer ranking in most recent quality of life survey		✓
		Investment in culture	Percentage of municipal budget allocated to culture		✓
	Safety	Crime	Violent crime rate per 100,000 population		✓
		Smart crime prevention	Number of technologies in use to assist with crime prevention. 1 point for each of the following: live streaming video cameras, taxi apps, predictive crime software technologies	✓	
	Health	Single health history	Percentage of residents with single, unified health histories facilitating patient and health provider access to complete medical records	✓	
		Life expectancy	Average life expectancy		✓

Table II-3: City Resilience Framework (CRF) – City Resilience Index (CRI) (Source: Arup, 2016b)

Key Dimension	Goal	Indicator	Description	ICT-Related	Non ICT-Related
Health and Well-being	Minimal human vulnerability: Extent to which everyone's basic needs are met	Safe and accessible housing	Number of homeless people per 100,000 population (ISO 37120)		✓
			Percentage of houses which have passed national safety standards (UK Office for National Statistics)		✓
			Percentage of population that could be served by city's access to stock of emergency shelters for 72 hours (Arup, 2015)		✓
		Adequate energy supply	Average percentage of household income spent on fuel and electricity by the poorest 20% of the population (International Atomic Energy Agency [IAEA] / International Energy Agency [IEA] / United Nations Department of Economic and Social Affairs [UNDESA])		✓
			Percentage of city population with authorized electrical service (ISO 37120)		✓
			Number of days that city fuel supplies could maintain essential household functions (through alternative sources) (Adapted from United Nations International Strategy for Disaster Risk Reduction [UNISDR], 2014)		✓
		Inclusive access to safe drinking water	Percentage of population that has access to safe and reliable water (WHO, 2012)		✓
			Percentage of population which can be supplied water by alternative methods for 72 hours during disruption (Arup, 2015)		✓
		Effective sanitation	Percentage of population with access to improved sanitation (ISO 37120)		✓
			The number of years since the city's wastewater contingency plan was updated (Arup, 2015)		✓
		Sufficient food supply	Percentage of malnourished children under five as a percentage of all citizens under five (World Bank, 2015)		✓
			Average distance of the centre of the 20% most deprived neighborhoods (Lower Super Output Area [LSOA] level and the Index Measure of Deprivation) from a vegetable market or supermarket selling fresh food and vegetables (Arup, 2015)		✓
			Percentage per capita food reserves within city (including supermarket agreements) for 72 hours (percentage population which could be served) (Adapted from UNISDR, 2014)		✓

	Diverse livelihood and employment: Is facilitated by access to finance, ability to accrue savings, skills training, business support, and social welfare	Inclusive labour policies	Average hourly compensation cost (wage + benefits) for an hour of labor (US Dollars) (OECD)		✓
			Percentage of population living below national poverty line (United Nations Social Development Network [UNSDN], 2015)		✓
		Relevant skills and training	Percentage of people unemployed for more than six months who have access to a programme that is intended to improve their employment chances (EU, 2015)		✓
			Job security: Probability to become unemployed (the number of people who were unemployed in this year, but were employed last year, divided by the total number of employed in last year, x 100 and expressed as a percentage) (OECD Better Life Index [BLI])		✓
		Dynamic local business development and innovation	Percentage employment change from the last year (Bureau of Labor Statistics, 2015)		✓
			City's unemployment rate (% of working-age population) (OECD BLI)		✓
			Number of new businesses registered within the city in past year, per 100,000 population (Case Western Reserve University)		✓
			Percentage of local businesses with female / minority owner (Arup, 2015)		✓
		Supportive financing mechanisms	Annual number of approved and regulated small business-loans or micro-credit per 100,000 population (Arup, 2015)		✓
			Percentage value of loans / credit provided to female / minority owned businesses as a percentage of overall loans (International Labor Organization [ILO])		✓
		Diverse protection of livelihoods following a shock	Percentage of buildings with insurance cover for high-risk hazards relevant to the city (UN-Habitat)		✓
			Percentage of population which has access to disaster recovery mechanisms from shocks (Arup, 2015)		✓
			Number of mechanisms in place to support local, small- and medium-sized businesses following a disaster (Arup, 2015)		✓
	Effective safeguards to human life and health: Relies on integrated health facilities and services, and responsive emergency services	Robust public health systems	Percentage of children 12-23 months who have received specific vaccines for Bacillus Calmette-Guerin (BCG), measles, and three doses each of Diphtheria - Pertussis - Tetanus (DPT) and polio vaccine (excluding polio 0 months) per poorest quintile of the population (percentage 12–23-year-olds within poorest 20% population) (UNSDN, 2015)		✓

			Average life expectancy at birth (years) (World Bank)		✓
			Drug-related mortality with drugs as primary cause of death per 100,000 population aged 15-64 (United Nations Office on Drugs and Crime [UNODC], 2012)		✓
		Adequate access to quality healthcare	Number of physicians (Doctor of Medicine [MD] / Doctor of Osteopathic Medicine [DO] degree) working within the city per 100,000 population (ISO 37120)		✓
			Maternal mortality rate per 100,000 live births (UNSDN, 2015)		✓
			Premature (before age of 70) Noncommunicable disease (NCD) mortality rate per 100,000 population (WHO, 2012)		✓
			Number of mental health practitioners per 100,000 population (ISO 37120)		✓
		Well-resourced emergency medical facilities	Hospital beds per 100,000 people (ISO 37120)		✓
			Percentage of hospitals that have carried out disaster preparedness drills in the last year (Adapted from UNISDR, 2008)		✓
		Effective emergency response services	Number of paramedics per 100,000 population (United States Department of Commerce)		✓
			Number of firefighters per 100,000 population (ISO 37120)		✓
			Number of (operational) police officers per 100,000 population (ISO 37120)		✓
			Number of search and rescue trained emergency responders with collapsed structures expertise per 100,000 population (Arup, 2015)		✓
			Number of reviews of city-wide emergency protocols undertaken in the past five years (Arup, 2015)		✓
Economy and Society	Collective identity and community support: Is perceived as active community engagement, strong social networks and social integration	Local community support	Percentage of children living outside of the care of a responsible adult (Arup, 2015)		✓
			Family benefits public spending as a percentage of total city GDP (OECD)		✓
			Percentage of people who responded that they know the names of their immediate neighbors (by survey) (Adapted from Associated Press-NORC [AP-NORC] - University of Chicago)		✓
		Cohesive communities	Hate crimes reported per 100,000 population (Federal Bureau of Investigation [FBI], 2015)		✓
			Women as a percentage of total elected to city-level office (ISO 37120)		✓
			Youth unemployment rate (percentage of youth labor force)		✓

			(UNSDN, 2015)		
		Strong identity and culture	Percentage of respondents who felt a sense of pride in their neighborhood (Arup, 2015)		✓
			Number of months throughout the year that have a major, free public festival (Arup, 2015)		✓
		Actively engaged citizens	Voter participation in last municipal election (as a percentage of eligible voters) (ISO 37120)		✓
			Proportion of corporate charitable giving within community as a percentage of city GDP (Arup, 2015)		✓
			Number of charities operating in the city per 100,000 population (Arup, 2015)		✓
	Comprehensive security and rule of law: Includes law enforcement, fair justice, and prevention of crime and corruption	Effective systems to deter crime	Homicides per 100,000 population, per year (Arup, 2015)		✓
			Percentage re-offending by youths leaving custody (Mayor's Office for Policing And Crime [MOPAC])		✓
			Percentage of women and men who report feeling safe walking alone at night in the city or area where they live (UNSDN, 2015)		✓
		Proactive corruption prevention	Percentage of local major local government contracts and tenders (of more than $15.500) made public (Arup, 2015)		✓
			Proportion of city residents that agree corruption is somewhat or very common (Arup, 2015)		✓
		Competent policing	Homicide arrest rate: The number of persons arrested for intentional homicide in a given year divided by the number of reported intentional homicides in the same year, x 100 and expressed as a percentage. (For the most recent year for which data are available) (UN Rule of Law)		✓
			Percentage of the police force which has undertaken disaster response training in the last five years (Arup, 2015)		✓
		Accessible criminal and civil justice	Percentage difference of criminal or civil punishments imposed by judges for the same type of crime from a total average compared to the defendant's or victim's race, for the two biggest ethnic groups. (Expressed as percentage difference) (UN Rule of Law)		✓
			Percentage of people taken into police custody who have the option of a lawyer made available to them before questioning (Arup, 2015)		✓
			Weeks between a small claims case (less than £10.000 / $15.500) being submitted to court and hearing (expressed in weeks) (Arup, 2015)		✓

	Sustainable economy: Is observed in sound management of city finances, diverse revenue streams, and the ability to attract business investment, allocate capital, and build emergency funds	Well-managed public finances	Own-source revenue as a percentage of total revenues (ISO 37120)		✓
			Debt service ratio: total long-term debt servicing costs including lease payments, temporary financing and other debt charges divided by total own source revenue and expressed as a percentage (ISO 37120)		✓
			Emergency planning budget as a percentage of total city budget (Arup, 2015)		✓
		Comprehensive business continuity planning	Number of years since city economic asset assessment (public and private) (Arup, 2015)		✓
			Percentage of large businesses (500+ employees) within the city that have developed business continuity plans in accordance with ISO 22301 (Arup, 2015)		✓
			Percentage of registered SMEs the city has engaged with regarding business continuity in the last five years (Arup, 2015)		✓
		Diverse economic base	Percentage employment per sector by broad industry group (Arup, 2015)		✓
			Average GDP per capita percentage change over last five years (Brookings, 2015)		✓
			GDP (Purchasing Power Parity [PPP], $) per capita (Brookings, 2015)		✓
			Percentage of total medium and large businesses (250+ employees) within the city that are a member of the chamber of commerce (Arup, 2015)		✓
		Attractive business environment	Average foreign direct investment (FDI) - attributable jobs over the last three years per 100,000 16–64-year-olds (Arup, 2015)		✓
			Number of businesses per 100,000 16–64-year-olds (ISO 37120)		✓
			Percentage of adults with higher education as a percentage of total population aged 16-64 (Adapted from ISO 37120)		✓
		Strong integration with regional and global economies	Value of city exports as a percentage of city GDP (Arup, 2015)		✓
			Average city GDP per capita minus national average GDP per capita expressed as a percentage (Arup, 2015)		✓
Infrastructure and Ecosystems	Reduced exposure and fragility: Relies on a comprehensive understanding of the hazards and risks to	Comprehensive hazard and exposure mapping	Percentage of city area for which a comprehensive exposure and vulnerability assessment has been undertaken within the past five years (Arup, 2015)		✓
			Years since the city's climate change strategic plan was updated (Arup, 2015)		✓

	which a city is exposed that informs the development of integrated strategies to physically protect the city combining sound environmental stewardship, robust design and maintenance of manmade infrastructure, and enforcement of appropriate building codes and regulations	Appropriate codes, standards and enforcement	Estimated percentage of new buildings completed within the city in the last five years that conform to current building codes and standards (Adapted from UNISDR Scorecard)		✓
			Percentage of buildings within the city with planning permission records (Arup, 2015)		✓
			Number of years since oldest current building code was reviewed (Arup, 2015)		✓
		Effectively managed protective ecosystems	Percentage of natural areas within the city that have undergone ecological evaluation for their protective services (Arup, 2015)		✓
			Percentage green, open space increase or decrease over the past five years (Arup, 2015)		✓
			Percentage of city area that has been officially recognized for environmental protection (including shorelines down to low-tide mark) (Adapted from World Bank)		✓
		Robust protective infrastructure	Number of years since the last city-wide review of the adequacy of the city's protective infrastructure assets (Arup, 2015)		✓
			Number of years the city's stormwater (or other protective) infrastructure has been inspected (Arup, 2015)		✓
			Percentage of annual budget for stormwater infrastructure spent on upgrades (Arup, 2015)		✓
	Effective provision of critical services: Results from active management and maintenance of ecosystems, and from diversity of provision, redundant capacity, and adequate maintenance of essential utility services, combined with robust contingency planning	Effective stewardship of ecosystems	Number of years since assessment of the city's ecosystem assets / services (Arup, 2015)		✓
			PM10 concentration (μg/m3) (ISO 37120)		✓
			Percentage change in the number of native species (ISO 37120)		✓
		Flexible infrastructure	How many years ahead does the city's electricity plan look (e.g., does it analyze the city's 10+ year needs?) (Number of years) (Arup, 2015)		✓
			Number of different supply sources providing at least 5% of electricity generation capacity (World Bank)		✓
			How many years ahead does the city's water plan look (e.g., does it analyze the city's 10+ year needs?) (Number of years) (Arup, 2015)		✓
			Number of different supply sources providing at least 5% of water supply capacity (World Bank adapted from electricity)		✓
			Average $ per $10.000 of total annual expenditure of city sanitation provider(s) spent on strategic, long-term (10+ years) planning activities (Arup, 2015)		✓

			Percentage of annual unsound waste disposal (as a percentage of total disposal) (Waste Atlas, 2015)		✓
			Number of different solid waste treatment or disposal plants processing at least 5% solid waste generated within the city (Number of sources) (World Bank)		✓
		Retained spare capacity	De-rated capacity margin: the amount of excess electricity supply above peak demand (expressed as a percentage) (Office of Gas and Electricity Markets [OFGEM])		✓
			Average annual residential electrical use in Kwh per year per capita (ISO 37120)		✓
			City electricity supply capacity as a percentage of total demand (Massachusetts Water Resources Authority [MWRA])		✓
			Total water consumption per capita (liters/day) (ISO 37120)		✓
			Percentage of the city's waste water that has received no treatment (ISO 37120)		✓
			Percentage of the city population with regular solid waste collection (ISO 37120)		✓
			Waste generation rate per capita (municipal solid waste, kg per capita per year) (World Bank)		✓
		Diligent maintenance and continuity	Average length of electrical interruptions (hours per year per customer) (ISO 37120)		✓
			Average annual hours of water service interruptions per household (ISO 37120)		✓
			Annual percentage of wastewater system losses (due to storms or malfunction) prior to treatment and/or discharge to the environment (Arup, 2015)		✓
			Percentage of defined medium- to long-term waste management service contracts e.g., Public Private Partnership and Public Private Community Partnership agreements (as a percentage of total waste service contracts) (Arup, 2015)		✓
		Adequate continuity for critical assets and services	Number of years since last citywide critical asset assessment (Arup, 2015)		✓
			Percentage of city's hospitals with back-up electricity generators (Arup, 2015)		✓
			Percentage of city's hospitals with back-up water supply to meet its needs for three days (Arup, 2015)		✓

	Reliable mobility and communications: Is enabled by diverse and affordable multi-modal transport systems and information and communication technology (ICT) networks, and contingency planning	Diverse and affordable transport networks	Average speed of road journeys from city centre to the city boundary (Km/h) (Adapted from York City Council and City of London)		✓
			Percentage of commuters using a travel mode other than a personal vehicle (as a percentage of total commuters) (ISO 37120)		✓
			Percentage of journeys undertaken by walking or cycling (Arup, 2015)		✓
			Number of other cities to which this city has daily connections by bus (Liverpool City Council)		✓
		Effective transport operation and maintenance	Average percentage of the city's transport budget spent on maintenance and upgrade over the past five years (Arup, 2015)		✓
			Transportation fatalities per 100,000 population (ISO 37120)		✓
			Number of years since the city evacuation plan was updated (Arup, 2015)		✓
		Reliable communication technology	Internet users (per 100 people) (Arup, 2015)	✓	
			Number of media types used to alert people in an emergency (Arup, 2015)	✓	
			Percentage of emergency responders with arrangements which enable them to communicate in an emergency (e.g., Mobile Telecommunication Privileged Access Scheme [MTPAS] - UK, satellite phones, airwaves, etc.) (Arup, 2015)	✓	
		Secure technology networks	Percentage of city government data with secure back-up remote storage (See Tier standard of backup) (Arup, 2015)	✓	
			Percentage of government databases protected by a dynamic proactive Information Technology (IT) security system (Arup, 2015)	✓	
			Percentage of infrastructure which relies on operational technology protected by a dynamic proactive IT security system (Arup, 2015)	✓	
Leadership and Strategy	Effective leadership and management: Is enabled by trusted individuals, multi-stakeholder consultation, evidence-based decision-making and disaster risk reduction activities	Appropriate government decision-making	Number of training and knowledge sharing agreements with international networks (Arup, 2015)		✓
			Percentage of non-sensitive city government documentation and data sets that are publicly available (Arup, 2015)		✓
		Effective coordination with other government bodies	Percentage of major policy / regulatory decisions made within the last year that were the product of city-upwards, downwards (regional, national) government consultation (Arup, 2015)		✓
			Percentage of major policy / regulatory decisions made within the last year that were that are the product of cross-departmental government consultation (Arup, 2015)		✓

		Proactive multi-stakeholder collaboration	Percentage of major projects within the last year which included private sector consultation (Arup, 2015)		✓
			Percentage of city government major policy and plan changes within the past year sent out to public consultation (Arup, 2015)		✓
		Comprehensive hazard monitoring and risk assessment	Number of years since city hazard maps have been updated (Arup, 2015)		✓
			Percentage of local severe weather warnings issued by national metrological agency which are received in a timely fashion by city emergency responders (Adapted from UNISDR, 2008)		✓
			The number of times the five most significant hazards identified in the city's local risk profile have been assessed by multi-stakeholders in the last five years (Arup, 2015)		✓
		Comprehensive emergency management	Percentage of government departments that have tested their own continuity arrangements in the last two years (Arup, 2015)		✓
			Number of times the city's multi-stakeholder emergency management strategy has been tested in the last five years (Adapted from UNISDR, 2008)		✓
			The number of times the five most significant hazards identified in the city's local risk profile have been exercised in the last five years (Add up total and divide by five) (Arup, 2015)		✓
			Number of times multi-stakeholder emergency responders meet and undertake joint activities (e.g., exercises, risk assessment, plan reviews) per year (Arup, 2015)		✓
			Number of times the emergency response centre capability has been tested (and successfully passed) in the last five years (for real or scenario) (Arup, 2015)		✓
	Empowered stakeholders: Is underpinned by education for all, and relies on access to up-to-date information and knowledge to enable people and organizations to take action	Adequate education for all	Percentage primary education completion rates (Adapted from World Bank)		✓
			Adult literacy rate (as a percentage) (World Bank)		✓
		Widespread community awareness and preparedness	Percentage of households that have a smoke alarm (Arup, 2015)	✓	
			Percentage of population that have made a household or a community resilience plan (Arup, 2015)		✓
			Percentage of citizens intended to be evacuated, which were successfully evacuated in the last disaster drill or disaster event in the last five years (Arup, 2015)		✓

		Effective mechanisms for communities to engage with the city government	Percentage of major city plans published in the last year that incorporate consultation with communities (Arup, 2015)		✓
	Integrated development planning	Comprehensive city monitoring and data management	Percentage of census data available for planning (Arup, 2015)		✓
			Number of years validity of population projections (Arup, 2015)		✓
			Percentage of residential dwellings within the city that are situated within high-risk areas (which could be addressed by zonation and relocation?) (Arup, 2015)		✓
		Consultative planning process	Percentage of current land use and zoning plans that have been subject to a formal consultation process (Arup, 2015)		✓
			Percentage of current land use and zoning plans that have been subject to a formal consultation process with utility providers and transport agencies (Arup, 2015)		✓
			Percentage of current land use and zoning plans that have been subject to a formal consultation process with minority communities affected by the development (Arup, 2015)		✓
		Appropriate land use and zoning	Areal size of informal settlements as a percentage of city area (ISO 37120)		✓
			Percentage of high-risk areas within the city where development is restricted or prohibited under planning guidelines (Arup, 2015)		✓
			Amount spent on transport in the last five years as percentage of overall city budget (Arup, 2015)		✓
			Number of years since the city plan was updated (Arup, 2015)		✓
		Robust planning approval process	Percentage of buildings (or new development) constructed within the city in the past 10 years that were approved or otherwise authorized by the relevant city planning authorities (Arup, 2015)		✓
			Percentage of planning applications submitted to the city during the past five years on which emergency services agencies have been consulted (Arup, 2015)		✓

Table II-4: International Telecommunication Union – Key Performance Indicators Related to the Use of ICT in Smart Sustainable Cities – Recommendation ITU-T Y.4901/L. 1601 (Source: ITU, 2016b)

Dimension	Sub-dimension	Indicator	Description	ICT-related	Non ICT-related
Information and Communication Technology	**Networks and access**	Availability of computers or similar devices (CI)	Proportion of households with at least one computer or similar device (tablet, smartphones, etc.)	✓	
		Availability of Internet access in households (CI)	Proportion of households with Internet access for any household member via a fixed or mobile network at any given time	✓	
		Availability of fixed broadband subscriptions (CI)	Fixed (wired) broadband subscriptions per 100 inhabitants	✓	
		Availability of wireless broadband subscriptions (CI)	Wireless-broadband subscriptions per 100 inhabitants	✓	
		Availability of mobile-cellular telephones (AI)	Mobile-cellular telephone subscriptions per 100 inhabitants	✓	
		International Internet bandwidth (AI)	International Internet bandwidth (bit/s) per Internet user	✓	
		Use of Internet by city inhabitants (AI)	Proportion of inhabitants using internet	✓	
		Coverage rate of digital broadcasting network (AI)	Proportion of digital broadcasting network covering families in the city	✓	
		Availability of ultra high-speed wireline connection (AI)	Proportion of households with access to downstream speeds equal to, or greater than, 30 Megabits/s	✓	
		Availability of high-speed mobile broadband (AI)	Proportion of city area which provides access to downstream speeds equal to, or greater than, 10 Megabits/s	✓	
		Availability of Wi-Fi in public areas (AI)	Number of Wi-Fi hotspots at certain points in the city centre	✓	
		Availability of smartphones and tablets (AI)	Number of smartphones and tablets per 100 inhabitants	✓	
		Quality of fixed broadband (AI)	Mean-download speed (fixed)	✓	
		Quality of mobile broadband (AI)	Cell-edge performance (mobile)	✓	
	Services and Information	Use of social media by the public sector (CI)	Use of social media by the public sector, to share information about regulations and to get feedback	✓	

	Platforms	Availability of electronic and mobile payment platforms (AI)	Existence of electronic and mobile payment platforms to facilitate access to city services for city inhabitants	✓	
	Information security and privacy	Information security of public services and systems (CI)	Proportion of incidents, due to illegal system access, unauthorized data storage or transmission, unauthorized hardware and software modifications, which lead to information disclosure or financial loss	✓	
		Existence of systems, rules and regulations to ensure Child Online Protection (COP) (CI)	Existence of rules and regulations to ensure COP. This also includes proportion of public web services and devices that ensure COP	✓	
		Existence of systems, rules and regulations to ensure privacy protection in public service (CI)	Existence of rules and regulations to ensure privacy protection in public service. This should also include proportion of public services and devices that ensure privacy protection	✓	
	Electromagnetic field	Compliance with WHO endorsed exposure guidelines (CI)	Application of WHO endorsed exposure guidelines for ICT installations in the city	✓	
		Adoption of a consistent planning approval process with respect to Electromagnetic Field (EMF) (CI)	Application of a consistent planning approval process with respect to EMF to enable efficient deployment of ICT systems	✓	
		Availability of EMF information (CI)	Availability of information for the public and other stakeholders and referencing WHO and ITU resources regarding compliance, health and installation issues	✓	
Environmental sustainability	**Air quality**	Application of ICT-based monitoring system for particles and toxic substances (CI)	Proportion of city area covered by outdoor ICT based monitoring system for particles and toxic substances	✓	
	Water, soil and noise	Application of city water monitoring through ICT (CI)	Proportion of the city water resources (rivers, lakes, etc.) monitored by ICT with respect to water pollution and quality	✓	
		Application of ICT-based noise monitoring (CI)	Proportion of the city area with applied ICT-based noise monitoring	✓	
Productivity	**Capital investment**	ICT-related R&D expenditure (CI)	Proportion of city GDP spent on ICT-related R&D	✓	
		Investment intensity in ICT projects enabling SSC (CI)	The amount of city investments in programs, initiatives and awards that enhance the smartness and sustainability of the city, expressed as proportion of city GDP	✓	

	Trade	Application of e-commerce transactions (CI)	Number of e-commerce transactions per 100 inhabitants through electronic and mobile payment	✓	
	Innovation	Research and Development intensity in ICT (CI)	Proportion of R&D intensive ICT companies among all companies	✓	
	Knowledge economy	Intangible investments as a proportion of GDP (CI)	Proportion of intangible investments (e.g., R&D, software, design, marketing, education and training) in new and existing businesses expressed as proportion of city GDP	✓	
		Employees belonging to ICT sector (CI)	Proportion of employees in ICT sector among all employees	✓	
		Companies providing e-services (CI)	Proportion of companies which provide network-based services (including e-commerce, e-learning, e-entertainment, cloud computing, etc.)	✓	
		Application of computing platforms (CI)	Proportion of companies that offer cloud computing and similar resources serving the public, other companies, government and other organizations	✓	
		Intangible investments in comparison with total investments (AI)	Proportion of intangible investments (e.g., R&D, software, design, marketing, education and training) in new and existing businesses related to overall investments	✓	
		Application of Geographic Information Systems (GIS) (AI)	Proportion of e-service companies with core business related to GIS serving the public, companies, government and other organizations	✓	
		Application of big data (AI)	Proportion of e-service companies with core business related to big data storage and analysis serving the public, companies, government and other organizations	✓	
Quality of life	**Education**	Use of e-learning system (CI)	Proportion of city inhabitants using e-learning systems	✓	
		Application of e-learning in schools (AI)	Proportion of pupils in primary and secondary schools having access to e-learning systems	✓	
		Application of e-learning in academic studies (AI)	Proportion of students aiming at an academic degree performing their education mainly through e-learning systems	✓	
	Health	Use of electronic health records (CI)	Proportion of city inhabitants with electronic health records	✓	

		Use of electronic medical records (CI)	Proportion of city inhabitants who have electronic medical records	✓	
		Sharing of medical resources and information among hospitals, pharmacies and other health care providers (CI)	Proportion of hospitals, pharmacies and health care providers using ICT means for sharing of medical resources such as hospital beds, and medical information, especially electronic medical records	✓	
		Adoption of telemedicine (CI)	Proportion of patients involved in telemedicine programs including services, such as e-consultation, e-monitoring, online health care advice and guidance, etc.	✓	
	Safety/security public place	Adoption of ICT for disaster management (CI)	Adoption of an ICT-based disaster management system including disaster preparedness, prevention, mitigation, and response as applicable to the city	✓	
		Availability of ICT-based safety systems (CI)	Availability of ICT-based systems that increase the perceived safety	✓	
Equity and social inclusion	**Openness and public participation**	Availability of online city information and feedback mechanisms (CI)	Proportion of city information available online and existence of ICT systems for easy access and anonymous feedback mechanism that enable cities to improve their governance	✓	
		Online civic engagement (CI)	Proportion of city inhabitants using online information and proportion of city inhabitants using ICT-based feedback mechanism	✓	
		Online support for new city inhabitants (CI)	Availability of ICT-based applications and services to provide establishment support for new city inhabitants	✓	
		Existence of strategies, rules and regulations to enable ICT literacy among inhabitants (CI)	Existence of strategies, regulations, voluntary work or interest organizations to enhance ICT literacy among all city inhabitants	✓	
		Availability of cultural resources online (AI)	Proportion of cultural institutions and events in the city for which online participation is offered	✓	
	Governance	Provision of online systems for administering public services and facilities (CI)	Proportion of public services and facilities (e.g., choice of schools, booking of public sports facilities, library services, etc.) that could be administered online	✓	
		Application of services to support persons with specific needs (CI)	Proportion of public facilities and buildings that provide ICT-based services and information to support persons with specific needs, and proportion	✓	

			of online public information customized for these persons		
		Existence of strategy, rules and regulations to enable the use of public data (AI)	Existence of a framework to enable the use of public data of cities	✓	
Physical infrastructure	**Infrastructure/connection to services – piped water**	Water supply system management using ICT (CI)	Proportion of the water supply systems under automatic monitoring using ICT so as to ensure water quality and reduce leakage	✓	
		City fresh water resources monitored using ICT (CI)	Proportion of the city fresh water sources monitored using ICT with respect to availability	✓	
		Availability of smart water meters (CI)	Proportion of the water consumers (including households, companies, etc.) with ICT-based water meters	✓	
		Availability of visualized real-time information regarding water use (AI)	Proportion of users with real-time information on quantum of water usage and water use pattern	✓	
	Infrastructure/connection to services – sewage	Sewage system management using ICT (CI)	Proportion of the sewage system monitored using ICT	✓	
		Drainage system management using ICT (CI)	Proportion of the drainage systems monitored in real-time using ICT	✓	
	Infrastructure/connection to services – electricity	Availability of smart electricity meters (CI)	Proportion of the electricity consumers (including households, companies, etc.) with ICT-based electricity meters	✓	
		Electricity supply system management using ICT (AI)	Proportion of power substation and user points under automatic inspection using ICT	✓	
		Availability of visualized real-time information regarding electricity use (AI)	Proportion of users with real-time information on quantum of electricity usage and electricity use pattern	✓	
	Infrastructure/connection to services – road infrastructure	Availability of traffic monitoring using ICT (CI)	Proportion of streets with traffic monitoring using ICT (e.g., using sensors to produce traffic volume maps, etc.)	✓	
		Availability of parking guidance systems (CI)	Proportion of parking lots and street parking spaces with ICT-based parking guidance systems	✓	
		Availability of real-time traffic information (CI)	Proportion of public transport stops and stations with real-time traffic information available (via electronic bus bulletin boards, smartphone apps, etc.)	✓	

		Street lighting management using ICT (CI)	Proportion of street lamps under automatic management using ICT (e.g., light / sound control and solar power charging)	✓	
		Gas system management using ICT (CI)	Proportion of gas supply systems under automatic monitoring using ICT	✓	
		Availability of visualized real-time information regarding gas use (AI)	Proportion of users with real-time information on quantum of gas usage and gas use pattern	✓	
		Availability of online bike/car sharing system (AI)	Proportion of city area covered by an online bike/car sharing system	✓	
		Use of real-time navigation (AI)	Proportion of real-time navigation users compared to all navigation system users	✓	
	Building	Automatic energy management in buildings (CI)	Proportion of public and private sector buildings using ICT-based systems to automatically regulate and reduce energy needs	✓	
		Integrated management in public buildings (CI)	Proportion of public buildings using integrated ICT systems to automate building management and create flexible, effective, comfortable and secure environment	✓	

Table II-5: International Telecommunication Union – Key Performance Indicators Related to the Sustainability Impacts of ICT in Smart Sustainable Cities – Recommendation ITU-T Y.4902/L. 1602 (Source: ITU, 2016c)

Dimension	Sub-dimension	Indicator	Description	ICT-related	Non ICT-related
Environmental sustainability	**Air quality**	Air pollution intensity (CI)	Intensity of particles and toxic substances		✓
	CO_2 emissions	GHG emissions (CI)	Amount of GHG emissions per capita		✓
		GHG emissions per sector per capita (AI)	GHG emissions per capita per sector including industrial (manufacturing, construction), commercial, household, transport, and waste disposal, etc.		✓
	Energy	Use of alternative and renewable energy (CI)	Proportion of renewable energy consumed in the city		✓
		Energy saving in households (CI)	Energy saving in households compared to a baseline		✓
		Electricity use for street lighting (AI)	Electricity used for street lighting per capita		✓
	Water, soil and noise	Quality of city water resources (CI)	Quality of water resources (rivers, lakes, etc.)		✓
		Recycling of waste (CI)	Proportion of waste recycled compared to total collected waste		✓
		Exposure to noise (CI)	Proportion of the city inhabitants with noise levels above international / national exposure limits at home		✓
		Soil pollution avoidance (CI)	Proportion of soil pollution incidents with successful early warning and emergency detection of heavy metal, chemicals, acid, etc. through ICT	✓	
		Green areas surface (CI)	Proportion of municipal territory allocated to publicly accessible green areas		✓
		Perception on environmental quality (CI)	Proportion of city inhabitants satisfied with the urban environment		✓
Productivity	**Capital investment**	Improvement of industry productivity through ICT (CI)	Productivity enhancement in industry through ICT measured as the impact of ICT on value added per person employed	✓	
	Employment	Service industry employment (CI)	Proportion of employees working in service industry in the city compared with the total employed workforce		✓
		Creative industry employment (AI)	Proportion of employees working in start-ups and creative industry in the city compared to the total		✓

			employed workforce		
	Inflation	Inflation rate (AI)	A city's inflation rate is based on a projection of its Consumer Price Index, which measures the rise in prices of goods and services		✓
	Savings	Saving rate (CI)	Proportion of total incomes for each household remaining after deducting consumption and expenditures		✓
	Export/import	Knowledge-intensive export/import (CI)	Proportion of export/import of knowledge-intensive goods and services within a city compared to the total industrial export / import		✓
	Household income/consumption	Household ICT expenditures (CI)	Proportion of household expenditures related to ICT	✓	
	Innovation	Investments in ICT innovation (CI)	Proportion of private sector expenditures invested in ICT innovation	✓	
		ICT related patens (CI)	Number of ICT related patents granted per capita	✓	
Quality of life	**Education**	Students ICT availability (CI)	Proportion of students/pupils with access to ICT capabilities in school	✓	
	Health	Healthy Life Years (HLY) (CI)	Number of remaining years that a person of a certain age is expected to live without disability		✓
		Coverage of health insurance (AI)	Proportion of city inhabitants covered by health insurances		✓
	Safety/security public place	Disaster and emergencies alert accuracy (CI)	Proportion of disasters and emergencies with timely alerts		✓
Equity and social inclusion	**Inequity of income/consumption (Gini coefficient)**	Income distribution (CI)	Income distribution in accordance with Gini coefficient		✓
	Social and gender inequity of access to services and infrastructure	Gender income disparity (CI)	Rate of income disparity between men and women		✓
	Openness and public participation	Use of online city services (CI)	Proportion of city inhabitants using online public services and facilities (e.g., choice of schools, booking of public sports facilities, library services, etc.).	✓	
		Perception on social inclusion (CI)	Proportion of city inhabitants satisfied with the social inclusion		✓

		Interest in online access to cultural resources (AI)	Online visits to cultural resources per capita	✓	
Physical infrastructure	**Infrastructure/connection to services – piped water**	Leakage in water supply system (CI)	Proportion of water leakage in the water supply system		✓
		Quality of piped water (AI)	Quality of water as supplied to end users		✓
	Infrastructure/connection to services – sewage	Sewage system coverage (CI)	Proportion of households connected to the sewage system		✓
	Infrastructure/connection to services – electricity	Reliability of electricity supply system (CI)	Proportion of time during which electricity supply system works without outages		✓
	Infrastructure/connection to services – health infrastructure	Availability of sporting facilities (CI)	Number of sports training facilities per capita		✓
	Infrastructure/connection to services – transport	Use of public transport (CI)	Proportion of travelers utilizing public transportation compared to overall city population		✓
		Road traffic efficiency (CI)	Freedom from traffic congestion exposure		✓

Table II-6: International Telecommunication Union – Key Performance Indicators for Smart Sustainable Cities to Assess the Achievement of Sustainable Development Goals – Recommendation ITU-T Y.4903/L. 1603 (Source: ITU, 2016d)

Area	Topic	Indicator	Description	Mapping to SDG Goals & Targets	ICT-related	Non ICT-related
Economy	ICT infrastructure	Internet access in households (CI)	Proportion of households with Internet access	9.c & 17.8	✓	
		Household with a computer (CI)	Proportion of households with at least one computer	9.c	✓	
		Wireless broadband subscriptions (AI)	Wireless broadband subscriptions per 100 inhabitants	9.c & 5.b	✓	
		Fixed broadband subscriptions (AI)	Proportion of households with fixed (wired) broadband	9.c	✓	
		Household with a mobile device (AI)	Proportion of households with at least one smartphone or similar device	9.c	✓	
	Innovation	R&D expenditure (CI)	R&D expenditure as a proportion of city GDP	9.5		✓
		Patents (CI)	Number of new patents granted per 100,000 inhabitants per year	9.b		✓
		Small and Medium-sized Enterprises (SMEs) (AI)	Proportion of Small and Medium-sized Enterprises (SMEs)	9.3 & 8.3		✓
	Employment	Employment rate (CI)	Employment rate	8.5		✓
		Creative industry employment (AI)	Proportion of employees working in the creative industry	-		✓
		Tourism industry employment (AI)	Proportion of employees working in the tourism industry	8.9		✓
	Trade – e-Commerce	e-Commerce purchase ratio (AI)	Proportion of population using e-Commerce for purchase per year	-	✓	
		Electronic and mobile payment (AI)	Electronic payments system usage per 100 city inhabitants	-	✓	
	Trade – Export / Import	Knowledge-intensive export/import (AI)	Proportion of exports/imports of knowledge-intensive goods and services	-		✓
	Productivity	Labor productivity (CI)	Annual growth rate of real GDP per employed person	8.2 & 2.3		✓
		Companies providing online services (AI)	Proportion of registered companies providing online services	-	✓	

	Physical infrastructure – Water supply	Availability of smart water meters (CI)	Proportion of the water consumers (including households, companies, etc.) with smart (ICT-based) water meters	9.1	✓	
		Water supply loss (AI)	Proportion of water leak in the water distribution system	9.1 & 9.4		✓
		Water supply ICT monitoring (AI)	Proportion of the water distribution system monitored by ICT		✓	
	Physical infrastructure – Electricity	Availability of smart electricity meters (CI)	Proportion of the electricity consumers (including households, companies, etc.) with smart (ICT-based) electricity meters	9.1	✓	
		Electricity system outage frequency (CI)	Average number of electrical interruptions per customer per year	7.b		✓
		Electricity system outage time (CI)	Average length of electrical interruptions	7.b		✓
		Electricity supply system management using ICT (AI)	Proportion of power substation and user points under automatic inspection using ICT	-	✓	
	Physical infrastructure – Health infrastructure	Sporting facilities (AI)	Area of total public sports facilities per 100,000 inhabitants	-		✓
	Physical infrastructure – Transport	Public transport network (CI)	Length of public transport systems per 100,000 inhabitants	11.2		✓
		Road traffic efficiency (CI)	Travel time index	11.2		✓
		Real-time public transport information (CI)	Proportion of public transport stops and stations with real-time traffic information available	11.2	✓	
		Share of Electric EVs (AI)	Proportion of EVs (Battery Electric Vehicle - BEV, Plug-in Hybrid Electric Vehicle - PHEV, Range Extended Electric Vehicle / Range Extender – REEV/REX, Fuel Cell Electric Vehicle - FCEV) in public fleets	-		✓
	Physical infrastructure – Road infrastructure	Traffic monitoring (AI)	Proportion of major streets monitored by ICT	9.1	✓	
		Pedestrian infrastructure (AI)	Portion of city with pedestrian, car free and traffic calming streets	-		✓
	Physical	Public building sustainability	Proportion of public buildings with sustainability	11.c		✓

	infrastructure - Building	(AI)	certifications			
	Physical infrastructure - Urban planning and public space	Urban development and spatial planning (AI)	Existence of a strategic city planning documents promoting compact development, mixed urban land use and avoiding urban sprawl	11.3 & 11.a		✓
	Public sector	Open data (AI)	Proportion of available open data of cities	-	✓	
		e-Public services adoption (AI)	Proportion adoption of electronic public services	-	✓	
Environment	**Air quality**	Air pollution (CI)	Air Quality Index (AQI) based on Particulate matter (PM10 and PM2.5), NO_2 (nitrogen dioxide), SO_2 (sulphur dioxide), O_3 (ozone) and CO (carbon monoxide)	11.6 & 12.4		✓
		GHG emissions (CI)	GHG emissions per capita	7.a & 11.6		✓
		Air pollution monitoring system (AI)	Number of outdoor installations of ICT-based air quality monitoring systems per km^2	11.6 & 12.4	✓	
	Water and sanitation	Quality of drinking water (CI)	Index of compliance with standards relating to water quality parameters for drinking water	6.3 & 6.4		✓
		Access to improved water source (CI)	Proportion of city population with sustainable access to improved water sources	6.1 & 1.4		✓
		Water consumption (CI)	Water consumption per capita	6.1 & 1.4 & 6.4		✓
		Wastewater treated (CI)	Proportion of wastewater receiving treatment	6.3 & 12.4		✓
		Wastewater collection (CI)	Proportion of households served by wastewater collection	6.3 & 1.4		✓
		Household sanitation (CI)	Proportion of households with access to improved sanitation facilities	6.2 & 1.4		✓
		Water saving in households (AI)	Proportion of households with water saving installations	6.4		✓
		Drainage system management (AI)	Proportion of drainage system ICT monitored	6.5 & 6.4	✓	
	Noise	Exposure to noise (CI)	Proportion of the city inhabitants exposed to noise levels above international/national exposure limits	-		✓
		ICT noise monitoring (AI)	Number of outdoor installations with applied ICT based noise monitoring per km^2	-	✓	
	Environmental	Compliance with WHO	Application of WHO endorsed exposure guidelines	-	✓	

	quality	endorsed exposure guidelines (CI)	for ICT installations in the city			
		Adoption of a consistent planning approval process with respect to EMF (CI)	Application of a consistent planning approval process with respect to EMF to enable efficient deployment of ICT systems	-	✓	
		Availability of EMF information (CI)	Availability of information for the public and other stakeholders and referencing WHO and ITU resources regarding compliance, health and installation issues	-	✓	
		Solid waste collection (CI)	Proportion of households with regular solid waste collection	11.6 & 12.4 & 1.4		✓
		Solid waste treatment (CI)	Proportion of solid waste: a) disposed to sanitary landfills; b) burnt in an open area; c) incinerated; d) disposed to an open dump; e) recycled; f) other with regard to total amount of solid waste produced	11.6 & 12.4 & 1.4		✓
		Green areas and public spaces (CI)	Publicly accessible green areas and public spaces per 100,000 inhabitants	11.7		✓
	Biodiversity	Native species monitoring (CI)	Change of number of native species	2.5 & 15.5		✓
		Protected natural area (AI)	Proportion of city area under environmental protection	11.4		✓
	Energy	Access to electricity (CI)	Proportion of households with access to electricity	7.1 & 1.4		✓
		Renewable energy consumption (CI)	Proportion of renewable energy consumed in the city	7.2		✓
		Electricity consumption (CI)	Electricity consumption per capita	-		✓
		Energy saving in households (AI)	Proportion of households with energy saving installations	7.3		✓
		Public buildings energy consumption (AI)	Annual energy consumption of public buildings	-		✓
Society & Culture	**Education**	Students ICT access (CI)	Proportion of students / pupils with classroom access to ICT facilities	4.4	✓	
		Adult literacy (CI)	Adult literacy rate	4.6		✓
		School enrollment (CI)	Proportion of school-aged population enrolled in schools	4.1		✓
		Higher education ratio (CI)	Proportion of city inhabitants with tertiary education degrees	4.3		✓

		e-Learning systems (AI)	Proportion of city inhabitants using e-learning systems	4.3	✓	
	Health	Electronic health records (CI)	Proportion of city inhabitants with electronic health records	3.8	✓	
		Sharing of medical resources (CI)	Proportion of hospitals, pharmacies and health care providers using ICT means for sharing of medical resources such as hospital beds, and medical information, especially electronic health records	3.8	✓	
		Life expectancy (CI)	Average life expectancy indicates the number of years a new-born infant would live	-		✓
		Maternal mortality (CI)	Maternal deaths per 100,000 live births	3.1		✓
		Doctors (CI)	Number of doctors per 100,000 inhabitants	3.c		✓
		Adoption of telemedicine (AI)	Proportion of patients involved in telemedicine programs		✓	
		In-patient hospital beds (AI)	Number of in-patient hospital beds per 100,000 inhabitants	-		✓
		Health insurance (AI)	Proportion of city inhabitants covered by health insurance	3.8		✓
	Safety – Disaster relief	Resilience plans (CI)	Presence of vulnerability assessment, financial (capital and operating) plans and technical systems for disaster mitigation	11.b, 13.1, 13.2 & 13.3		✓
		Natural disaster related deaths (AI)	Natural disaster related deaths per 100,000 inhabitants	1.5, 11.5 & 13.1		✓
		Disaster related economic losses (AI)	Natural disaster related economic losses relative to GDP	11.5		✓
	Safety – Emergency	Emergency service response time (CI)	Average response time for emergency services	-		✓
		Disaster and emergency alert (AI)	Proportion of disasters and emergencies with timely alerts	13.3, 13.1 & 11.b		✓
	Safety – ICT	Information security and privacy protection (CI)	Existence of systems, rules and regulations to ensure information security and privacy protection in public service	-	✓	
		Child Online Protection (COP) (AI)	Existence of rules and regulations to ensure COP	1.3	✓	

	Housing	Housing expenditure (CI)	Proportion expenditure of income for housing	11.1		✓
		Informal settlements (CI)	Proportion of urban population living in slums, informal settlements or inadequate housing	11.1		✓
	Culture	Connected libraries (CI)	Number of connected libraries per 100,000 population	9.c & 4.4	✓	
		Cultural infrastructure (CI)	Number of cultural institutions per 100,000 inhabitants	8.9 & 11.4		✓
		Cultural resources online (CI)	Proportion of cultural institutions and events for which online participation is offered	11.4	✓	
		Protected cultural heritage sites (AI)	Proportion of city area related to protected cultural heritage sites	11.4		✓
	Social inclusion	Public participation (CI)	Promotion of inhabitants' participation in public affairs	16.7		✓
		Gender income equity (CI)	Ratio of average hourly earnings of female and male employees, by occupation, age group and persons with disabilities	8.5, 10.4 & 5.1		✓
		Opportunities for people with special needs (CI)	Existence of public services and benefits for people with special needs	11.2, 11.7, 1.3, 4.5, 4.a, 8.5 & 10.2		✓
		Gini coefficient (AI)	Income distribution in accordance with Gini coefficient	10.4		✓

Table II-7: Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 United Nations Agenda for Sustainable Development (Source: UN, 2020)

Target	Indicator	ICT-related	Non ICT-related
1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions	1.2.1 Proportion of population living below the national poverty line, by sex and age		✓
	1.2.2 Proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions		✓
1.3 Implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable	1.3.1 Proportion of population covered by social protection floors / systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable		✓
1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance	1.4.1 Proportion of population living in households with access to basic services		✓
3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being	3.4.2 Suicide mortality rate		✓
3.5 Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol	3.5.2 Alcohol per capita consumption (aged 15 years and older) within a calendar year in litres of pure alcohol		✓
3.6 By 2020, halve the number of global deaths and injuries from road traffic accidents	3.6.1 Death rate due to road traffic injuries		✓
3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.9.1 Mortality rate attributed to household and ambient air pollution		✓
4.3 By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university	4.3.1 Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex		✓
4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship	4.4.1 Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill	✓	

4.6 By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy	4.6.1 Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex		✓
5.b Enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women	5.b.1 Proportion of individuals who own a mobile telephone, by sex	✓	
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services		✓
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of domestic and industrial wastewater flows safely treated		✓
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time		✓
	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources		✓
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.2 Proportion of population with primary reliance on clean fuels and technology	✓	
8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value	8.5.1 Average hourly earnings of female and male employees, by occupation, age and persons with disabilities		✓
	8.5.2 Unemployment rate, by sex, age and persons with disabilities		✓
8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training	8.6.1 Proportion of youth (aged 15-24 years) not in education, employment or training (NEETs)		✓
11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing		✓
11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons	11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities		✓
11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	11.3.1 Ratio of land consumption rate to population growth rate		✓
	11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and		✓

	democratically		
11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)		✓
11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations	11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population (corresponds also to SDG 1, target 1.5, indicator 1.5.1)		✓
	11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters		✓
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities		✓
	11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)		✓
11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities		✓
	11.7.2 Proportion of persons victim of physical or sexual harassment, by sex, age, disability status and place of occurrence, in the previous 12 months		✓
11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels	11.b.2 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies (corresponds also to SDG 1, target 1.5, indicator 1.5.4 and to SDG 13, target 13.1, indicator 13.1.3)		✓
16.7 Ensure responsive, inclusive, participatory and representative decision-making at all levels	16.7.2 Proportion of population who believe decision-making is inclusive and responsive, by sex, age, disability and population group		✓

Table II-8: Collection Methodology for Key Performance Indicators for Smart Sustainable Cities – United for Smart Sustainable Cities (U4SSC) Initiative (Source: ITU et al., 2017)

Dimension	Sub-dimension	Category	Indicator	Description	Type	ICT-related	Non ICT-related	SDG Reference(s)
Economy	**ICT**	**ICT infrastructure**	Household Internet access (CI)	Percentage of households with Internet access	Smart	✓		SDG Indicator 17.8.1
			Fixed broadband subscriptions (CI)	Percentage of households with fixed (wired) broadband	Smart	✓		SDG Indicators 17.6.2 & 17.8.1
			Wireless broadband subscriptions (CI)	Wireless broadband subscriptions per 100,000 inhabitants	Smart	✓		SDG Indicators 17.8.1, 9.c.1 & 5.b.1
			Wireless broadband coverage (CI)	Percentage of the city served by wireless broadband (by technology)	Smart	✓		SDG Indicators 17.8.1, 9.c.1 & 5.b.1
			Availability of Wi-Fi in public areas (AdI)	Number of (public) Wi-Fi hotspots in the city	Smart	✓		SDG Target 9.c
		Water and sanitation	Smart water meters (CI)	Percentage implementation of smart water meters	Smart	✓		SDG Target 6.4 & SDG Indicator 6.4.1
			Water supply ICT monitoring (AdI)	Percentage of the water distribution system monitored by ICT	Smart	✓		SDG Target 6.4 & SDG Indicator 6.4.1
		Drainage	Drainage / storm water system ICT monitoring (AdI)	Percentage of drainage / storm water system monitored by ICT	Smart	✓		SDG Target 6.2
		Electricity supply	Smart electricity meters (CI)	Percentage implementation of smart electricity meters	Smart	✓		SDG Target 7.3
			Electricity supply ICT monitoring (AdI)	Percentage of electricity supply system monitored by ICT	Smart	✓		SDG Target 7.3
			Demand response penetration (AdI)	Percentage of electricity customers with demand response capabilities	Smart	✓		SDG Target 7.3
		Transport	Dynamic public transport information (CI)	Percentage of urban public transport stops for which traveler information is	Smart	✓		SDG Target 11.2

				dynamically available to the public in real time				
			Traffic monitoring (CI)	Percentage of major streets monitored by ICT	Smart	✓		SDG Target 11.2
			Intersection control (AdI)	Percentage of road intersections using adaptive traffic control or prioritization measures	Smart	✓		SDG Target 11.2
		Public sector	Open data (AdI)	Percentage and number of inventoried open datasets that are published	Smart	✓		SDG Targets 16.6 & 16.7
			e-Government (AdI)	Number of public services delivered through electronic means	Smart	✓		SDG Targets 16.6 & 16.7
			Public sector e-Procurement (AdI)	Percentage of public sector procurement activities that are conducted electronically	Smart	✓		SDG Targets 16.6 & 16.7
	Productivity	**Innovation**	R&D expenditure (CI)	R&D expenditure as a percentage of city GDP	Structural		✓	SDG Indicator 9.5.1
			Patents (CI)	Number of new patents granted per 100,000 inhabitants per year	Structural		✓	SDG Target 9.b
			Small and Medium-Sized Enterprises (SMEs) (AdI)	Percentage of small and medium-sized enterprises (SMEs)	Structural		✓	SDG Indicator 9.3.1
		Employment	Unemployment rate (CI)	Percentage of the total city labor force that is unemployed	Structural		✓	SDG Indicator 8.5.2
			Youth unemployment rate (CI)	Percentage of the city youth labor force that is unemployed	Structural		✓	SDG Indicator 8.5.2 & SDG Target 8.6
			Tourism industry employment (AdI)	Percentage of the city-related labor force working in the tourism industry	Structural		✓	SDG Indicator 8.9.1
			ICT sector employment (AdI)	Percentage of employees involved with ICT	Structural	✓		SDG Target 8.3
	Infrastru-cture	**Water and sanitation**	Basic water supply (CI)	Percentage of city households with access to a basic water	Sustainable		✓	SDG indicator 6.1.1

				supply				
			Potable water supply (CI)	Percentage of households with a safely managed drinking water service	Sustainable		✓	SDG indicator 6.1.1
			Water supply loss (CI)	Percentage of water loss in the water distribution system	Sustainable		✓	SDG Target 6.4
			Wastewater collection (CI)	Percentage of households served by wastewater collection	Sustainable		✓	SDG Target 6.3
			Household sanitation (CI)	Percentage of the city households with access to basic sanitation facilities	Sustainable		✓	SDG Indicator 6.2.1
		Waste	Solid waste collection (CI)	Percentage of city households with regular solid waste collection	Sustainable		✓	SDG indicators 11.6.1 & 12.4.2
		Electricity supply	Electricity system outage frequency (CI)	Average number of electrical interruptions per customer per year	Structural		✓	SDG Target 7.1
			Electricity system outage time (CI)	Average length of electrical interruptions	Structural		✓	SDG Target 7.1
			Access to electricity (CI)	Percentage of households with authorized access to electricity	Structural		✓	SDG Indicator 7.1.1
		Transport	Public transport network (CI)	Length of public transport network per 100,000 inhabitants	Sustainable		✓	SDG Target 11.2
			Public transport network access (AdI)	Percentage of the city population that has convenient access (within 0.5 km) to public transport	Sustainable		✓	SDG Target 11.2
			Bicycle network (CI)	Length of bicycle paths and lanes per 100,000 population	Sustainable		✓	SDG Target 11.2
			Transportation modal share (AdI)	The percentage of people using various forms of transportation to travel to work	Sustainable		✓	SDG Target 11.2
			Travel time index (AdI)	Ratio of travel time during peak periods to travel time at free flow periods	Sustainable		✓	SDG Target 11.2
			Shared bicycles (AdI)	Number of shared bicycles per	Sustainable		✓	SDG Target 11.2

				100,000 inhabitants				
			Shared vehicles (AdI)	Number of shared vehicles per 100,000 inhabitants	Sustainable		✓	SDG Target 11.2
			Low-carbon emission passenger vehicles (AdI)	Percentage of low-carbon emission passenger vehicles	Sustainable		✓	SDG Target 11.2
		Buildings	Public building sustainability (AdI)	Percentage area of public buildings with recognized sustainability certifications for ongoing operations	Sustainable		✓	SDG Targets 7.3 & 11.3
			Integrated building management systems in public buildings (AdI)	Percentage of public buildings using integrated ICT systems to automate building management and create flexible, effective, comfortable and secure environment	Smart	✓		SDG Indicator 11.1.1 & SDG Target 11.c
		Urban planning	Pedestrian infrastructure (AdI)	Percentage of the city designated as a pedestrian / car free zone	Sustainable		✓	SDG Target 11.3
			Urban development and spatial planning (AdI)	Existence of urban development and spatial planning strategies or documents at the city level	Sustainable		✓	SDG Indicator 11.a.1 & SDG Target 11.3
Environment	**Environment**	**Air quality**	Air pollution (CI)	Air quality index (AQI) based on reported value for: Particulate matter (PM10, and PM2.5), NO2 (nitrogen dioxide), SO2 (sulphur dioxide), O3 (ozone)	Sustainable		✓	SDG Target 11.6 & SDG Indicator 11.6.2
			GHG emissions (CI)	GHG emissions per capita	Sustainable		✓	SDG Target 11.6 & SDG Indicator 13.2.1
		Water and sanitation	Drinking water quality (CI)	Percentage of households covered by an audited Water Safety Plan	Sustainable		✓	SDG Indicator 6.1.1
			Water consumption (CI)	Total water consumption per capita	Sustainable		✓	SDG Indicator 6.4.1

			Freshwater consumption (CI)	Percentage of water consumed from freshwater sources	Sustainable		✓	SDG Indicator 6.4.2
			Wastewater treatment (CI)	Percentage of wastewater receiving treatment (primary, secondary, tertiary)	Sustainable		✓	SDG indicator 6.3.1
		Waste	Solid waste treatment (CI)	The percentage of solid waste dealt with in the following ways should be reported on: a) disposed to sanitary landfills; b) burnt in an open area; c) incinerated; d) disposed in an open dump; e) recycled; f) other (with regard to total amount of solid waste produced).	Sustainable		✓	SDG indicator 11.6.1
		Environmental quality	EMF exposure (CI)	Percentage of mobile network antenna sites in compliance with WHO endorsed EMF exposure guidelines	Sustainable		✓	SDG Target 16.b
			Noise exposure (AdI)	Percentage of city inhabitants exposed to excessive noise levels	Sustainable		✓	SDG Target 11.6
		Public spaces and nature	Green areas (CI)	Green area per 100,000 inhabitants	Sustainable		✓	SDG Indicator 11.7.1
			Green area accessibility (AdI)	Percentage of inhabitants with accessibility to green areas	Sustainable		✓	SDG Indicator 11.7.1
			Protected natural areas (AdI)	Percentage of city area protected as natural sites	Sustainable		✓	SDG Indicators 15.1.2, 15.b.1 & SDG Target 14.5
			Recreational facilities (AdI)	Area of total public recreational facilities per 100,000 inhabitants	Sustainable		✓	SDG Indicator 11.7.1
	Energy	**Energy**	Renewable energy consumption (CI)	Percentage of renewable energy consumed in the city	Sustainable		✓	SDG Indicator 7.2.1
			Electricity	Electricity consumption per	Sustainable		✓	SDG Target 7.3

			consumption (CI)	capita				
			Residential thermal energy consumption (CI)	Residential thermal energy consumption per capita	Sustainable		✓	SDG Target 7.3
			Public building energy consumption (CI)	Annual energy consumption of public buildings	Sustainable		✓	SDG Target 7.3
Society and Culture	**Education, health and culture**	**Education**	Student ICT access (CI)	Percentage of students with classroom access to ICT facilities	Smart	✓		SDG Indicators 4.4.1, 4.a.1 & SDG Target 5.b
			School enrollment (CI)	Percentage of school-aged population enrolled in schools	Structural		✓	SDG Target 4.1
			Higher education degrees (CI)	Higher level education degrees per 100,000 inhabitants	Structural		✓	SDG Target 4.3
			Adult literacy (CI)	Adult literacy rate	Structural		✓	SDG Indicator 4.6.1
		Health	Electronic health records (AdI)	The percentage of city inhabitants with complete health records electronically accessible to all health providers	Smart	✓		SDG Target 3.d
			Life expectancy (CI)	Average life expectancy	Structural		✓	SDG Target 3.4
			Maternal mortality rate (CI)	Maternal deaths per 100,000 live births	Structural		✓	SDG Indicator 3.1.1
			Physicians (CI)	Number of physicians per 100,000 inhabitants	Structural		✓	SDG indicator 3.c.1
			In-patient hospital beds (AdI)	Number of in-patient public hospital beds per 100,000 inhabitants	Structural		✓	SDG Target 3.8
			Health insurance / public health coverage (AdI)	Percentage of city inhabitants covered by basic health insurance program or a public health system	Structural		✓	SDG Target 3.8
		Culture	Cultural expenditure (CI)	Percentage expenditure on city cultural heritage	Structural		✓	SDG Target 11.4
			Cultural infrastructure (AdI)	Number of the cultural institutions per 100,000	Structural		✓	SDG Target 11.4

				inhabitants				
	Safety, housing and social inclusion	Housing	Informal settlements (CI)	Percentage of city inhabitants living in slums, informal settlements or inadequate housing	Structural		✓	SDG Indicator 11.1.1
			Expenditure on housing (AdI)	Percentage share of income expenditure for housing	Structural		✓	SDG Target 11.1
		Social inclusion	Gender income equality (CI)	Ratio of average hourly earnings of female to male workers	Structural		✓	SDG indicator 8.5.1
			Gini coefficient (CI)	Income distribution in accordance with Gini coefficient	Structural		✓	SDG Target 10.2
			Poverty share (CI)	Percentage of city inhabitants living in income poverty	Structural		✓	SDG Target 1.1
			Child care availability (AdI)	Percentage of pre-school age children (0-3) covered by (public and private) day-care centres	Structural		✓	SDG Targets 4.2, 5.5 & 10.4
		Citizen participation	Voter participation (CI)	Percentage of the eligible population that voted during the last municipal election	Structural		✓	SDG Targets 16.7, 11.3 & SDG Indicator 11.3.2
		Safety	Natural disaster related deaths (CI)	Number of natural disaster related deaths per 100,000 inhabitants	Sustainable		✓	SDG indicators 1.5.1 & 13.1.2
			Disaster related economic losses (CI)	Economic losses (related to natural disasters) as a percentage of the city's GDP	Sustainable		✓	SDG indicator 1.5.2
			Resilience plans (AdI)	This involves implementation of risk and vulnerability assessments, financial (capital and operating) plans and technical systems for disaster mitigation addressing natural and human induced disasters and hazards	Sustainable		✓	SDG Indicator 11.b.1
			Population living in	Percentage of inhabitants living	Sustainable		✓	SDG Targets 1.5

			disaster prone areas (AdI)	in natural hazards prone areas				& 11.b
			Emergency service response time (AdI)	Average response time for emergency services	Structural		✓	SDG Target 3.d
			Police service (CI)	Number of police officers per 100,000 inhabitants	Structural		✓	SDG Target 3.d
			Fire service (CI)	Number of firefighters per 100,000 inhabitants	Structural		✓	SDG Target 3.d
			Violent crime rate (CI)	Violent crime rate per 100,000 inhabitants	Structural		✓	SDG Target 16.1 & SDG Indicator 16.3.1
			Traffic fatalities (CI)	Traffic fatalities per 100,000 inhabitants	Structural		✓	SDG Indicator 3.6.1
		Food security	Local food production (AdI)	Percentage of local food supplied from within 100 km of the urban area	Sustainable		✓	SDG Targets 2.4 & 2.c

Table II-9: ISO 37120 Standard – Sustainable Cities and Communities – Indicators for City Services and Quality of Life (Source: ISO, 2018a)

Theme	Indicator	Description	ICT-related	Non ICT-related
Economy	City's unemployment rate (CI)	The number of working-age primary residents who, during the survey reference period, were not in paid employment or self-employment, but available for work and seeking work (numerator) divided by the total labor force (denominator).		✓
	Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties (SI)	The total assessed value of commercial and industrial properties (numerator) divided by the total assessed value of all properties (denominator).		✓
	Percentage of persons in full-time employment (SI)	The number of persons in full- time employment (numerator) divided by the total labor force (denominator).		✓
	Youth unemployment rate (SI)	The total number of a city's unemployed youth (numerator) divided by the city's youth labor force (denominator).		✓
	Number of businesses per 100,000 population (SI)	The total number of businesses in a city (numerator) divided by one 100,000th of the city's total population (denominator). Businesses shall refer to companies or enterprises.		✓
	Number of new patents per 100,000 population per year (SI)	The total number of new patents issued to persons and corporations of the city (numerator) divided by one 100 000th of the city's total population (denominator).		✓
	Annual number of visitor stays (overnight) per 100,000 population (SI)	The sum of overnight visitor stays (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Commercial air connectivity (number of non-stop commercial air destinations) (SI)	The sum of all non-stop commercial (i.e., scheduled) flights departing from all airports serving the city.		✓
	Average household income (USD) (PI)	The sum of total income received during the calendar year by all households within city boundaries (numerator) divided by the total number of households within city boundaries (denominator).		✓
	Annual inflation rate based on the average of the past five years (PI)	The sum of the rate of inflation of the preceding five years (numerator) divided by five (denominator).		✓
	City product per capita (USD) (PI)	City product per capita is the same concept as gross national product but applied to a city or municipality only. It provides indication of city economic development, employment and investment. Moreover, it provides better indication of international trade than other more traditional measures such as gross domestic product.		✓
Education	Percentage of female school-	The number of a city's female school-aged population enrolled at primary and secondary		✓

	aged population enrolled in schools (CI)	levels in public and private schools (numerator) divided by the total number of a city's female school-aged population (denominator).		
	Percentage of students completing primary education: survival rate (CI)	Total number of a city's students belonging to a school-cohort who complete the final grade of primary education (numerator) divided by the total number of a city's students belonging to a school cohort, i.e., those originally enrolled in the first grade of primary education (denominator). The survival rate of primary education shall refer to the percentage of a cohort of students enrolled in the first grade of primary education who reached the final grade of primary education.		✓
	Percentage of students completing secondary education: survival rate (CI)	Total number of a city's students belonging to a school cohort who complete the final grade of secondary education (numerator) divided by the total number of a city's students belonging to a school cohort, i.e., those originally enrolled in the first grade of secondary education (denominator).		✓
	Primary education student-teacher ratio (CI)	Number of enrolled primary school students (numerator) divided by the number of full-time equivalent (FTE) primary school classroom teachers (denominator).		✓
	Percentage of school-aged population enrolled in schools (SI)	Number of a city's school-aged population enrolled in primary and secondary levels in public and private schools (numerator) divided by the total number of the city's school-aged population (denominator).		✓
	Number of higher education degrees per 100,000 population (SI)	Number of people holding higher education (tertiary education) degrees (numerator) divided by one 100,000th of the city's total population.		✓
Energy	Total end-use energy consumption per capita (GJ/year) (CI)	Total end-use energy consumed by a city in gigajoules (numerator) divided by the total population of the city (denominator).		✓
	Percentage of total end-use energy derived from renewable sources (CI)	Total consumption of end-use energy generated from renewable sources divided by total end-use energy consumption.		✓
	Percentage of city population with authorized electrical service (residential) (CI)	Number of people in the city with authorized electrical service (numerator) divided by the total population of the city (denominator).		✓
	Number of gas distribution service connections per 100,000 population (residential) (CI)	Number of people in the city with connection to gas distribution services (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Final energy consumption of public buildings per year (GJ/m2) (CI)	Annual energy consumption of public buildings. Total end use of energy in public buildings (GJ) within a city (numerator) divided by total floor space of these buildings in m^2 (denominator).		✓
	Electricity consumption of public street lighting per Km of	Total electricity consumption of public street lighting (numerator) divided by the total distance of streets where street lights are present (denominator).		✓

	lighted street (kWh/year) (SI)			
	Average annual hours of electrical service interruptions per household (SI)	Total sum of hours of interruption multiplied by the number of households impacted (numerator) divided by the total number of households (denominator).		✓
	Heating degree days (PI)	Degree days indicate the energy demands of buildings as a response to their local and regional climate. 'Heating' degree days is a measure of the space heating requirements of buildings. Heating degree days shall be calculated by subtracting the mean daily air temperature from the standard baseline air temperature, and then summed for each day of the year to meet an annual total.		✓
	Cooling degree days (PI)	Degree days indicate the energy demands of buildings as a response to their local and regional climate. "Cooling" degree days is a measure of the space cooling requirements. Cooling degree days shall be calculated by subtracting the mean daily air temperature from the standard baseline air temperature, and then summed for each day of the year to meet an annual total.		✓
Environment and climate change	Fine particulate matter (PM2.5) concentration (CI)	Total mass of collected particles that are 2,5 µm or less in diameter (numerator) divided by the volume of air sampled in standard cubic metres (µg/m3) (denominator).		✓
	Particulate matter (PM10) concentration (CI)	Total mass of collected particles in micrograms in the PM10 size range (numerator) divided by the volume of air sampled in standard cubic metres (denominator).		✓
	Greenhouse gas emissions measured in tones per capita (CI)	Total amount of greenhouse gases in tones (equivalent carbon dioxide units) generated over a calendar year by all activities within the city, including indirect emissions outside city boundaries (numerator) divided by the current population of the city (denominator).		✓
	Percentage of areas designated for natural protection (SI)	Total land area of designated natural protection and/or biodiversity (numerator) divided by the total land area of the city (denominator).		✓
	NO2 (nitrogen dioxide) concentration (SI)	Sum of daily concentrations for a whole year (numerator) divided by 365 days (denominator).		✓
	SO2 (sulfur dioxide) concentration (SI)	Sum of daily concentrations for a whole year (numerator) divided by 365 days (denominator).		✓
	O3 (ozone) concentration (SI)	Sum of daily concentrations for a whole year (numerator) divided by 365 days (denominator).		✓
	Noise pollution (SI)	Noise pollution shall be calculated by assessing the population exposed to noise pollution (the numerator), divided by the total population of the city (denominator).		✓
	Percentage change in number of native species (SI)	Urbanization affects biodiversity through urban sprawl/habitat fragmentation, loss of fertile agricultural lands and spread of invasive alien species. It is calculated as the total net change in species (numerator) divided by the total number of species from the five taxonomic groups from most recent survey (denominator).		✓
Finance	Debt service ratio (debt service	This indicator reflects the amount of financial resources that are available for day-to-day		✓

	expenditure as a percentage of a city's own-source revenue) (CI)	operations and how much money is spent paying down debt. It is calculated as the total long-term debt servicing costs (numerator) divided by total own-source revenue (denominator).		
	Capital spending as a percentage of total expenditures (CI)	The amount of capital expenditure by the city expressed as a percentage of the total city expenditure is an indicator of capital reinvestment and the fiscal health of the city. It is calculated as the total expenditure on fixed assets in the preceding year (numerator) divided by the total expenditure (operating and capital) (denominator) by the city in that same period.		✓
	Own-source revenue as a percentage of total revenues (SI)	This indicator measures the level of dependence of the city on other levels of government for revenues to deliver its services to the public. It is calculated as the total amount of funds obtained through permit fees, user charges for city services and taxes collected for city purposes only (numerator) divided by all operating or reoccurring revenues, including those provided by other levels of government transferred to the city (denominator).		✓
	Tax collected as a percentage of tax billed (SI)	This indicator measures the ratio of the actual tax collected to the mandated tax. It is calculated as the total revenues generated by tax collection (numerator) divided by the amount of taxes that have been billed (denominator).		✓
	Gross operating budget per capita (USD) (PI)	Gross operating budget per capita provides a measure to understand the amount which local governments spend on their operating budgets in a simple way to allow for greater comparability between cities. It is calculated as the gross operating budget (numerator) divided by the population of the city (denominator).		✓
	Gross capital budget per capita (USD) (PI)	A city's capital budget is a reserved fund for upgrades and additions to city services and infrastructure to make a city more livable and attractive. It is calculated as the gross capital budget (numerator) divided by the population of the city (denominator).		✓
Governance	Women as a percentage of total elected to city-level office (CI)	The percentage of women elected to city-level office is a direct reflection of inclusiveness in governance. It is calculated as the total number of elected city-level positions held by women (numerator) divided by the total number of elected city-level positions (denominator).		✓
	Number of convictions for corruption and/or bribery by city officials per 100,000 population (SI)	Total number of convictions for corruption and/or bribery by city officials (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Number of registered voters as a percentage of the voting age population (SI)	Determining the percentage of the number of registered voters from the voting age population can reveal the legitimacy and quality of the electoral process in a city. It is calculated as the total number of registered voters, as determined by the official voter register (numerator) divided by the voting age population (denominator).		✓
	Voter participation in last	The percentage of the registered voting population that voted in the last municipal		✓

	municipal election (as a percentage of registered voters) (SI)	election is an indicator of the public's level of participation and degree of interest in local government. It is calculated as the number of persons who voted in the last municipal election (numerator) divided by the total number of registered voters (denominator).		
Health	Average life expectancy (CI)	Life expectancy reflects the overall mortality level of a population. It is calculated as the average number of years to be lived by a group of people born in the same year, if health and living conditions at the time of their birth remained the same throughout their lives.		✓
	Number of in-patient hospital beds per 100,000 population (CI)	The number of in-patient hospital beds is one of the few available indicators which monitor the level of a health service delivery. It is calculated as the total number of in-patient public and private hospital beds (numerator), divided by one 100 000th of the city's total population (denominator).		✓
	Number of physicians per 100,000 population (CI)	The availability of physicians is an important indicator of the strength of a city's health system. It is calculated as the number of general or specialist physicians whose workplace is in the city (numerator) divided by one 100 000th of the city's total population (denominator).		✓
	Under age five mortality per 1000 live births (CI)	The underage five mortality rate is a leading indicator of the level of child health and overall development in cities. Child mortality is an indicator of the status of the city as a healthy or unhealthy place to live. It refers to the probability of a child, born in a specified year, dying before reaching the age of five, and is expressed as a rate per 1000 live births.		✓
	Number of nursing and midwifery personnel per 100,000 population (SI)	The number of nursing and midwifery personnel is a good indication of the city's health system and the strength of its outreach for maternal health. It is calculated as the total number of nurses and midwives (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Suicide rate per 100,000 population (SI)	Suicide rate is a serious issue in many cities and reflects on mental health, which is central to human development. It is calculated as the total number of reported deaths by suicide (numerator) divided by one 100,000th of the city's total population (denominator).		✓
Housing	Percentage of city population living in inadequate housing (CI)	The percentage of the population living in inadequate housing is an indicator of the number of persons living in substandard housing conditions. It is calculated as the number of people living in inadequate housing (numerator) divided by the city population (denominator).		✓
	Percentage of population living in affordable housing (CI)	Housing can account for the highest amount of household spending; thus, a measure of affordability in a city can be attributed to the amount households spend on housing as a percentage of household income. It is calculated as the total number of households that do not surpass local, regional, provincial or national regulations on housing affordability based on a percentage of household income spending on income (numerator) divided by		✓

		the total number of households (denominator).		
	Number of homeless per 100,000 population (SI)	Total number of homeless people (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Percentage of households that exist without registered legal titles (SI)	Understanding the percentage of households that exist without registered legal titles informs municipal leaders on housing security for city residents as well as housing conditions and infrastructure requirements, and builds a better database for less formal parts of the city. It is calculated as the number of households that exist without registered legal titles (numerator) divided by the total number of households (denominator).		✓
	Total number of households (PI)	This indicator provides general insight for local authorities to develop a stronger understanding of the current and future needs of their city. It is calculated as the sum of all individual households within city boundaries.		✓
	Persons per unit (PI)	Persons per unit can provide indication into crowded or underutilized living spaces within cities. It is calculated as the total number of persons living in a city (numerator) divided by the total number of dwelling units in the city (denominator).		✓
	Vacancy rate (residential) (PI)	This indicator can provide general insight for local authorities to develop a stronger understanding of the current and future housing needs of their city. It is calculated as the number of unoccupied dwellings (numerator) divided by total number of dwellings in the city (denominator).		✓
	Living space (Km2) per person (PI)	Living space (in square meters) per person can provide an indication of crowded or underutilized dwelling units within cities. It is calculated as the total area of all dwelling units in a city (numerator) divided by the total number of persons living in the dwelling units (denominator).		✓
	Secondary residence rate (PI)	This indicator can provide general insight for local authorities to develop a stronger understanding of the supply and use of housing in the city and better plan for the current and future housing needs of their city. It is calculated as the number of secondary dwelling units (numerator) divided by the total number of dwelling units in the city (denominator).		✓
	Residential rental dwelling units as a percentage of total dwelling units (PI)	This indicator provides general insight for local authorities to develop a stronger understanding of the current and future housing supply to better plan and support housing needs in the city. It is calculated as the total number of residential rental dwelling units in the city (numerator) divided by the total number of dwelling units in the city (denominator).		✓
Population and social conditions	Percentage of city population living below the international poverty line (CI)	The percentage of the city's population living below the international extreme poverty threshold is an indicator of absolute poverty. It reflects social equity and reflects levels of economic and social marginality and/or inclusiveness in a city. It is calculated as the number of people living below the international extreme poverty threshold set by the		✓

		United Nations (numerator) divided by the total current population of the city (denominator).		
	Percentage of city population living below the national poverty line (SI)	The percentage of the city's population living below the national poverty line is an indicator of relative poverty. It reflects social equity and levels of economic and social marginality and/or inclusiveness in a city. It is calculated as the number of people living below the national poverty line set at country level (numerator) divided by the total current population of the city (denominator).		✓
	Gini coefficient of inequality (SI)	The Gini coefficient is a statistical measure of economic inequality. By analyzing the distribution of income or consumption across a population, cities are able to quantify a society's relative inequality, as well as changes in inequality over time.		✓
	Annual population change (PI)	With over half of the world's population choosing to locate in urban areas, population change within cities is an important metric to both know and forecast for planning purposes. It is calculated as the city's current population minus the city's previous annual population (numerator) divided by the city's previous annual population (denominator).		✓
	Percentage of population that are foreign born (PI)	Immigrant populations will play a greater role in providing countries and municipalities with sustainable labor and revenue streams as birth rates decrease. It is calculated as the total number of people who were born in a country other than that of the city (numerator) divided by the total city population (denominator).		✓
	Population demographics (PI)	Population demographics are essential for constructing age pyramids, which show the distribution of age categories for a city population. They can also be used to calculate gender ratios.		✓
	Percentage of population that are new immigrants (PI)	Total population of new city immigrants (numerator) divided by the total city population (denominator).		✓
	Percentage of city population that are non-citizens (PI)	The percentage of the city population that are non-citizens provides a general overview of the local population. Non-citizens could include people who are temporarily in the city for employment contracts or to pursue education. Knowledge of a city's non-citizen population can provide insight into municipal policies or programs. It is calculated as the total city non-citizen population (numerator) divided by the city's total population (denominator).		✓
	Number of university students per 100,000 population (PI)	The number of students pursuing university education in a city has implications for urban planning, housing, economic development and quality of life. It is calculated as the total number of full- and part-time university students (numerator) divided by one 100,000th of the city population (denominator).		✓
Recreation	Square meters of public indoor recreation space per capita (SI)	The square meters of indoor public recreation space (numerator) divided by the population of the city (denominator).		✓
	Square meters of public outdoor	The square meters of outdoor public recreation space (numerator) divided by the		✓

	recreation space per capita (SI)	population of the city (denominator).		
Safety	Number of firefighters per 100,000 population (CI)	Total number of certified and paid full-time-equivalent firefighters (numerator) divided by one 100,000th of the city population (denominator).		✓
	Number of fire-related deaths per 100,000 population (CI)	Total number of citizen fire-related deaths recorded in a 12-month period (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Number of natural-hazard-related deaths per 100,000 population (CI)	Total number of natural-hazard-related deaths recorded in a 12-month period (numerator) divided by one 100,000th of the city population (denominator).		✓
	Number of police officers per 100,000 population (CI)	Number of permanent full-time (or FTE) sworn-in police officers (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Number of homicides per 100,000 population (CI)	Number of reported homicides (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Number of volunteer and part-time firefighters per 100,000 population (SI)	Total number of volunteer and part-time firefighters (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Response time for emergency response services from initial call (SI)	Sum of time elapsed from receiving the initial distress calls to the time of on-site arrival of the emergency personnel and equipment in minutes and seconds for the year (numerator) divided by the number of emergency responses in the same year (denominator).		✓
	Crimes against property per 100,000 population (SI)	Total number of all property crimes reported (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Number of deaths caused by industrial accidents per 100,000 population (SI)	Sum of deaths caused by industrial accidents in the last 12 months (numerator) divided by 100,000th of the city's population (denominator).		✓
	Number of violent crimes against women per 100,000 population (SI)	Total number of violent crimes against women (numerator) divided by one 100,000th of the city's total population (denominator).		✓
Solid waste	Percentage of city population with regular solid waste collection (residential) (CI)	Number of people within the city who are served by regular solid waste collection (numerator) divided by the total city population (denominator).		✓
	Total collected municipal solid waste per capita (CI)	Total amount of solid waste (household and commercial) generated in tones (numerator) divided by the total city population (denominator).		✓
	Percentage of the city's solid waste that is recycled (CI)	Total amount of the city's solid waste that is recycled in tones (numerator) divided by the total amount of solid waste produced in the city in tones (denominator).		✓
	Percentage of the city's solid waste that is disposed of in a	The amount of the city's solid waste that is disposed of in a sanitary landfill in tones (numerator) divided by the total amount of solid waste produced in the city in tones		✓

	sanitary landfill (CI)	(denominator).		
	Percentage of the city's solid waste that is treated in energy-from-waste plants (CI)	Total amount of the city's solid waste that is disposed of in energy-from-waste plants in tones (numerator) divided by the total amount of solid waste produced in the city in tones (denominator).		✓
	Percentage of the city's solid waste that is biologically treated and used as compost or biogas (SI)	The amount of the city's solid waste that is composted or anaerobically digested in tones minus the waste refuse of the composting and anaerobic digestion plants (numerator) divided by the total amount of solid waste produced in the city in tones (denominator).		✓
	Percentage of the city's solid waste that is disposed of in an open dump (SI)	The amount of the city's solid waste that is disposed of in an open dump in tones (numerator) divided by the total amount of solid waste produced in the city in tones (denominator).		✓
	Percentage of the city's solid waste that is disposed of by other means (SI)	Total amount of the city's solid waste that is disposed of by other means in tones (numerator) divided by the total amount of solid waste produced in the city in tones (denominator). Other means include, for example, solid waste that is openly burned.		✓
	Hazardous waste generation per capita (tones) (SI)	The annual total amount of hazardous waste in tones (numerator) divided by total city population (denominator).		✓
	Percentage of the city's hazardous waste that is recycled (SI)	Total amount of hazardous waste that is recycled in tones (numerator) divided by the total amount of hazardous waste that is generated in tones (denominator).		✓
Sport and culture	Number of cultural institutions and sporting facilities per 100,000 population (CI)	Total number of cultural institutions and sporting facilities in the city (numerator) divided by one 100 000th of the city's population (denominator).		✓
	Percentage of municipal budget allocated to cultural and sporting facilities (SI)	Total number of cultural institutions and sporting facilities in the city (numerator) divided by one 100 000th of the city's population (denominator).		✓
	Annual number of cultural events (e.g., exhibitions, festivals, concerts) per 100,000 population (SI)	Total number of cultural events (numerator) divided by one 100 000th of the city's population (denominator).		✓
Telecommunication	Number of Internet connections per 100,000 population (SI)	Number of Internet connections in the city (numerator) divided by one 100,000th of the city's total population (denominator).	✓	
	Number of mobile phone connections per 100,000 population (SI)	Total number of mobile phone connections in the city (numerator) divided by one 100,000th of the city's total population (denominator).	✓	
Transportation	Km of public transport system per 100,000 population (CI)	Total length (in Km) of the public transport systems operating within the city (numerator) divided by one 100,000th of the city's total population (denominator).		✓

	Annual number of public transport trips per capita (CI)	Total annual number of public transport trips originating in the city – "ridership of public transport" – (numerator) divided by the total city population (denominator).		✓
	Percentage of commuters using a travel mode to work other than a personal vehicle (SI)	Number of commuters working in the city who use a mode of transportation other than a private Single Occupancy Vehicle (SOV) as their primary way to travel to work (numerator) divided by all trips to work, regardless of mode (denominator).		✓
	Km of bicycle paths and lanes per 100,000 population (SI)	Total length (in Km) of bicycle paths and lanes (numerator) divided by one 100 000th of the city's total population (denominator).		✓
	Transportation deaths per 100,000 population (SI)	Number of deaths related to transportation of any kind within the city's administrative boundary (numerator), divided by one 100 000th of the city's total population (denominator).		✓
	Percentage of population living within 0,5 km of public transit running at least every 20 min during peak periods (SI)	Total number of inhabitants living within 0,5 km of public transit running at least every 20 min during peak periods (numerator) divided by the total city population (denominator).		✓
	Average commute time (SI)	Average time in hours and minutes that it takes a working person to travel from home to place of employment.		✓
	Number of personal automobiles per capita (PI)	Total number of registered personal automobiles in a city (numerator) divided by the total city population (denominator).		✓
	Number of two-wheeled motorized vehicles per capita (PI)	Total number of two-wheeled motorized vehicles in the city (numerator) divided by the total city population (denominator).		✓
Urban / local agriculture and food security	Total urban agricultural area per 100,000 population (CI)	As food security is becoming a global challenge, it is important that policies promote inclusion of areas devoted to urban agriculture and also plans of new urban development projects with the goal of producing food through reutilization of urban resources. It is calculated as the total designated urban agricultural area used for food production located within city boundaries (numerator) divided by one 100 000th of the city's total population (denominator).		✓
	Amount of food produced locally as a percentage of total food supplied to the city (SI)	The weight of locally produced food supplied to an urban area, in tones (numerator) divided by total food supplied to the city, in tones (denominator).		✓
	Percentage of city population undernourished (SI)	Food availability, stability, accessibility and affordability are prerequisites for a healthy society and its sustainable development. It is calculated as the total number of the city population undernourished (numerator) divided by the total population of the city (denominator).		✓
	Percentage of city population that is overweight or obese -	Obesity is a risk factor for many chronic illnesses, particularly heart disease and diabetes. Although a variety of factors contribute to obesity, physical activity and dietary		✓

	Body Mass Index (BMI) (SI)	practices help prevent this obesity. The health consequences of excess weight include increased risk of physical chronic conditions and psychosocial problems. It is calculated as the total number of the city population that is overweight or obese (numerator) divided by the total population of the city (denominator).		
Urban planning	Green area (hectares) per 100,000 population (CI)	The amount of vegetated and/or natural surface cover is an indicator of how much "green" space a city has. It is calculated as the total area (in hectares) of green in the city (numerator) divided by one 100,000th of the city's total population (denominator).		✓
	Areal size of informal settlements as a percentage of city area (SI)	Settlements characterized by irregular tenure, unplanned development and unauthorized shelter that is not in compliance with local building codes and regulations are generally marginal and precarious, and affect social well-being, human health and economic development. The size of informal settlements is an indicator of the extent of the challenges for the reporting city in meeting shelter needs and demand. It is calculated as the area of informal settlements within the city boundary (in Km^2) (numerator) divided by the city area in Km^2 (denominator).		✓
	Jobs-housing ratio (SI)	A well-planned city focuses on the implications of new growth on its economy, existing communities and the environment. Growth is concentrated in areas that can accommodate a mix of housing, commerce, industry and recreation to maximize the use of existing infrastructure, minimize travel times to and from work, and minimize servicing costs resulting from new growth. Encouraging mixed-use developments combining housing and employment opportunities is essential to achieve these objectives. It is calculated as the total number of jobs (numerator) divided by the total number of dwelling units (denominator).		✓
	Basic service proximity (SI)	The ease with which residents are able to access basic services is an important indicator of overall livability and quality of life. This indicator measures the percentage of the population that lives within established proximity to basic services. It is calculated as the number of inhabitants who live near at least one basic service (numerator) divided by the total population of the city (denominator).		✓
	Population density (per Km2) (PI)	If density is designed well, it can be viewed as a community asset as it increases the proximity between residents and local goods and services. Population density is one metric that can used to help determine this. It is calculated as the total city population (numerator) divided by the city's land area.		✓
	Number of trees per 100,000 population (PI)	The number of trees per 100 000 population is a useful measure of a city's commitment to urban and environmental sustainability, as well as municipal beautification. Trees are often cited as an important landscape feature to reduce the impacts of climate change due to their role in removing carbon dioxide from the Earth's atmosphere. It is calculated as the total number of trees in the city (numerator) divided by one 100,000th of the city's total population (denominator).		✓

	Built-up density (PI)	It is calculated as the total floor area in square metres (for all buildings) (numerator) divided by total city area in square metres subtracted by green space area in square metres.		✓
Wastewater	Percentage of city population served by wastewater collection (CI)	Number of people within the city who are served by wastewater collection (numerator) divided by the city population (denominator).		✓
	Percentage of city's wastewater receiving centralized treatment (CI)	Total volume of city wastewater collected for primary, secondary and tertiary treatment in centralized wastewater treatment facilities (numerator) divided by the total volume of wastewater produced in the city (denominator).		✓
	Percentage of population with access to improved sanitation (CI)	Total number of people using improved sanitation facilities (numerator) divided by the total city population (denominator).		✓
	Compliance rate of wastewater treatment (SI)	Number of compliant tests required by local regulation multiplied by 100 (numerator) divided by the number of tests performed as required by local regulation (denominator).		✓
Water	Percentage of city population with potable water supply service (CI)	Total number of people with potable water supply service (numerator) divided by total city population (denominator).		✓
	Percentage of city population with sustainable access to an improved water source (CI)	Total population with access to an improved water source (numerator) divided by the total city population. An improved water source shall refer to piped water, public tap, borehole or pump, protected well, protected spring or rainwater.		✓
	Total domestic water consumption per capita (litres/day) (CI)	Total amount of the city's water consumption for domestic use (numerator) divided by the total city population (denominator).		✓
	Compliance rate of drinking water quality (CI)	Sum of the number of compliant tests multiplied by 100 (numerator) divided by the number of treated water quality tests carried out (denominator).		✓
	Total water consumption per capita (litres/day) (SI)	Total amount of the city's water consumption in litres per day (numerator) divided by the total city population (denominator).		✓
	Average annual hours of water service interruptions per household (SI)	Total sum of hours of interruption multiplied by the number of households impacted (numerator) divided by the total number of households (denominator).		✓
	Percentage of water loss (unaccounted for water) (SI)	Volume of water supplied minus the volume of utilized water (numerator) divided by the total volume of water supplied (denominator).		✓

Table II-10: ISO 37122 Standard – Sustainable Cities and Communities – Indicators for Smart Cities (Source: ISO, 2019a)

Theme	Indicator	Description	ICT-related	Non ICT-related
Economy	Percentage of service contracts providing city services which contain an open data policy	An open data policy demonstrates a city's commitment to better manage business information throughout the information lifecycle. Identifying and making data accessible helps to ensure that the public is informed and engaged through a transparent, accountable and accessible government. It is calculated as the total number of service contracts providing city services which contain an open data policy (numerator) divided by the total number of service contracts in the city (denominator).	✓	
	Survival rate of new businesses per 100,000 population	New businesses make a positive contribution to local economies, and start-up activity can signal a city's economic potential. New businesses can potentially contribute a substantial number of new jobs to the economy and tend to have faster employment growth rates, especially those in innovation-driven/technologically focused enterprises, such as computer or software development. It is calculated as the survival rate of new businesses in the city (numerator) divided by 1/100,000 of the city's total population (denominator).		✓
	Percentage of the labor force employed in occupations in the ICT sector	It is calculated as the number of city residents in the labor force employed in occupations in the ICT sector (numerator) divided by the city's total labor force (denominator).	✓	
	Percentage of the labor force employed in occupations in the education and R&D sectors	It is calculated as the number of city residents in the labor force employed in occupations in the education and research and development sectors (numerator) divided by the city's total labor force (denominator).		✓
Education	Percentage of city population with professional proficiency in more than one language	Foreign language skills are indicative of a diverse, employable workforce. They also suggest highly successful educational programming. It is calculated as the total number of people who are able to communicate in more than one foreign language with professional proficiency (numerator) divided by the city's total population (denominator).		✓
	Number of computers, laptops, tablets or other digital learning devices available per 1.000 students	Computer literacy is an essential aspect of professional employability in many sectors, and it allows an alternative form of civic engagement for citizens. The increase in accessibility of electronic devices for students, as well as the exposure to computers, laptops, tablets or other digital learning devices, can enhance a student's computer literacy. It also allows citizens to access a broader array of information, empowering people in all walks of life to seek, evaluate, use and create information effectively to achieve personal, social, occupational and educational goals. It is calculated as the total number of computers, laptops, tablets or other digital learning devices with Internet access available to primary and secondary school students attending primary and secondary school in the city (numerator) divided by 1/1000 of the city's total primary and secondary school population (denominator).	✓	

	Number of Science, Technology, Engineering and Mathematics (STEM) higher education degrees per 100,000 population	STEM education helps to create critical thinkers, increase science literacy, and enable the next generation of innovators. Furthermore, STEM is important because science pervades every part of our lives, and the need for STEM degree holders is increasing with the growing demand for innovators of products and processes that will help sustain and promote economic growth. It is calculated as the number of people holding higher education degrees with a specialization or major in a discipline within a STEM subject (numerator) divided by 1/100,000 of the city's total population (denominator).	✓	
Energy	Percentage of electrical and thermal energy produced from wastewater treatment, solid waste and other liquid waste treatment and other waste heat resources, as a share of the city's total energy mix for a given year	Waste heat is an endogenous energy resource of every city. Waste heat can be obtained from wastewater and solid waste treatment plants or any other industrial processes, as well as from the tertiary and transport sectors (e.g., heat rejected from data centres or the subway ventilation). It is calculated as the total amount of electrical and thermal energy expressed in GJ produced from wastewater treatment, solid waste and other liquid waste treatment and other waste heat resources (numerator) divided by the city's total end-use energy demand in the same units as the numerator (GJ) (denominator).		✓
	Electrical and thermal energy (GJ) produced from wastewater treatment per capita per year	Wastewater is a renewable resource that conveys thermal and chemical energy. In some instances, wastewater is found to contain nearly five times the amount of energy needed to process and treat the wastewater. It is important for cities to recognize the potential of wastewater as a sustainable energy source and utilize wastewater in their energy source mix. It is calculated as the total amount of electrical and thermal energy expressed in GJ produced from wastewater treatment in the city (numerator) divided by the city's total population (denominator).		✓
	Electrical and thermal energy (GJ) produced from solid waste or other liquid waste treatment per capita per year	While reduction, recycling and composting can do their part to mitigate the environmental impacts of municipal solid waste, not all types of materials can be practically and economically recycled in an environmentally beneficial manner. This leftover solid waste might therefore present an opportunity to recover energy, using new and possibly cleaner technologies. Other liquid waste such as fats, oils and grease are also a source of energy. It is calculated as the total amount of electrical and thermal energy expressed in GJ produced from solid waste and other liquid waste treatment in the city (numerator) divided by the city's total population (denominator).		✓
	Percentage of the city's electricity that is produced using decentralized electricity production systems	It is calculated as the amount of electricity produced by decentralized electricity production systems/facilities in GJ (numerator) divided by the total amount of electricity consumed in the city in the same units as the numerator (GJ) – this includes electricity produced by both centralized and decentralized electricity production facilities (denominator).		✓
	Storage capacity of the city's energy grid per total city energy consumption	The peak energy demand is a less spoken vector that increases energy costs and limits the penetration of renewables. Smart grids will accommodate energy storage (typically electrical and thermal storage, but also "clean" fuels such as hydrogen) to reduce demand		✓

		peaks and transfer energy usage to periods of intermittent renewable energy production. Efficient storage capacity is essential to balance the supply and demand for energy in a region, and it can be achieved by several strategies. It is calculated as the total amount of energy that can be stored annually on the city's electrical grid and thermal grids (district heating and cooling schemes) in gigajoules (GJ) (numerator) divided by the city's total energy consumption (denominator).		
	Percentage of street lighting managed by a light performance management system	Remotely managed light points contribute to higher energy efficiency and can be optimized and adapted to switch on and off and to dim in any area of the city. Also, remotely managed lights can potentially improve safety in the city, where any failure of a light point which leads to insufficiently illuminated streets can be immediately monitored and localized to ensure fast repair. Lastly, real energy consumption per light point can be measured and reported accurately with the light management system, to better monitor energy cost and CO_2 reduction schemes. It is calculated as the number of light points that can be controlled by a light performance management system (numerator) divided by the number of total light points in the city (denominator).	✓	
	Percentage of street lighting that has been refurbished and newly installed	Street lighting can account for 15% to 50% of total electricity consumption of municipalities. Refurbishing city street lights and installing new lighting can help improve energy efficiency, thus reducing street lighting energy consumption. In addition, the recent market introduction of energy-efficient technologies for street lighting offers high-cost savings with comparatively short payback times. The annual energy and maintenance cost savings might then possibly cover the investment and capital costs. It is expressed as the number of refurbished and newly installed light points (numerator) within the year divided by the total number of light points (denominator).		✓
	Percentage of public buildings requiring renovation / refurbishment	Buildings are the largest energy consumers in most cities. Reduced and efficient energy use can create substantial savings and can enhance the stability of the energy supply. As such, buildings requiring renovation/refurbishment can hinder progress to reduce energy consumption, thus contributing more to climate change and other negative externalities. It is calculated as the square metres of public buildings requiring renovation/refurbishment (numerator), divided by the total square metres of public buildings (denominator).		✓
	Percentage of buildings in the city with smart energy meters	Smart energy meters record and display the consumption of energy in real time. Smart meter data can be sent to a central location wirelessly, thus providing energy providers with the means to understand how and when power is being used to better plan and conserve energy. Also, smart meter data help consumers better understand and monitor energy usage. It is calculated as the number of buildings in the city with smart energy meters (numerator) divided by the total number of buildings in the city (denominator).	✓	
	Number of electric vehicle charging stations per registered	Unlike conventional vehicles that use gasoline or diesel-powered engines, electric vehicles (EVs) are powered by electricity from batteries. EVs therefore emit fewer greenhouse		✓

	electric vehicle (EV)	gases and tailpipe pollutants than conventional vehicles. EVs are also cheaper to operate because fuel costs are minimal or nil. However, with limited motor and battery capacity (meaning shorter travel range), electric cars need regular and convenient access to vehicle (i.e., battery) charging stations. It is calculated as the total number of electric vehicle charging stations in the city (numerator) divided by the total number of registered electric vehicles in the city (denominator).		
Environment and climate change	Percentage of buildings built or refurbished within the last 5 years in conformity with green building principles	Buildings that are constructed in conformity with green building principles are substantially more sustainable. 'Green' buildings are built with higher design standards which dramatically reduce energy consumption. Green buildings can also be built or refurbished according to green building standards, which offer continual building benchmarking to track environmental performance. It is calculated as the total number of buildings built or refurbished within the last 5 years in conformity with green building principles (numerator) divided by the city's total number of buildings built or refurbished in the last 5 years (denominator).		✓
	Number of real-time remote air quality monitoring stations per Km2	A remotely operated, real-time air monitoring system can help to assess climate change impacts on the environment (e.g., air quality). Such systems can also provide real-time observations, data processing and analysis, giving people timely information on the city's air quality. It is calculated as the total number of real-time remote air quality monitoring stations in the city (numerator) divided by the city's land area (denominator).	✓	
	Percentage of public buildings equipped for monitoring indoor air quality	Poor indoor air quality affects health, comfort and productivity of building occupants. These impacts can affect a large number of occupants and especially sensitive persons such as children or the elderly. To limit the health and economic consequences of poor indoor air quality, smart cities could measure and identify the sources and factors that influence the quality of indoor air and then propose appropriate solutions. It is calculated as the total number of public buildings within the city that are equipped to monitor indoor air quality (numerator) divided by the total number of buildings in the city (denominator).	✓	
Finance	Annual amount of revenues collected from the sharing economy as a percentage of own-source revenue	The sharing economy or peer-to-peer-based sharing of access to goods and services is a growing component of the municipal economy. The inclusion of these economies into existing policy allows for taxation, which supplements municipal capital budgets. It is represented as the total amount of funds collected per year from permit fees, user fees, licensing fees and taxes as permitted by law or legislation from sharing economy transactions (numerator) divided by the city's total own-source revenue (denominator).		✓
	Percentage of payments to the city that are paid electronically based on electronic invoices	The use of electronic invoices (e-invoices) and transfer of payments to the city increases security and reduces costs for the city and its businesses and citizens. Cities that combine e-invoice and e-transfers with automatic accounting and control systems can experience a noticeable increase in productivity. It is calculated as the number of payments to the city	✓	

		that are made electronically based on an e-invoice (numerator) divided by the total number of payments made to the city (denominator).		
Governance	Annual number of online visits to the municipal open data portal per 100,000 population	Open data portals provide a means of increasing public access to data managed by municipalities. It creates greater transparency and allows for innovation by community organisations and citizens. Although many municipalities offer online portals, not all are equally visited. It is calculated as the total number of municipal open data portal visits (numerator) divided by 1/100,000 of the city's total population (denominator).	✓	
	Percentage of city services accessible and that can be requested online	Delivering city services that can be requested online through digital portals provide benefits to citizens and local governments. Municipalities can provide services without fixed hours and can provide these services with reduced resources. Moreover, the use of mobile technology, such as geo-tagging and photos, is aiding the efficiency and effectiveness of city services. It is calculated as the total number of city services offered to people and businesses through a centralised Internet interface (numerator) divided by the total number of city services offered by the city (denominator).	✓	
	Average response time to inquiries made through the city's non-emergency inquiry system (days)	A non-emergency inquiry system is an important access point to municipal services. It refers to the response rate of non-emergency access points through various mediums including telephone, apps, Twitter, email and in-person contacts. The access point can be used by citizens as well as businesses. It is expressed as the total number of hours from initial call/form submission taken to respond to all inquiries made through the city's non-emergency system (numerator) divided by the total number of inquiries received by the city's non-emergency system (denominator).		✓
	Average downtime of the city's IT infrastructure	In a commercial environment, the cost of downtime during a security incident - from lost sales and revenue to a loss of customer confidence - can negatively impact businesses. The equivalent impact to a city can be estimated on city service performances/commitments. It is calculated as the number of hours that the city's IT infrastructure is not available due to an incident (i.e., system power outage, scheduled maintenance) (numerator) divided by the total number of incidents causing IT infrastructure outages (denominator).	✓	
Health	Percentage of the city's population with an online unified health file accessible to health care providers	The digitisation and centralization of health histories enables health care providers to care for patients using a holistic approach. Health care providers, regardless of their speciality or location, can access the health history of these individuals and provide better care accordingly. It is calculated as the total number of persons with an online unified health file that can be accessed by any type of health care provider (numerator) divided by the total population in the city (denominator).	✓	
	Annual number of medical appointments conducted remotely per 100,000 population	Remote medical appointments provide a vital alternative to traditional walk-in appointments. Consideration could include aging populations, decreased mobility or limited access to transportation. It is calculated as the total number of medical appointments conducted remotely, such as through online video services or	✓	

		teleconferencing (numerator) divided by 1/100,000 of the city's total population (denominator).		
	Percentage of the city population with access to real-time public alert systems for air and water quality advisories	Poor air and water quality affect human health and contribute to human mortality and morbidity in cities. Air quality alert systems provide important information and advice to the public to minimize air pollutant exposure. Similarly, water quality alert systems inform people whether or not the quality of the city's water is suitable for drinking, or use for other activities. Air and water quality alert systems can help to mitigate or lessen the impacts of pollutants on public health. It is calculated as the number of people with access to real-time public alert systems for air and water quality advisories (numerator) divided by the city's total population (denominator).	✓	
Housing	Percentage of households with smart energy meters	Smart energy meters record and display the consumption of energy in real time. Smart meter data can be sent to a central location wirelessly, thus providing electricity providers with the means to understand how and when power is being used to better plan and conserve energy. Also, smart meter data help consumers better understand and monitor energy usage. It is calculated as the total number of households with smart energy meters (numerator) divided by the total number of households in the city (denominator).	✓	
	Percentage of households with smart water meters	Smart water meters record and display the consumption of water in real time. Smart meter data can be sent to a central location wirelessly, thus providing water providers with the means to understand how and when water is being used to better plan and conserve water. Also, smart meter data help consumers better understand and monitor water usage. It is calculated as the total number of households with smart water meters (numerator) divided by the total number of households in the city (denominator).	✓	
Population and social conditions	Percentage of public buildings that are accessible by persons with special needs	Public buildings that are accessible by persons with special needs create an inclusive city by removing barriers for persons affected by mobility challenges. It is calculated as the number of public buildings within the city that are accessible by persons with special needs (numerator) divided by total number of public buildings in the city (denominator).		✓
	Percentage of municipal budget allocated for the provision of mobility aids, devices and assistive technologies to citizens with special needs	Ensuring a city is accessible for all its citizens and visitors promotes an equitable and inclusive society. Allocating a portion of the municipal budget for provision of mobility aids, devices and assistive technologies to citizens with special needs helps to maintain the accessibility of the city year over year for all its citizens and visitors and to support autonomy (and homecare) of persons with special needs, including seniors. It is calculated as the sum of the cost of providing mobility aids, devices and assistive technologies the city spends in one fiscal year (numerator) divided by the total city budget allocated for a given year (denominator).	✓	
	Percentage of marked pedestrian crossings equipped with	Accessible pedestrian signals enable persons with special needs to safely cross intersections and to perform their daily activities. It is calculated as the number of marked	✓	

	accessible pedestrian signals	pedestrian crossings equipped with accessible pedestrian signals (numerator) divided by the total number of marked pedestrian crossings (denominator).		
	Percentage of municipal budget allocated for provision of programmes designated for bridging the digital divide	As cities experience a demographic shift, the need for age-friendly urban design and city services is becoming ever more critical. Cities need to address the consequences of this unprecedented demographic shift through age-friendly planning and city services. Developing programmes (for example, technology classes for senior citizens) is one way to create an environment in which senior citizens, but also people with disabilities, can acquire or improve technological skills to actively participate in a technology-driven society and fight against digital divide. This also empowers citizens to become active users of new technology. It is calculated as the sum of the city's annual expenditure on programming designated for bridging the digital divide (numerator) divided by the city's total annual budget (denominator).	✓	
Recreation	Percentage of public recreation services that can be booked online	Online recreation booking offers increased accessibility and awareness for the public, as well as data sources for public recreation participation. It is calculated as the number of public recreation services that can be booked online (numerator) divided by total number of public recreation services that a city offers (denominator).	✓	
Safety	Percentage of the city area covered by digital surveillance cameras	The presence of surveillance cameras is a deterrent against crime and other offences. When incidents do occur, video surveillance offers an accurate representation of the events, as well as key information to solve crimes and other offences. Digital cameras are more reliable than film, and they have higher capacity, better picture quality, and create files that are easily distributed and difficult to tamper with. It is calculated as the amount of city land area covered by digital video surveillance cameras in square kilometres (numerator) divided by the city's total land area (denominator).	✓	
Solid waste	Percentage of waste drop-off centres (containers) equipped with telemetering	Many cities have to limit traffic in the city and simplify garbage collection organization. Moreover, many cities have streets that are narrow and substandard and that provide only limited access to households and neighborhoods. In cities in less developed countries, roads and pathways are not always accessible to garbage trucks for collection. Developing waste drop-off centres with telemetering (where citizens bring their waste) is a local solution that could help cities reach the objective of reducing traffic in the city, overcoming limited access, and simplifying garbage collection and disposal. Telemetering aids in the optimization and efficiency of garbage collection by informing garbage collection trucks on the level of waste currently held in containers at the drop-off centre. It is calculated as the number of waste drop-off centres (containers) for garbage disposal equipped with telemetering devices (numerator) divided by the total waste drop-off centres (containers) within the city (denominator).	✓	
	Percentage of the city population	Individual monitoring of household waste quantities provides valuable information for	✓	

	that has a door-to-door garbage collection with an individual monitoring of household waste quantities	both citizens and cities. Understanding the weight of household waste can help optimize garbage collection and reduce costs. In addition, telemetering reduces street traffic by adapting the number of vehicles to the actual quantity of waste to be collected. Benefits are a more fluent traffic with consequences for the reduction of GHG emissions, better design of collection rounds, and better allocation of human resources with corresponding savings. It is calculated as the number of people living in the city where there is a door-to-door household garbage collection equipped with monitoring device (numerator) divided by the city's total population (denominator).		
	Percentage of total amount of waste in the city that is used to generate energy	Waste which has significant organic matter content can be a source of energy either directly by recovering heat from energy from a waste plant (incinerator) or by producing energy from the digestion of waste or other new technologies using this energy for cogeneration, biomethane production for injection in the gas network, or for fuel production. It is calculated as the total amount of waste utilized to generate energy (numerator) divided by the total amount of waste generated in the city (denominator).		✓
	Percentage of total amount of plastic waste recycled in the city	Plastic waste is a global environmental issue. To prevent the dispersion in the environment of plastics the best solution is to limit the production of plastics and develop plastic recycling. Taking into account the potential ecological impacts of microplastics on waterbodies and oceans, cities can promote plastic recycling within their territories. This necessitates the monitoring of plastic production and promotes increased use of recycled plastics within other products. It is calculated as the total amount of plastics coming out of sorting plants and recycled (numerator) divided by the total amount of plastics on the market within the city boundaries (denominator).		✓
	Percentage of public garbage bins that are sensor-enabled public garbage bins	Solid waste management and monitoring requires immediate attention in all cities. Sensor-enabled solutions for public garbage bins is one-way cities can improve waste monitoring and collection of public garbage bins. Sensor-enabled garbage bins can lead to optimised route planning and scheduling of waste collection, potentially leading to significant cost reductions in solid waste collection. It is calculated as the number of public garbage bins that are sensor-enabled (numerator) divided by the total number of public garbage bins in the city (denominator).	✓	
	Percentage of the city's electrical and electronic waste that is recycled	With the rapid increase in the popularity of cellular phones, computers, televisions and other electronic devices, it is increasingly important that cities ensure that electronic waste (or e-waste) undergoes environmentally sound management at the end of its useful life. E-waste recycling programmes help keep electronic devices out of landfills and recover useful resources. It is calculated as the total amount of the city's electrical and electronic waste that is recycled in tonnes (numerator) divided by the total amount of electrical and electronic waste produced in the city in tonnes (denominator).		✓

Sport and culture	Number of online bookings for cultural facilities per 100,000 population	Cultural facilities and cultural / sporting events play a pivotal role in connecting people and in building a more cohesive and open society. The digitisation of access to cultural institutions helps to increase the availability of cultural resources to a broader audience. It is calculated as the number of online bookings for cultural facilities (numerator) divided by 1/100,000 of the city’s total population (denominator).	✓	
	Percentage of the city’s cultural records that have been digitized	The process of digital preservation, or digitisation, is the formal endeavor of ensuring digital information, such as digital data, is managed to ensure continued access and usability. The digital preservation of cultural records is one form of digital preservation which ensures cultural artefacts are maintained for future users. Furthermore, digital preservation connects and provides people with wider access to heritage materials, which helps to stimulate an innovative information society. Digitisation of a city’s cultural record contributes to the conservation and preservation of heritage and scientific resources; it creates new educational opportunities; it can be used to encourage tourism; and it provides ways of improving access by citizen to their heritage. It is calculated as the number of the city’s cultural records that have been digitised (numerator) divided by the total number of cultural records of the city (denominator).	✓	
	Number of public library book and e-book titles per 100,000 population	Libraries help to educate the general population, in addition to providing civic spaces for interaction. Libraries can be considered a local gateway to knowledge, and provide “a basic condition for lifelong learning, independent decision-making and cultural development of the individual and social groups”. Ultimately, as stated in UNESCO’s Public Library Manifesto, “the public library [can be thought of as] a living force for education, culture and information, and as an essential agent for the fostering of peace and spiritual welfare through the minds of men and women”. It is calculated as the total number of library book titles and the total number of library e-book titles (numerator) divided by 1/100,000 of the city’s total population (denominator).		✓
	Percentage of city population that are active public library users	Libraries help to educate the general population, in addition to providing civic spaces for interaction. The number of active library users is a measure of the reach and effectiveness of local libraries providing “a basic condition for lifelong learning, independent decision-making and cultural development of the individual and social groups”. It is calculated as the total number of city residents that are active library users measured as citizens who are registered public library members or measurably use library services (numerator) divided by the city's total population (denominator).		✓
Telecommunication	Percentage of the city population with access to sufficiently fast broadband	Sufficiently fast broadband helps enable individuals to exercise their right to freedom of opinion and expression, and promotes the progress of society through wider access to information. It has most recently become a fundamental human right as identified by the United Nations, and provides citizens with the opportunity to explore and retrieve information that is available on the World Wide Web. It is calculated as the total number	✓	

		of people in the city with access to sufficiently fast broadband (numerator) divided by the city's total population (denominator).		
	Percentage of city area under a white zone/dead spot/not covered by telecommunication connectivity	Telecommunication enables not only communication without barriers, but access to services such as the Internet. White zones and dead spots are therefore a hindrance to communication and access to basic services. It is calculated as the total city land area classified as being under a white zone/dead spot/not covered by telecommunication connectivity in Km^2 (numerator) divided by the city's total land area in Km^2 (denominator).	✓	
	Percentage of the city area covered by municipally provided Internet connectivity	A public Internet connection allows people who do not have mobile data plans or regular Internet access to connect to the Internet, enabling them to take advantage of the economic and social benefits the Internet can offer. In addition, publicly accessible Internet can help enable municipalities to passively track users for future planning purposes. It is calculated as the total land area of the city serviced with Internet connectivity in Km^2 (numerator) divided by the city's total land area in Km^2 (denominator).	✓	
Transportation	Percentage of city streets and thoroughfares covered by real-time online traffic alerts and information	The prominence and growth of online civic tools have created a culture of sharing civic data in real time, including online traffic alerts and information. These data can be user-driven by utilizing geospatial crowdsourcing of mobile data, or collected through sensors or cameras installed by road and transportation authorities. The application of such technologies enables authorities to efficiently plan for future conditions, and for users to effectively travel through city streets and thoroughfares. It is calculated as the number of street and thoroughfare kilometres within the city covered by real-time online traffic alerts and information (numerator) divided by the total number of street and thoroughfare kilometres within city limits (denominator).	✓	
	Number of users of sharing economy transportation per 100,000 population	Cities are increasingly utilizing sharing economy transportation to supplement existing mobility needs. The extent to which policymakers and planners are aware of the number of users of sharing economy transportation in the city will allow for better development of plans and reconfiguration of a city's transportation system to accommodate for these changes. It is calculated as the total number of users actively using sharing economy transportation (numerator) divided by 1/100,000 of the city's total population (denominator).	✓	
	Percentage of vehicles registered in the city that are low-emission vehicles	Low-emission vehicles provide an alternative to traditional vehicles operating with internal combustion engines, which expel noxious gasses such as unburned hydrocarbons. Low-emission vehicles have the potential to improve local air quality. It is calculated as the total number of registered and approved low-emission vehicles registered in the city (numerator) divided by the total number of registered vehicles in the city (denominator).		✓
	Number of bicycles available through municipally provided	Bicycle sharing or a bike-share scheme is a service in which bicycles are made available for shared use to individuals on a short-term basis. Generally, individuals can borrow and		✓

	bicycle-sharing services per 100,000 population	return the bike at different locations. Bicycle sharing promotes greater rates of bicycle use in cities by reducing traditional barriers to ridership, including costs, bicycle theft and repair. Bicycle sharing provides an alternative to traditional transportation modes such as public transit or private automobiles. This indicator provides municipalities with a measure of the availability of bicycles in the bicycle share system. It is calculated as the total number of bicycles available through municipally provided bicycle-sharing services in the city (numerator) divided by 1/100,000 of the city's total population (denominator).		
	Percentage of public transport lines equipped with a publicly accessible real-time system	Real-time information on public transport lines can be shared with citizens to avoid traffic congestion and long waits for services that are delayed or cancelled. Publicly accessible real-time alerts keep citizens well-informed of the city's public transport services. It is calculated as the number of public transport lines that are equipped with a publicly accessible real-time system to provide people with real-time operation information (numerator) divided by the total number of public transport lines within the city limits (denominator).	✓	
	Percentage of the city's public transport services covered by a unified payment system	A unified payment system encourages multiple modal transportation across transportation modes such as bus, LRT, subway and trains, and reduces the need for public transport users to stop and pay at multiple transfer points during a single trip. A unified payment system for public transport users is not limited to a specific transport line or mode, but covers all types of public transportation modes. It is calculated as the number of city public transport services connected by a unified payment system (numerator) divided by the city's total number of public transport services (denominator).		✓
	Percentage of public parking spaces equipped with e-payment systems	E-payment systems offer the public easier methods of payment because they are not dependent on cash or cheques, and they reduce time spent in line-ups. An e-payment system also creates opportunities for smart pricing, depending on the time of day or frequency of use. It is calculated as the number of public parking spaces equipped with an e-payment system as a payment method (numerator) divided by the total number of public parking spaces in the city (denominator).	✓	
	Percentage of public parking spaces equipped with real-time availability systems	Real-time systems help to distribute information on parking space availability, hours of operation, fee guidelines and accessibility options. Also, real-time systems help people to more efficiently identify available public parking spaces, thus helping to reduce fuel use and vehicle emissions incurred in that process. It is calculated as the number of public parking spaces that are equipped with real-time availability systems (numerator) divided by the total number of public parking spaces in the city (denominator).	✓	
	Percentage of traffic lights that are intelligent / smart	Intelligent/smart traffic lights help to control vehicle and pedestrian flow through streets and intersections in an optimal manner, thereby improving mobility and reducing consumption of transportation fuels. They can also be used to inform the optimal path for emergency responders moving quickly through the city. It is calculated as the number of	✓	

		traffic lights in the city that are intelligent/smart (numerator) divided by the total number of traffic lights in the city (denominator).		
	City area mapped by real-time interactive street maps as a percentage of the city's total land area	Real-time interactive street maps provide up-to-date information for people commuting through the city, or planning to travel in and around the city. This allows people to more efficiently plan their travel times and routes, as well as identify points of access that accommodate persons with special needs. It is calculated as the total city area mapped by real-time interactive street maps (numerator) divided by the city's total land area (denominator).	✓	
	Percentage of vehicles registered in the city that are autonomous vehicles	Autonomous vehicles could reduce traffic fatalities by eliminating accidents caused by human error, which could be the most significant advance in automobile safety history. This could be achieved by shifting focus from minimization of post-crash injuries to collision prevention altogether. It is calculated as the total number of autonomous vehicles registered in the city (numerator) divided by the total number of registered vehicles in the city (denominator).	✓	
	Percentage of public transport routes with municipally provided and/or managed Internet connectivity for commuters	A public Internet connection allows people who do not have mobile data plans or regular Internet access to connect to the Internet, enabling them to take advantage of the economic and social benefits the Internet offers. In addition, publicly accessible Internet can help municipalities to passively track users for future planning. It is calculated as the number of kilometres of public transport routes in the city with municipally provided and/or managed Internet connectivity for commuters (numerator) divided by the total number of kilometres of public transport routes in the city (denominator).	✓	
	Percentage of roads conforming with autonomous driving systems	Road conformity with automated driving systems requires databases that accurately define roads (type of road, number of lanes, traffic data) as well as infrastructures that ensure real-time localization of the autonomous vehicles (e.g., availability of communication network infrastructures [GNSS, Wi-Fi, 5G]). It is calculated as the number of kilometres of road conforming with autonomous driving systems (numerator), divided by the total number of kilometres of road (denominator).	✓	
	Percentage of the city's bus fleet that is motor-driven	The deployment of public transport vehicles that are motor-driven instead of engine-driven helps cities to reduce operating costs and vehicle tailpipe emissions, while providing public transport users with an eco-friendly mode of transportation. Furthermore, motor-driven public transport vehicles reduce noise and vibrations originating from engine systems, thereby improving passenger safety and comfort. It is calculated as the number of buses in the city's bus fleet that are motor-driven (numerator) divided by the total number of buses in the city's bus fleet (denominator).		✓
Urban / local agriculture and food security	Annual percentage of municipal budget spent on urban agriculture initiatives	Urban agriculture makes an important contribution to household food security, especially in times of crisis or food shortages. Locally produced food requires shorter supply chains and less transportation and refrigeration, and can thus help to conserve energy, water and		✓

		other resources. It is calculated as the total amount of the city budget spent on urban agriculture initiatives for a given year (numerator) divided by the city's total municipal budget for the same year (denominator).		
	Annual total collected municipal food waste sent to a processing facility for composting per capita (in tons)	Although food and organic matter are essential for life and healthy soil, significant amounts of food and organic waste end up in the municipal waste stream destined, for example, to a landfill or incinerator. There is recognition both within cities and globally that food and organic wastes are a growing problem, and that current waste management practices are not sustainable. There are environmental consequences to sending food and organic materials to disposal. The environmental benefits of recycling and composting food waste can be significant. Composting transforms food waste into usable products such as fertilizer, which can then be used in agriculture and food production, enhancing food productivity and promoting smart, sustainable growth. It is calculated as the total amount of food waste (household and commercial) collected in tonnes (numerator) divided by the city's total population (denominator).		✓
	Percentage of the city's land area covered by an online food-supplier mapping system	Maps displaying food suppliers in the city help to connect citizens to food resources. Food maps also provide baseline data on the state of access to nutritious food supplies and assets, allowing cities to take stock of their food resources. It is calculated as the total land area covered by an online food-supplier mapping system (numerator) divided by the city's total land area (denominator).	✓	
Urban planning	Annual number of citizens engaged in the planning process per 100,000 population	Citizen engagement is a key attribute in effective planning and policy-making. Successful citizen engagement improves this process because the community has input and influence in the municipal government plan. It is calculated as the total number of citizens participating in or engaged in the planning process on an annual basis (numerator) divided by 1/100,000 of the city's total population (denominator).		✓
	Percentage of building permits submitted through an electronic submission system	The building permit application and approval process can hinder development feasibility and profitability. Making available the option for a building permit application submission to be completed electronically might help to expedite the process of building permitting by eliminating the need for city staff to perform routine data entry and enabling applicants to submit building permits more quickly. It is calculated as the number of building permits submitted through an electronic submission system (numerator) divided by the total number of building permits submitted through an electronic submission system and an in-person manual system (i.e., paper application) (denominator).	✓	
	Average time for building permit approval (days)	The development application and building permit approval process can hinder development feasibility and profitability. This indicator allows municipalities to compare their development application and building permit approval times with other municipalities to improve their internal processes. It is calculated as the sum in days of building permits from start to completion (numerator) divided by the total number of		✓

		building permits (denominator).		
	Percentage of the city population living in medium-to-high population densities	Population density is a fundamental condition of cities and it affects how they function. Urban planners advocate higher population densities for the widely held theory that cities operate more efficiently when residents live in denser urban surroundings. A higher population density can contribute to smart growth, given that other aspects, such as automobile dependency, are less of an issue. The growth is "smart" because it is meant to be sustainable and long-lasting, and not be solely dependent on automobiles. It is calculated as the number of people living in a medium-to-high population density area (numerator) divided by the city's total population (denominator).		✓
Wastewater	Percentage of treated wastewater being reused	Wastewater reuse is a means to save water in areas where scarcity is increasing and lack of water might occur. It is a solution consistent with circular economy principles that help to face climate changes and adaptation challenges. It is also a way to prevent discharge of untreated wastewater into the environment. It is calculated as the total annual volume of treated wastewater that is reused (numerator) divided by the total annual volume of treated wastewater (denominator).		✓
	Percentage of biosolids that are reused (dry matter mass)	Biosolids might have significant content of minerals (i.e., N, P), oligo-elements and organic matter that can be reused either for agricultural fertilising and soil improving, or for calorific value in energy-from-waste plants or digestion facilities to produce biomethane that is reusable for gas injection or fuel production. Biosolids reuse is an important component of the circular economy, helping to reduce discharge or disposal of biosolids into the environment. Some types of biosolids reuse can help to mitigate expected decreases in mineral resources such as phosphorus. Production of new phosphorus resources, such as struvite, will therefore be needed in the future. It is calculated as the total annual quantity of biosolids that are reused in dry matter mass (numerator) divided by the total annual quantity of biosolids produced and measured at site outlets in the city in dry matter mass (denominator).		✓
	Energy derived from wastewater as a percentage of total energy consumption of the city	Wastewater which has significant organic matter content can be a source of energy either by producing energy from the digestion of wastewater or biosolids or other new technologies using this energy for cogeneration, biomethane production for injection in the gas network, or for fuel production, recovering heat from wastewater within the wastewater network. It is calculated as the sum of the total annual quantity of energy derived from the network of wastewater and wastewater treatment plants (numerator) divided by the total energy consumption of the city (denominator).		✓
	Percentage of total amount of wastewater in the city that is used to generate energy	Wastewater which has significant organic matter content can be a source of energy either by producing energy from the digestion of wastewater or biosolids or other new technologies using this energy for cogeneration, biomethane production for injection in the gas network, or for fuel production, or by recovering heat from wastewater within the		✓

		wastewater network. It is calculated as the total amount of wastewater utilized to generate energy (numerator) divided by the total amount of wastewater in the city (denominator).		
	Percentage of the wastewater pipeline network monitored by a real-time data-tracking sensor system	Equipping a city's wastewater pipeline network with sensor-based technologies allows for continuous measurement of effluent levels in the network, the detection of discharges to storm spillways, and the calculation of flow and volume discharges into the environment and their potential cost reductions. Furthermore, sensor-based systems allow for remote management and operation of sewage networks and rainwater, detecting problems and proceeding with quick and efficient solutions. It is calculated as the length of the wastewater pipeline network monitored by a real-time data tracking sensor system in kilometres (numerator) divided by the total length of the wastewater pipeline network in kilometres (denominator).	✓	
Water	Percentage of drinking water tracked by real-time, water quality monitoring station	A real-time ICT-based system for monitoring drinking water quality can help to inform city residents of drinking water quality and to mitigate health impacts from degraded drinking water. An ICT-based system also provides real-time observations, allowing immediate data processing and analysis of water quality information. It is calculated as the amount of drinking water that has undergone water quality monitoring by a real-time water quality monitoring station in the city (numerator) divided by the total amount of drinking water distributed in the city (denominator).	✓	
	Number of real-time environmental water quality monitoring stations per 100,000 population	A real-time system for monitoring environmental water quality can help to reduce climate change impacts on the environment and its water ecosystems. Using an ICT-based system in environmental water monitoring can provide real-time observations, giving the city and its citizens timely information on water quality. It is calculated as the total number of real-time environmental water quality monitoring stations in the city (numerator) divided by 1/100,000 of the city's total population (denominator).	✓	
	Percentage of the city's water distribution network monitored by a smart water system	This indicator is calculated as the length of the water distribution network covered by a smart water system in Km (numerator) divided by the total length of the water distribution network in Km (denominator).	✓	
	Percentage of buildings in the city with smart water meters	Smart water meters record and display the consumption of water in real time. Smart meter data can be sent to a central location wirelessly, thus providing water providers with the means to understand how and when water is being used, and to better plan and conserve its use. Also, smart meter data help consumers better understand and monitor water usage. It is calculated as the number of buildings in the city with smart water meters (numerator) divided by the total number of buildings in the city (denominator).	✓	

Table II-11: ISO / DIS 37123 Standard – Sustainable Cities and Communities – Indicators for Resilient Cities (Source: ISO, 2018b)

Theme	Indicator	Description	ICT-related	Non ICT-related
Economy	Historical disaster losses as a percentage of city product	Direct economic losses from disaster(s) within the city summed over a period of five years (numerator) divided by the total city product summed over the same time period (denominator). Historical losses reflect direct economic losses (in monetary terms) that result from disasters.		✓
	Average annual disaster loss as a percentage of city product	Average direct economic losses from disaster(s) estimated from city-wide catastrophe modeling scenarios (numerator) divided by the total city product (denominator). The result shall be multiplied by 100 and expressed as average annual disaster loss as a percentage of city product. Over time, average annual loss data can be used to quantify the expected benefits of investing in disaster risk reduction measures.		✓
	Percentage of essential service providers that have a documented business continuity plan	Total number of essential service providers that have a documented business continuity plan (numerator) divided by the total number of essential service providers (denominator). The result shall be multiplied by 100 and expressed as the percentage of essential service providers that have a documented business continuity plan.		✓
	Percentage of properties with insurance coverage for high-risk hazards	Total number of properties (residential and non-residential) within the city with insurance coverage for high-risk hazards affecting the city (numerator) divided by the total number of properties (households and businesses) in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of properties with insurance coverage for high-risk hazards.		✓
	Percentage of total insured value to total value at risk within the city	Total insured value of all residential and non-residential properties within the city (numerator) divided by the total value of all residential and non-residential properties in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of total insured value to total value at risk within the city.		✓
	Employment Concentration	Number of people in the city employed in the three largest sectors of the local economy (as measured by total employment) (numerator) divided by the city's total labor force (denominator). The result shall be multiplied by 100 and expressed as a percentage.		✓
	Percentage of the workforce in informal employment	Number of people working in informal employment (numerator) divided by the city's total workforce (denominator). This result shall then be multiplied by 100 and expressed as the percentage of the workforce in informal employment.		✓

Education	Percentage of schools that teach emergency preparedness and disaster risk reduction	Number of schools within the city that teach emergency preparedness and disaster risk reduction (numerator) divided by the total number of schools in the city (denominator). The result shall be multiplied by 100 and expressed as a percentage of schools that teach emergency preparedness and disaster risk reduction. Schools shall refer to primary and secondary educational institutions.		✓
	Percentage of population trained in emergency preparedness and disaster risk reduction	Total number of people within the city trained by responsible authorities in emergency preparedness and disaster risk reduction activities in the previous 12 months (numerator) divided by the city's total population (denominator). The result shall be multiplied by 100 and expressed as a percentage of population trained in emergency preparedness and disaster risk reduction.		✓
	Percentage of the vulnerable population that has been engaged with emergency preparedness and disaster risk reduction activities	Number of vulnerable people within the city that have been engaged with emergency preparedness and disaster risk reduction activities by responsible authorities (numerator) divided by the total vulnerable population (denominator). The result shall be multiplied by 100 and expressed as the percentage of vulnerable population that has been engaged with emergency preparedness and disaster risk reduction.		✓
	Percentage of emergency preparedness publications provided in alternative languages	Number of emergency preparedness publications provided in alternative languages within the city (numerator) divided by the total number of emergency preparedness publications published by the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of emergency preparedness publications information provided in alternative languages.		✓
	Educational disruption	Number of teaching days lost annually due to shocks or stresses. Teaching days lost shall refer to days when educational institutions are not operational during regular hours of teaching. Partial lost teaching days shall be included in the calculation of this indicator (e.g., a half-day of lost teaching due to an extreme event). Any closure of an education facility in the city shall be counted as one teaching day lost. Multiple educational facilities closed on the same calendar date shall be counted as one teaching day lost.		✓
Energy	Number of different electricity sources providing at least 5 percent of total energy supply capacity	Number of different, or separate, electricity supply sources to the city each providing at least 5 percent of total energy supply capacity.		✓
	Electricity supply capacity as a percentage of peak electricity demand	Electricity supply capacity available to the city (numerator) divided by the city's monthly peak electricity demand averaged over the calendar year (denominator). The result shall be multiplied by 100 and expressed as the electricity supply capacity as a percentage of peak electricity demand.		✓

Environment and climate change	Magnitude of urban heat island effects (atmospheric)	Difference between mean daily air temperatures recorded simultaneously in one urban and one non-urban area, averaged over a 12-month period. Urban area shall refer to a central part of the city on the order of several hectares, with close-set buildings, paved roads, heavy traffic flow, and high population density. Non-urban area shall refer to a peripheral part of the city on the order of several hectares, with few buildings and roads, abundant natural land cover, and low population density.		✓
	Percentage of natural areas within the city that have undergone ecological evaluation for their protective services	Total area of publicly owned natural areas within the city that have undergone ecological evaluation for their protective services (numerator) divided by the total area of all publicly owned natural areas in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of natural areas within the city that have undergone ecological evaluation for their protective services.		✓
	Territory undergoing ecosystem restoration as a percentage of total city area	Territory (in Km^2) undergoing ecosystem restoration within the city boundary (numerator) divided by the total city area in Km^2 (denominator). The result shall then be multiplied by 100 and expressed as a percentage.		✓
	Annual frequency of extreme rainfall events	Number of extreme rainfall events in a given year. Extreme rainfall events shall refer to precipitation events in which 50 mm or more of rain has fallen within the city over a 24-hour period.		✓
	Annual frequency of extreme heat events	Number of extreme heat events in a given year.		✓
	Annual frequency of extreme cold events	Number of extreme cold events in a given year.		✓
	Annual frequency of flood events	Number of flood events in the city in a given year.		✓
	Percentage of city land area covered by tree canopy	The percentage of city area covered by tree canopy shall be calculated as the city land area covered by tree canopy (numerator) divided by city's total land area (denominator). The result shall then be multiplied by 100 and expressed as the percentage of city land area covered by tree canopy. Tree canopy shall refer to the layered biomass of tree leaves, branches, and stems that obscures the underlying ground surface when viewed from above.		✓
Finance	Annual expenditure on upgrades and maintenance of city service assets as a percentage of total city budget	Annual total of all funds spent on maintenance and upgrades of assets for the provision of city services (numerator) divided by the total annual budget of the city (denominator). The result shall be multiplied by 100 and expressed as the expenditure on maintenance and upgrades of city service assets as a percentage of total city budget.		✓

	Annual expenditure on upgrades and maintenance of storm water infrastructure as a percentage of total city budget	Annual total of all funds spent on upgrades and maintenance of storm water physical and management infrastructure (numerator) divided by the total annual budget of the city (denominator). The result shall be multiplied by 100 and expressed as the expenditure on upgrades and maintenance of storm water infrastructure as a percentage of total city budget.		✓
	Annual expenditure allocated to ecosystem restoration in the city's territory as a percentage of total city budget	Total of all funds spent annually on ecosystem restoration assets for the specific purpose of enhancing the protective and other ecosystem services that enhance the resilience of the city (numerator) divided by the total city budget (denominator). The result shall be multiplied by 100 and expressed as the expenditure on ecosystem restoration as a percentage of total city capital budget.		✓
	Annual expenditure on green and blue infrastructure as a percentage of total city budget	Total of all funds spent on creating or enhancing green and blue infrastructure assets for the specific purpose of providing infrastructure-related services for the city (numerator) divided by the total city budget (denominator). The result shall be multiplied by 100 and expressed as the expenditure on green and blue infrastructure as a percentage of total city budget.		✓
	Annual expenditure on emergency management planning as a percentage of total city budget	Total annual expenditure on emergency management planning (numerator) divided by the total annual city budget (denominator). The result shall be multiplied by 100 and expressed as the annual expenditure on emergency management planning as a percentage of total city budget.		✓
	Annual expenditure on social and community services as a percentage of total city budget	Total annual expenditure on social and community services by the city (numerator) divided by the total annual budget of the city (denominator). The result shall be multiplied by 100 and expressed as the expenditure on social and community services as a percentage of total city budget.		✓
	Total allocation of disaster reserve funds as a percentage of total city budget	Total allocation of disaster reserve funds (numerator) divided by the total city budget (denominator). The result shall be multiplied by 100 and expressed as the total allocation of disaster reserve funds as a percentage of total city budget.		✓
Governance	Annual number of multi-stakeholder risk assessments	Number of multi-stakeholder risk assessments that have occurred in the previous 5 years.		✓
	Frequency with which disaster management plans are updated	Total number of city-wide disaster management plan updates that occurred in the previous 5 years (numerator) divided by five (denominator).		✓
	Percentage of city departments that are engaged in preparing for and responding to potential risks	Number of city departments that are actively engaged in preparing for and responding to potential risks (numerator) divided by the total number of city departments within the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of city departments that are engaged in preparing for and responding to potential risks. Consideration should be given to inclusion of third parties including businesses where these entities provide key services on		✓

		behalf of city departments.		
	Percentage of essential city services covered by a documented continuity plan	Total number of essential services that are covered by a documented continuity plan (numerator) divided by the total number of essential services provided in the city by government entities (denominator). The result shall be multiplied by 100 and expressed as the percentage of essential city services covered by a documented continuity plan.		✓
	Percentage of city electronic data with secure and remote back-up storage	Volume of city electronic data with secure and remote back-up storage (numerator) divided by the total volume of electronic city data (denominator). The result shall be multiplied by 100 and expressed as the percentage of city data with secure and remote back up storage.	✓	
	Percentage of public meetings dedicated to resilience in the city	Number of public meetings dedicated to resilience in the city (numerator) divided by the total number of public meetings in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of public meetings dedicated to resilience in the city.		✓
	Number of intergovernmental agreements dedicated to planning for shocks as percentage of total intergovernmental agreements	Number of intergovernmental agreements involving the city that are dedicated to planning for shocks (numerator) divided by the total number of intergovernmental agreements (denominator). The result shall be multiplied by 100 and expressed as the number of intergovernmental agreements dedicated to planning for shocks as a percentage of total intergovernmental agreements.		✓
Health	Average waiting time in hospital emergency rooms	Number of minutes that all registered patients in all emergency rooms across the city have waited to be admitted for treatment in a twelve-month period (numerator) divided by the total number of patients admitted for treatment in all emergency rooms in the same twelve-month period (denominator). The result shall be expressed as the average waiting time in hospital emergency rooms in minutes.		✓
	Percentage of health care facilities equipped with capabilities and medical supplies for acute needs	Total number of health care facilities equipped with capabilities and medical supplies for acute needs within the city (numerator) divided by the total number of health care facilities within the city (denominator). The result shall be multiplied by 100 and expressed as a percentage of health care facilities equipped with adequate capabilities and medical supplies for acute needs.		✓
	Percentage of hospitals equipped with back-up electricity supply	Number of hospitals equipped with back-up electricity supply (numerator) divided by the total number of hospitals in the city (denominator). The result shall then be multiplied by 100 and expressed as the percentage of health care facilities equipped with equipped with back-up electricity supply.		✓
	Percentage of population with basic health insurance	The total number of residents within the city with basic health insurance coverage (numerator) divided by the city's total population (denominator). The result shall		✓

		be multiplied by 100 and expressed as a percentage of population with basic health insurance.		
	Percentage of children that are fully immunized	Number of children aged 0 to 14 that have been fully immunized in the city (numerator) divided by the total number of children aged 0 to 14 in the city (denominator). The result shall then be multiplied by 100 and expressed as the percentage of children that are fully immunized.		✓
	Number of infectious disease outbreaks per year	Count of infectious disease outbreaks in a given year in the city.		✓
Housing	Capacity of designated emergency shelters per 100,000 population	Total capacity of all designated emergency shelters in the city (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the capacity of designated emergency shelters per 100,000 population.		✓
	Percentage of buildings structurally vulnerable to high-risk hazards	The total number of buildings in the city that are vulnerable to high-risk hazards (numerator) divided by the total number of buildings in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of buildings structurally vulnerable to high-risk hazards.		✓
	Percentage of residential buildings not in conformity with building codes and standards	Total number of residential buildings in the city not in conformity with building codes and standards (numerator) divided by the total number of residential buildings in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of residential buildings not in conformity with building codes and standards.		✓
	Percentage of damaged infrastructure that was "built back better" after a disaster	Total number and length of infrastructures within the city that were "built back better" after a disaster or extreme event (numerator) divided by the total number and length of infrastructures within the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of damaged infrastructure that was built back better after a disaster. This indicator can only be assessed in instances where a disaster or extreme event has impacted the city resulting in damage to buildings and structures.		✓
	Annual number of deaths in residential fires per 100,000 population	Annual number of deaths in residential fires (numerator) divided by one 100,000th of the city's total population. The result shall be expressed as the annual number of deaths in residential fires per 100,000 population.		✓
	Annual number of residential properties flooded as a percentage of total residential properties in the city	Annual number of residential properties that have flooded in the city (numerator) divided by the total number of residential properties in the city (denominator). The result shall then be multiplied by 100 and expressed as the annual number of residential properties flooded as a percentage of total residential properties in the city.		✓

	Percentage of residential properties located in high-risk zones	Number of residential properties located in high-risk zones within the city (numerator) divided by the total number of residential properties in the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of residential properties located in high-risk zones.		✓
Population and social conditions	Vulnerable population as a percentage of city population	Total number of vulnerable people within the city (numerator) divided by the city's total population (denominator). The result shall be multiplied by 100 and expressed as the vulnerable population as a percentage of total city population.		✓
	Percentage of population with access to social assistance programs	Number of people within the city with access to social assistance programs (numerator) divided by the total population of the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of population with access to social assistance programs.		✓
	Percentage of population at high risk from natural hazards	Number of people in the city at high-risk of exposure to natural hazards (numerator) divided by the total city population (denominator). The result shall be multiplied by 100 and expressed as the percentage of population at high risk from natural hazards.		✓
	Spatial segregation as measured by the Index of Dissimilarity based on income grouping	Spatial segregation as measured by the Index of Dissimilarity based on income grouping shall be calculated using the following formula, where is the number of people in income group g in city C and is the total population of city C. Higher levels of the Index of Dissimilarity reflect more even populations across the different income groups.		✓
	Percentage of neighborhoods with regular and open neighborhood association meetings	Number of neighborhoods in the city with regular and open neighborhood association meetings (numerator) divided by the total number of neighborhoods in the city (denominator). The result shall then be multiplied by 100 and expressed as the percentage of neighborhoods with regular, open neighborhood association meetings.		✓
	Annual percentage of the city population directly affected by natural hazards	Calculation: annual number of people evacuated, relocated, injured, or sickened due to natural hazards (numerator) divided by the total city population (denominator). The result shall be multiplied by 100 and expressed as the annual percentage of the city population directly affected by natural hazards.		✓
Recreation	Percentage of city population living within 0,5 km of public outdoor recreation space	Number of people living within 0.5 km of public outdoor recreation space (numerator) divided by the total city population (denominator). The result shall be multiplied by 100 and expressed as the percentage of city population living within 0,5 km of public outdoor recreation space.		✓
Safety	Percentage of city population covered by multi-hazard early warning system	Total number of people within the city covered by multi-hazard early warning systems (numerator) divided by the city's total population (denominator). The result shall be multiplied by 100 and expressed as a percentage of population covered by multi-hazard early warning systems.		✓

	Percentage of emergency responders that have received disaster response training	Total number of emergency responders that have received disaster response training in the city (numerator) divided by the total number of emergency responders in the city (denominator). The result shall be multiplied by 100 and expressed as a percentage of emergency responders that have received disaster response training.		✓
	Percentage of local hazard warnings issued by national agencies annually that are received in a timely fashion by the city	Number of local hazard warnings issued annually by national agencies that are received in a timely fashion by the city (numerator) divided by the annual total number of local hazard warnings issued by national agencies to the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of local hazard warnings issued by national agencies that are received in a timely fashion by the city.		✓
	Number of health and educational facilities in the city destroyed or damaged by natural hazards per 100,000 population	Total number of health and education facilities destroyed or damaged by natural hazards within the city (numerator) divided by one 100,000th of the city's population (denominator). The result shall be expressed as the number of health and educational facilities in the city destroyed or damaged by natural hazards per 100,000 population.		✓
Solid waste	Number of active waste disposal sites available for debris and rubble per Km^2	Number of active waste disposal sites in the city where debris and rubble can be disposed of (numerator) divided by the total land area of the city (Km^2) (denominator). The result shall then be expressed as the number of active waste disposal sites available for debris and rubble per Km^2.		✓
Telecommunication	Percentage of emergency responders in the city equipped with specialized communication technologies able to operate reliably during a disaster event	Number of emergency responders within the city having access to professional mode radio, satellite telephony, or privileged-access mobile communications networks (numerator) divided by the total number of emergency responders in the city (denominator). The result shall be multiplied by 100 and expressed as a Percentage of emergency responders in the city equipped with specialized communication technologies able to operate reliably during a disaster event.	✓	
	Percentage of city population that receives communications about emergency preparedness and disaster risk reduction	Number of people within the city that are reached by communications about emergency preparedness and disaster risk reduction (numerator) divided by the total city population (denominator). The result shall be multiplied by 100 and expressed as the percentage of city population that receives communications about emergency preparedness and disaster risk reduction	✓	
Transportation	Percentage of public transportation trips operating on schedule	Number of public transportation trips operating on schedule (numerator) divided by the total number of public transportation trips (denominator). The result shall be multiplied by 100 and expressed as the percentage of public transportation trips operating on schedule.		✓
	Number of evacuation routes	Total number of evacuation routes (numerator) divided by one 100,000th of the		✓

	available per 100,000 population	city's total population (denominator). The result shall be expressed as the number of evacuation routes available per 100,000 population.		
Urban / local agriculture and food security	Percentage of city population that can be served by city food reserves for 72 hours in an emergency	Number of people within the city that can be served by city food reserves for 72 hours (numerator) divided by the total city population (denominator). The result shall be multiplied by 100 and expressed as the percentage of population that could be served by intra-city food reserves for 72 hours.		✓
	Percentage of the city's population living more than one Km from a grocery store	Number of people in the city that live more than one Km from a grocery store (numerator) divided by the city's total population (denominator). The result shall be multiplied by 100 and expressed as the percentage of the city's population living more than one Km from a grocery store. A grocery store shall refer to a retail shop that primarily sells food.		✓
Urban planning	Percentage of city area covered by publicly available hazard maps	The area of city covered by publicly available hazard maps (numerator) divided by the total city area (denominator). The result shall be multiplied by 100 and expressed as the percentage of total city area covered by publicly available hazard maps.		✓
	Pervious land area as a percentage of total city land area	The area of pervious land within the city (in Km^2) (numerator) divided by the total city land area (in Km^2) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.		✓
	Percentage of city land area in high-risk zones where risk reduction measures have been implemented	The city land area in high-risk hazard zones where risk reduction measures have been implemented (Km^2) (numerator) divided by the total land area of the city (Km^2) (denominator). The result shall be multiplied by 100 and expressed as the percentage of city land area in high-risk zones where risk reduction measures have been implemented.		✓
	Percentage of city departments and utility services that integrate the results of risk assessment in their planning and investment	The number of city departments and utility services that integrate the results of risk assessments in their planning and investment (numerator) divided by the total number of city departments and utility services within the city (denominator). The result shall be multiplied by 100 and expressed as the percentage of city departments and utility services that integrate the results of risk assessment in their planning and investment.		✓
	Percentage of the city's wastewater treated through decentralized wastewater treatment	Total volume of the city's wastewater that has undergone decentralized treatment (numerator) divided by the total volume of wastewater produced and collected in the city (denominator). This result shall then be multiplied by 100 and expressed as the percentage of the city's wastewater treated via a decentralized wastewater treatment.		✓
Wastewater	Percentage of the city's wastewater treated through decentralized wastewater treatment	Total volume of the city's wastewater that has undergone decentralized treatment (numerator) divided by the total volume of wastewater produced and collected in the city (denominator). This result shall then be multiplied by 100 and expressed		✓

		as the percentage of the city's wastewater treated via a decentralized wastewater treatment.		
Water	Number of different sources providing at least 5 percent of total water supply capacity	Number of different, or separate, water supply sources to the city each providing at least 5 percent of water supply capacity. The 5 percent threshold is used by major international organizations such as the World Bank to ease calculations and to capture the major supply sources		✓
	Percentage of city population that can be supplied potable water by alternative methods for 72 hours	Number of people in the city that can be supplied potable water by alternative methods for 72 hours (numerator) divided by the total city population (denominator). The result shall be multiplied by 100 and expressed as the percentage of city population that can be supplied potable water by alternative methods for 72 hours.		✓

Table II-12: The Proposed Indicator Framework – Conceptual Structure, Potential Indicators, Sources & ICT-Relevance

Sub-domains	Key Issues	Potential Indicators	Smart Cities - Ranking of European Medium-Sized Cities	Smart Cities Wheel	City Resilience Framework - CRF	ITU-T 4901	ITU-T 4902	ITU-T 4903	UN 2030 Agenda Indication Framework	U4SSC Framework	ISO 37120	ISO 37122	ISO 37123	ICT-Related	Non ICT-Related
Economy	Innovation / Innovative spirit	Employment rate in knowledge-intensive sectors	X												X
		Patents per 100,000 inhabitants (or per inhabitant)	X					X		X	X				X
		ICT-related patents					X							X	
		R&D expenditure	X	X				X		X					X
		ICT-related R&D expenditure				X								X	
		R&D intensity in ICT				X								X	
		Investment intensity in ICT projects enabling SSC				X								X	
		Number of new opportunity-based startups		X											X
		Percentage of GDP invested in R&D in private sector		X											X
		Intangible investments as a proportion of GDP				X								X	
		Intangible investments in comparison with total investments				X								X	
		Innovation cities index		X										X	
		Application of Geographic Information System (GIS)				X								X	
		Application of big data				X								X	
		Number of officially registrated ENRoLL living labs		X											X
		Investments in ICT innovation					X							X	
	Entrepre-neurship	Self-employment rate	X		X										X
		Number of new businesses registered within the city in past year per 100,000 population	X												X

		Survival rate of new businesses per 100,000 population										X			X
		Number of businesses per 100,000 population									X				X
		Percentage of essential service providers that have a documented business continuity plan											X		X
		Percentage of large businesses (500+ employees) within the city that have developed business continuity plans in accordance with ISO 22301			X										X
		Application of computing platforms				X								X	
		Companies providing e-services				X		X						X	
		Percentage of registered SMEs the city has engaged with regarding business continuity in the last five years			X										X
		Small and Medium-sized Enterprises (SMEs)						X		X					X
		Percentage of total medium and large businesses (250+ employees) within the city that are a member of the chamber of commerce			X										X
	Finance	Debt service ratio (debt service expenditure as a percentage of a city’s own-source revenue)									X				X
		Capital spending as a percentage of total expenditures									X				X
		Own-source revenue as a percentage of total revenues									X				X
		Tax collected as a percentage of tax billed									X				X
		Gross operating budget per capita (USD)									X				X
		Gross capital budget per capita (USD)									X				X
		Annual number of approved and regulated small business-loans or micro-credit per 100,000 population			X										X
		Percentage value of loans / credit provided to female / minority owned businesses as a percentage of overall loans			X										X
		Average GDP per capita percentage change over last five years			X										X
		Average FDI (foreign direct investment) – attributable jobs over the last three years per 100,000 16–64-year-olds			X										X
		Annual amount of revenues collected from the sharing economy as a percentage of own-source revenue										X			X

	Employment	Employment rate						X							X
		Tourism industry employment						X		X					X
		Unemployment rate by sex, age and persons with disabilities	X		X				X	X	X				X
		Percentage of persons in full-time employment		X							X				X
		Employees belonging to ICT sector				X				X		X		X	
		Percentage of the labor force employed in occupations in the education and R&D sectors										X			X
		Proportion in part-time employment	X												X
		Percentage of getting a new job - flexibility	X												X
		Youth unemployment rate			X					X	X				X
		Creative industry employment	X	X			X	X							X
		Service industry employment					X								X
		Employment concentration											X		X
		Percentage of the workforce in informal employment											X		X
		Proportion of youth (aged 15-24 years) not in education, employment or training (NEETs)							X						X
		Average hourly compensation cost (wage + benefits) for an hour of labor (USD)			X										X
		Job security: Probability to become unemployed			X										X
		Percentage employment change from the last year			X										X
		Percentage employment per sector by broad industry group			X										X
	Economic image & trademarks	Inflation rate					X								X
		Annual inflation rate based on the average of the past five years									X				X
		Saving rate					X								X
		Average city GDP per capita minus national average GDP per capita expressed as a percentage			X										X
		City product per capita (USD)									X				X

		Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties									X				X
		Importance as knowledge centre (top research centres, top university, etc.)	X												X
		Importance as decision-making centre (HQ, etc.)	X												X
	Productivity	GDP per employed person	X												X
		Gross Regional Product per capita		X											X
		Labor productivity						X							X
		Improvement of industry productivity through ICT					X							X	
	Trade	Application of e-commerce transactions				X								X	
		Electronic and mobile payment						X						X	
		e-Commerce purchase ratio						X						X	
		Knowledge-intensive export / import					X	X							X
		Value of city exports as a percentage of city GDP			X										X
		Percentage GRP based on technology exports		X											X
	(Inter)national embeddedness	Companies with HQ in the city quoted on national stock market	X												X
		Air transport of passengers	X												X
		Air transport of freight	X												X
		Number of international congresses and fairs attendees		X											X
		Number of other cities to which this city has daily connections by bus			X										X
		Commercial air connectivity (number of non-stop commercial air destinations)									X				X
	Urban agriculture & food	Total urban agricultural area per 100,000 population									X				X
		Amount of food produced locally as a percentage of total food supplied to the city									X				X
		Local food production								X					X
		Annual percentage of municipal budget spent on urban agriculture initiatives										X			X

		Annual total collected municipal food waste sent to a processing facility for composting per capita (in tonnes)										X			X
		Percentage of the city’s land area covered by an online food-supplier mapping system										X		X	
		Percentage per capita food reserves within city (including supermarket agreements) for 72 hours (percentage population which could be served)			X										X
Transport & Technology Aspects	**Transport &Mobility**	Use of public transport					X								X
		Road traffic efficiency					X								X
		Road traffic efficiency – Travel time index						X		X					X
		Real-time public transport information						X		X				X	
		Share of Electric Vehicles (EVs)						X							X
		Traffic monitoring						X		X				X	
		Intersection control								X				X	
		Annual number of public transport trips per capita		X							X				X
		Number of personal automobiles per capita									X				X
		Percentage of commuters using a travel mode to work other than a personal vehicle			X						X				X
		Number of two-wheeled motorized vehicles per capita									X				X
		Km of bicycle paths and lanes per 100,000 population		X						X	X				X
		Transportation deaths per 100,000 population	X		X					X	X				X
		Percentage of population living within 0,5 Km of public transit running at least every 20 min during peak periods									X				X
		Average commute time									X				X
		Percentage of public transportation trips operating on schedule											X		X
		Number of shared bicycles per 100,000 inhabitants (or per capita)		X						X					X
		Number of shared vehicles per 100,000 inhabitants (or per capita)		X						X					X

		Percentage of non-motorized transport trips of total transport		X											X
		Percentage of total revenue from public transit obtained via unified smart card systems		X										X	
		Presence of demand-based pricing (e.g., congestion pricing, variably priced toll lanes, variably priced parking spaces)		X										X	
		Percentage of traffic lights connected to real time traffic management system		X										X	
		Percentage of public transit services that offer real time information to the public. 1 point for each transit category up to 5 total points (bus, regional train, metro, rapid transit system (e.g., BRT, Tram) and sharing models (e.g., bikesharing, carsharing)		X										X	
		Percentage of marked pedestrian crossings equipped with accessible pedestrian signals										X		X	
		Percentage of municipal budget allocated for the provision of mobility aids, devices and assistive technologies to citizens with special needs										X		X	
		Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities							X	X					X
		Availability of multimodal transit app with at least three services integrated		X										X	
		Pedestrian infrastructure						X		X					X
		Public transport network	X					X		X	X				X
		Number of electric vehicle charging stations per registered electric vehicle		X								X			X
		Satisfaction with access to public transport	X												X
		Satisfaction with quality of public transport	X												X
		Inter(national) accessibility	X												X
		Green mobility share (non-motorized individual traffic)	X												X
		Percentage of the city's bus fleet that is motor-driven										X			X

		Percentage of public transport routes with municipally provided and/or managed Internet connectivity for commuters										X		X	
		Percentage of roads conforming with autonomous driving systems										X		X	
		Percentage of vehicles registered in the city that are autonomous vehicles										X			X
		City area mapped by real-time interactive street maps as a percentage of the city's total land area										X		X	
		Percentage of traffic lights that are intelligent/smart				X						X		X	
		Percentage of public parking spaces equipped with real-time availability systems				X						X		X	
		Percentage of public parking spaces equipped with e-payment systems										X		X	
		Percentage of the city's public transport services covered by a unified payment system		X								X			X
		Percentage of public transport lines equipped with a publicly accessible real-time system										X		X	
		Number of bicycles available through municipally provided bicycle-sharing services per 100,000 population										X			X
		Percentage of vehicles registered in the city that are low-emission vehicles								X		X			X
		Number of users of sharing economy transportation per 100,000 population										X		X	
		Percentage of city streets and thoroughfares covered by real-time online traffic alerts and information										X		X	
		Availability of traffic monitoring using ICT				X								X	
		Availability of real-time traffic information				X								X	
		Gas system management using ICT				X								X	
		Availability of visualized real-time information regarding gas use				X								X	

		Availability of online bike/car sharing system				X								X	
		Use of real-time navigation				X								X	
		Transportation modal share								X					X
		Use of economical cars	X												X
		Average speed of road journeys from city centre to the city boundary (km per hour)			X										X
		Percentage of journeys undertaken by walking or cycling			X										X
		Average percentage of the city’s transport budget spent on maintenance and upgrade over the past five years			X										X
		Amount spent on transport in the last five years as percentage of overall city budget			X										X
		Availability of Internet access in households	X	X		X		X		X				X	
		Availability of computers or similar devices				X		X						X	
		Percentage of residents with smartphone access		X										X	
		Number of infrastructure components with installed sensors 1 point for each: traffic, public transit demand, parking, air quality, waste, H_2O, public lighting etc.		X										X	
		Number of Wi-Fi hotspots per Km^2		X										X	
	Technology	Percentage of the city population with access to sufficiently fast broadband										X		X	
		Percentage of city area under a white zone/dead spot/not covered by telecommunication connectivity										X		X	
		Availability of fixed broadband subscriptions				X								X	
		Fixed broadband subscriptions						X		X				X	
		Wireless broadband subscriptions per 100,000 inhabitants (or per 100 inhabitants)				X		X		X				X	
		Wireless broadband coverage								X				X	

		Availability of mobile-cellular telephones				X								X	
		Coverage rate of digital broadcasting network				X								X	
		Availability of ultra high-speed wireline connection				X								X	
		Availability of high-speed mobile broadband				X								X	
		Availability of Wi-Fi in public areas				X				X				X	
		Availability of smartphones and tablets				X								X	
		Quality of fixed broadband				X								X	
		Quality of mobile broadband				X								X	
		International Internet bandwidth				X								X	
		Number of Internet connections per 100,000 population (or per 100 inhabitants)			X						X			X	
		Number of mobile phone connections per 100,000 population									X			X	
		Percentage of commercial and residential users with internet download speed at least 2 Megabits/sec		X										X	
		Percentage of commercial and residential users with internet download speed at least 1 Gigabit/sec		X										X	
		Percentage of city electronic data with secure and remote back-up storage (See Tier standard of backup)			X								X	X	
		Number of media types used to alert people in an emergency			X									X	
		Percentage of government databases protected by a dynamic proactive IT security system			X									X	
		Percentage of infrastructure which relies on operational technology protected by a dynamic proactive IT security system			X									X	
Environment	**Environmental quality / Pollution**	EMF exposure								X					X
		Sunshine hours	X												X
		Green space share	X												X
		Fine particulate matter (PM2.5) concentration	X	X					X		X				X

		Particulate matter (PM10) concentration	X		X				X		X				X
		Mortality rate attributed to household and ambient air pollution							X						X
		Fatal chronic lower respiratory diseases per inhabitant	X												X
		Number of real-time remote air quality monitoring stations per Km^2										X		X	
		Air pollution						X		X					X
		Air pollution intensity					X								X
		Air pollution monitoring system						X						X	
		Application of ICT-based monitoring system for particles and toxic substances				X								X	
		Greenhouse Gas (GHG) emissions		X			X	X		X	X				X
		GHG emissions per sector per capita					X								X
		Exposure to noise – Noise pollution					X	X		X	X				X
		Soil pollution avoidance					X							X	
		Quality of city water resources					X								X
		ICT noise monitoring						X						X	
		Application of ICT-based noise monitoring				X								X	
		NO_2 (nitrogen dioxide) concentration									X				X
		SO_2 (sulfur dioxide) concentration									X				X
		O3 (ozone) concentration	X								X				X
		Magnitude of urban heat island effects (atmospheric)											X		X
		Annual frequency of extreme rainfall events											X		X
		Annual frequency of extreme heat events											X		X
		Annual frequency of extreme cold events											X		X
		Annual frequency of flood events											X		X
		Percentage of city land area covered by tree canopy											X		X
		Perception on environmental quality					X								X

	Environmental protection / Awareness	Individual efforts on protecting nature	X												X
		Opinion on nature protection	X												X
		Protected natural areas								X					X
		Percentage of areas designated for natural protection			X						X				X
		Territory undergoing ecosystem restoration as a percentage of total city area											X		X
		Percentage of natural areas within the city that have undergone ecological evaluation for their protective services			X								X		X
		Annual expenditure allocated to ecosystem restoration in the city's territory as a percentage of total city budget											X		X
		Pervious land area as a percentage of total city land area											X		X
		Number of years since assessment of the city's ecosystem assets / services			X										X
		Protected natural area						X							X
		Availability of EMF information				X		X							X
	Solid waste	Solid waste tratment						X		X					X
		Solid waste collection						X		X					X
		Percentage of city population with regular solid waste collection (residential)			X						X				X
		Total collected municipal solid waste per capita		X							X				X
		Percentage of the city's solid waste that is recycled		X			X				X				X
		Percentage of the city's solid waste that is disposed of in a sanitary landfill									X				X
		Percentage of the city's solid waste that is treated in energy-from-waste plants									X				X
		Percentage of the city's solid waste that is disposed of in an open dump									X				X
		Percentage of the city's solid waste that is disposed of by other means									X				X

		Percentage of the city’s solid waste that is biologically treated and used as compost or biogas									X				X
		Hazardous waste generation per capita (tones)									X				X
		Percentage of the city’s hazardous waste that is recycled									X				X
		Percentage of waste drop-off centres (containers) equipped with telemetering										X		X	
		Percentage of the city population that has a door-to-door garbage collection with an individual monitoring of household waste quantities										X		X	
		Percentage of total amount of waste in the city that is used to generate energy										X			X
		Percentage of total amount of plastic waste recycled in the city										X			X
		Percentage of public garbage bins that are sensor-enabled public garbage bins										X		X	
		Percentage of the city’s electrical and electronic waste that is recycled										X			X
		Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities							X						X
		Percentage of annual unsound waste disposal (as a percentage of total disposal)			X										X
		Number of different solid waste treatment or disposal plants processing at least 5% solid waste generated within the city (Number of sources)			X										X
		Waste generation rate per capita (municipal solid waste, Kg per capita per year)			X										X
		Percentage of defined medium- to long-term waste management service contracts e.g. Public Private Partnership and Public Private Community Partnership agreements (as a percentage of total waste service contracts)			X										X

		Number of active waste disposal sites available for debris and rubble per Km^2											X		X
	Wastewater	Wastewater treated						X	X	X					X
		Wastewater collection						X		X					X
		Percentage of city population served by wastewater collection									X				X
		Percentage of city's wastewater receiving centralized treatment									X				X
		Compliance rate of wastewater treatment									X				X
		Percentage of treated wastewater being reused										X			X
		Percentage of biosolids that are reused (dry matter mass)										X			X
		Energy derived from wastewater as a percentage of total energy consumption of the city										X			X
		Percentage of total amount of wastewater in the city that is used to generate energy										X			X
		Percentage of the wastewater pipeline network monitored by a real-time data-tracking sensor system										X		X	
		The number of years since the city's wastewater contingency plan was updated													X
		Percentage of the city's waste water that has received no treatment			X										X
		Annual percentage of wastewater system losses (due to storms or malfunction) prior to treatment and/or discharge to the environment			X										X
		Percentage of the city's wastewater treated through decentralized wastewater treatment											X		X
	Biodiversity	Native species monitoring						X							X
		Percentage change in number of native species			X						X				X
	Water management	Efficient use of water (use per GDP)	X												X
		Water saving in households						X							X

		Application of city water monitoring through ICT				X								X	
		Percentage of drinking water tracked by real-time, water quality monitoring station										X		X	
		Number of real-time environmental water quality monitoring stations per 100,000 population										X		X	
		Percentage of the city's water distribution network monitored by a smart water system				X		X		X		X		X	
		City fresh water sources monitored using ICT				X								X	
		Availability of smart water meters				X		X		X				X	
		Availability of visualized real-time information regarding water use				X								X	
		Total domestic water consumption per capita (litres/day)		X							X				X
		Total water consumption per capita (litres/day)			X			X		X	X				X
		Fresh water consumption								X					X
		Compliance rate of drinking water quality									X				X
		Average annual hours of water service interruptions per household			X						X				X
		Change in water-use efficiency over time							X						X
		Level of water stress: freshwater withdrawal as a proportion of available freshwater resources							X						X
		Percentage of water loss - Leakage in water supply system					X	X		X	X				X
		Annual expenditure on upgrades and maintenance of storm water infrastructure as a percentage of total city budget			X								X		X
		Number of different sources providing at least 5% of total water supply capacity			X								X		X
		Number of years the city's storm water (or other protective) infrastructure has been inspected			X										X

		How many years ahead does the city's water plan look (e.g., does it analyze the city's 10+ year needs?)			X										X
		Percentage of city population that can be supplied potable water by alternative methods for 72 hours during disruption			X								X		X
	Sewage / Drainage	Sewage system management using ICT				X								X	
		Drainage / storm water system management using ICT				X		X		X				X	
		Sewage system coverage					X								X
	Energy	Efficient use of electricity (use per GDP)	X												X
		Percentage of total end-use energy derived from renewable resources		X							X				X
		Availability of smart electricity meters				X		X		X				X	
		Electricity supply system management using ICT				X		X		X				X	
		Demand response penetration								X				X	
		Availability of visualized real-time information regarding electricity use				X								X	
		Renewable energy consumption					X	X		X					X
		Energy saving in households compared to a baseline					X								X
		Energy saving in households with energy saving installations						X							X
		Electricity consumption of public street lighting per Km of lighted street (kWh/year)					X				X				X
		Reliability of electricity supply system					X								X
		Electricity system outage frequency						X		X					X
		Electricity system outage time			X			X		X	X				X
		Electricity consumption						X		X					X
		Residential thermal energy consumption								X					X
		Total end-use energy consumption per capita (GJ/year)									X				X
		Percentage of city population with authorized electrical service (residential)			X						X				X

		Number of gas distribution service connections per 100,000 population (residential)									X				X
		Energy consumption of public buildings per year						X		X	X				X
		Heating degree days									X				X
		Cooling degree days									X				X
		Percentage of electrical and thermal energy produced from wastewater treatment, solid waste and other liquid waste treatment and other waste heat resources, as a share of the city's total energy mix for a given year										X			X
		Electrical and thermal energy (GJ) produced from wastewater treatment per capita per year										X			X
		Electrical and thermal energy (GJ) produced from solid waste or other liquid waste treatment per capita per year										X			X
		Percentage of the city's electricity that is produced using decentralized electricity production systems										X			X
		Storage capacity of the city's energy grid per total city energy consumption										X			X
		Percentage of street lighting managed by a light performance management system										X		X	
		Percentage of street lighting that has been refurbished and newly installed										X			X
		Percentage of public buildings requiring renovation/refurbishment										X			X
		Proportion of population with primary reliance on clean fuels and technology							X					X	
		Percentage of municipal grid meeting all requirements for smart grid (1. 2-way communication, 2. Automated control systems for addressing system outages, 3. Real-time information for customers, 4. Permites distributed generation, 5. Supports net metering)		X										X	

		Number of different electricity sources providing at least 5 % of total energy supply capacity											X		X
		Electricity supply capacity as a percentage of peak electricity demand											X		X
		Average percentage of household income spent on fuel and electricity by the poorest 20% of the population			X										X
		Number of days that city fuel supplies could maintain essential household functions (through alternative sources)			X										X
		How many years ahead does the city's electricity plan look (e.g., does it analyze the city’s 10+ year needs?)			X										X
		Number of different supply sources providing at least 5% of electricity generation capacity													X
		De-rated capacity margin: the amount of excess electricity supply above peak demand (expressed as a percentage)			X										X
		City electricity supply capacity as a percentage of total demand			X										X
People	**Lifelong Learning, Training & Level of Qualification**	Population qualified at level 5-6 of ISCED	X												X
		Percentage of people unemployed for more than six months who have access to a programme that is intended to improve their employment chances			X										X
		Percentage of city population with professional proficiency in more than one language	X									X			X
		Use of e-learning system				X		X						X	
		Application of e-learning in schools				X								X	
		Application of e-learning in academic studies				X								X	
		Number of public library book and e-book titles per 100,000 population										X			X
		Book loans per resident	X												X
		Participation in lifelong learning in percentage	X												X

		Participation in language courses	X												X
		Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex							X						X
		Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex							X						X
		Percentage of schools that teach emergency preparedness and disaster risk reduction											X		X
		Percentage of population trained in emergency preparedness and disaster risk reduction											X		X
		Percentage of the vulnerable population that has been engaged with emergency preparedness and disaster risk reduction activities											X		X
	Social & ethnic plurality	Immigration-friendly environment (attitude towards immigration)	X												X
		Percentage of city population that are non-citizens									X				X
		Percentage of population that are new immigrants	X								X				X
		Percentage of population that are foreign born	X	X							X				X
	Participation in public life	Participation in voluntary work	X												X
		Political activity of inhabitants	X												X
		Importance of politics for inhabitants	X												X
		Voter participation in last municipal election (as a percentage of registered voters)	X	X	X					X	X				X
		Number of registered voters as a percentage of the voting age population									X				X
		Percentage of respondents who felt a sense of pride in their neighborhood			X										X
		Percentage of neighborhoods with regular and open neighborhood association meetings											X		X
	ICT skills	Use of online city services					X							X	

		Use of Internet by city inhabitants				X								X	
		Existence of strategies, rules and regulations to enable ICT literacy among inhabitants				X								X	
		Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill							X					X	
		Percentage of municipal budget allocated for provision of programmes designated for bridging the digital divide										X		X	
		Proportion of individuals who own a mobile telephone, by sex							X					X	
Living	**Culture & sports**	Cinema attendance per inhabitant	X												X
		Museums visits per inhabitant	X												X
		Theatre attendance per inhabitant	X												X
		Connected libraries						X						X	
		Protected cultural heritage sites						X							X
		Cultural expenditure								X					X
		Percentage of municipal budget allocated to cultural and sporting facilities		X							X				X
		Annual number of cultural events (e.g., exhibitions, festivals, concerts) per 100,000 population									X				X
		Number of cultural institutions and sporting facilities per 100,000 population						X		X	X				X
		Availability of cultural resources online				X		X						X	
		Sporting facilities						X							X
		Availability of sporting facilities					X								X
		Interest in online access to cultural resources					X							X	
		Number of online bookings for cultural facilities per 100,000 population										X		X	
		Percentage of the city's cultural records that have been digitized										X		X	

		Number of months throughout the year that have a major, free public festival			X										X
		Percentage of city population that are active public library users										X			X
		Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)							X						X
	Health	In-patient hospital beds per 100,000 inhabitants (or per inhabitant)	X		X			X		X	X				X
		Number of doctors per 100,000 inhabitants (or per inhabitant)	X					X							X
		Number of physicians per 100,000 population			X					X	X				X
		Alcohol per capita consumption (aged 15 years and older) within a calendar year in litres of pure alcohol within a calendar year in litres of pure alcohol							X						X
		Satisfaction with quality of health system	X												X
		Life expectancy	X	X	X			X		X	X				X
		Maternal mortality			X			X		X					X
		Under age five mortality per 1.000 live births									X				X
		Number of nursing and midwifery personnel per 100,000 population									X				X
		Suicide rate per 100,000 population							X		X				X
		Percentage of city population that is overweight or obese - Body Mass Index (BMI)									X				X
		Percentage of the city’s population with an online unified health file accessible to health care providers		X								X		X	
		Annual number of medical appointments conducted remotely per 100,000 population										X		X	
		Percentage of the city population with access to real-time										X		X	

		public alert systems for air and water quality advisories													
		Use of electronic health records				X		X		X				X	
		Use of electronic medical records				X								X	
		Sharing of medical resources				X		X						X	
		Adoption of telemedicine				X		X						X	
		Compliance with WHO endorsed exposure guidelines				X		X						X	
		Healthy Life Years (HLY)					X								X
		Coverage of health insurance					X	X		X			X		X
		Percentage of health care facilities equipped with capabilities and medical supplies for acute needs											X		X
		Percentage of hospitals equipped with back-up electricity supply			X								X		X
		Drug-related mortality with drugs as primary cause of death per 100,000 population aged 15-64			X										X
		Premature (before age of 70) NCD mortality rate per 100,000 population			X										X
		Percentage of hospitals that have carried out disaster preparedness drills in the last year			X										X
		Number of paramedics per 100,000 population			X										X
		Percentage of city’s hospitals with back-up water supply to meet its needs for three days			X										X
		Number of infectious disease outbreaks per year											X		X
	Safety	Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population							X						X
		Damage to critical infrastructure and number of disruptions to basic services, attributed to disasters							X						X
		Proportion of persons victim of physical or sexual harassment, by sex, age, disability status and place of occurrence, in the previous 12 months							X						X

		Adoption and implementation by the local governments of disaster risk reduction strategies in line with national disaster risk reduction strategies and the Sendai Framework for Disaster Risk Reduction 2015-2030													X
		Death rate due to road traffic injuries							X						X
		Adoption of ICT for disaster management				X								X	
		Availability of ICT-based safety systems				X								X	
		Disaster and emergencies alert accuracy					X	X							X
		Information security and privacy protection						X						X	
		Information security of public services and systems				X								X	
		Child Online Protection (COP)				X		X						X	
		Existence of systems, rules and regulations to ensure privacy protection in public service				X								X	
		Population living in disaster prone areas								X					X
		Number of firefighters per 100,000 population			X					X	X				X
		Number of fire-related deaths per 100,000 population									X				X
		Natural disaster related deaths						X		X	X				X
		Disaster related economic losses						X		X					X
		Number of volunteer and part-time firefighters per 100,000 population									X				X
		Response time for emergency response services from initial call						X		X	X				X
		Number of police officers per 100,000 population			X					X	X				X
		Percentage of the police force which has undertaken disaster response training in the last five years			X										X
		Number of homicides per 100,000 population			X						X				X
		Crimes against property per 100,000 population									X				X
		Number of deaths caused by industrial accidents per 100,000 population									X				X
		Number of violent crimes against women per 100,000									X				X

		population													
		Percentage of the city area covered by digital surveillance cameras										X		X	
		Violent crime rate per 100,000 population	X	X						X					X
		Number of technologies in use to assist with crime prevention, 1 point for each of the following: livestreaming video cameras, taxi apps, predictive crime software technologies		X										X	
		Number of services integrated in a singular operations center leveraging real-time data. 1 point of each: emergency/disaster response, fire, police, weather, transit, air quality		X										X	
		Death rate by assault	X												X
		Satisfaction with personal safety	X												X
		Percentage of population which has access to disaster recovery mechanisms from shocks			X										X
		Number of search and rescue trained emergency responders with collapsed structures expertise per 100,000 population			X										X
		Hate crimes reported per 100,000 population			X										X
		Percentage of women and men who report feeling safe walking alone at night in the city or area where they live			X										X
		Homicide arrest rate			X										X
		Percentage of local severe weather warnings issued by national metrological agency which are received in a timely fashion by city emergency responders			X										X
		Percentage of government departments that have tested their own continuity arrangements in the last two years			X										X
		Percentage of population that have made a household or a community resilience plan			X										X

		Percentage of citizens intended to be evacuated, which were successfully evacuated in the last disaster drill or disaster event in the last 5 years			X										X
		Percentage of emergency preparedness publications provided in alternative languages											X		X
		Annual number of deaths in residential fires per 100,000 population											X		X
		Percentage of residential properties located in high-risk zones			X								X		X
		Percentage of city population covered by multi-hazard early warning system											X		X
		Percentage of emergency responders that have received disaster response training											X		X
		Percentage of local hazard warnings issued by national agencies annually that are received in a timely fashion by the city											X		X
		Number of health and educational facilities in the city destroyed or damaged by natural hazards per 100,000 population											X		X
		Percentage of city population that receives communications about emergency preparedness and disaster risk reduction											X	X	
		Percentage of population that could be served by city's access to stock of emergency shelters for 72 hours			X										X
		Percentage of city population that can be served by city food reserves for 72 hours in an emergency											X		X
		Capacity of designated emergency shelters per 100,000 population											X		X
		Percentage of city area covered by publicly available hazard maps											X		X
		Number of evacuation routes available per 100 000 population											X		X
		Number of reviews of city-wide emergency protocols undertaken in the past five years			X										X

		Annual percentage of the city population directly affected by natural hazards											X		X
		Share of housing fulfilling minimal standards	X												X
		Satisfaction with personal housing situation	X												X
		Housing expenditure						X		X					X
		Household ICT expenditures					X							X	
		Public building sustainability		X				X		X					X
		Total number of households									X				X
		Persons per unit									X				X
		Vacancy rate (residential)									X				X
		Living space (Km^2) per person	X								X				X
		Secondary residence rate									X				X
		Residential rental dwelling units as a percentage of total dwelling units									X				X
	Housing / Buildings	Percentage of commercial and industrial building with smart meters		X										X	
		Percentage of commercial buildings with building automation system		X										X	
		Percentage of commercial buildings with smart water meters		X										X	
		Percentage of buildings in the city with smart water meters										X		X	
		Percentage of households with smart energy meters		X								X		X	
		Percentage of households with smart water meters		X								X		X	
		Percentage of public buildings equipped for monitoring indoor air quality										X		X	
		Percentage of buildings built or refurbished within the last five years in conformity with green building principles										X			X
		Percentage of buildings in the city with smart energy meters										X		X	
		Automatic energy management in buildings				X								X	
		Integrated management in public buildings				X				X				X	
		Percentage of houses which have passed national safety			X										X

		standards													
		Percentage of buildings with insurance cover for high-risk hazards relevant to the city			X								X		X
		Estimated percentage of new buildings completed within the city in the last five years that conform to current building codes and standards			X										X
		Percentage of buildings within the city with planning permission records			X										X
		Percentage of households that have a smoke alarm			X									X	
		Percentage of buildings (or new development) constructed within the city in the past 10 years that were approved or otherwise authorized by the relevant city planning authorities			X										X
		Percentage of properties (residential and non-residential) with insurance coverage for high-risk hazards											X		X
		Percentage of total insured value to total value at risk within the city											X		X
		Percentage of buildings structurally vulnerable to high-risk hazards											X		X
		Percentage of residential buildings not in conformity with building codes and standards											X		X
		Annual number of residential properties flooded as a percentage of total residential properties in the city											X		X
		Percentage of adults with higher education as a percentage of total population aged 16-64			X										X
		Student per inhabitant	X												X
	Education	Satisfaction with access to educational system	X												X
		Satisfaction with quality of educational system	X												X
		Number of computers, laptops, tablets or other digital learning devices available per 1.000 students										X		X	

		Number of science, technology, engineering and mathematics (STEM) higher education degrees per 100,000 population										X		X	
		Students ICT availability					X	X		X				X	
		Adult literacy rate			X			X		X					X
		Higher education ratio						X							X
		Percentage of female school-aged population enrolled in schools									X				X
		Percentage of students completing primary education: survival rate			X						X				X
		Percentage of students completing secondary education: survival rate		X							X				X
		Primary education student-teacher ratio									X				X
		School enrollment						X		X	X				X
		Number of higher education degrees per 100,000 population		X						X	X				X
		Number of university students per 100,000 population									X				X
		Educational disruption											X		X
	Social cohesion / Inclusion	Perception on personal risk of poverty	X												X
		Perception on social inclusion					X								X
		Percentage of city population living below the international poverty line	X								X				X
		Percentage of city population living below the national poverty line by sex and age			X				X	X	X				X
		Opportunities for people with special needs						X							X
		Gender income equity					X	X	X	X					X
		Income distribution - Gini coefficient of inequality		X			X	X		X	X				X
		Number of homeless per 100,000 population			X						X				X
		Percentage of city population living in inadequate housing									X				X
		Percentage of population living in affordable housing									X				X
		Percentage of households that exist without registered legal titles									X				X

		Informal settlements						X	X	X					X
		Percentage of public buildings that are accessible by persons with special needs										X			X
		Percentage of inhabitants with housing deficiency in any of the following five areas (potable water, sanitation, overcrowding, deficient material quality, or lacking electricity		X											X
		Proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions							X						X
		Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable							X						X
		Proportion of population living in households with access to basic services							X						X
		Proportion of population using safely managed drinking water services							X						X
		Percentage of children living outside of the care of a responsible adult			X										X
		Percentage of people who responded that they know the names of their immediate neighbors			X										X
		Women as a percentage of total elected to city-level office	X		X						X				X
		Percentage of people taken into police custody who have the option of a lawyer made available to them before questioning			X										X
		Vulnerable population as a percentage of city population											X		X
		Percentage of population with access to social assistance programs											X		X
		Percentage of population at high risk from natural hazards											X		X
		Percentage of local businesses with female / minority owner			X										X

		Spatial segregation as measured by the Index of Dissimilarity based on income grouping										X		X
	Quality of life / Well-being	Access to electricity						X		X					X
		Percentage of city population with potable water supply service									X				X
		Potable water supply								X					X
		Basic water supply								X					X
		Percentage of city population with sustainable access to an improved water source						X			X				X
		Percentage of population that has access to safe and reliable water			X										X
		Percentage of population with access to improved sanitation			X						X				X
		Household improved sanitation						X							X
		Household sanitation								X					X
		Quality of drinking water						X		X					X
		Quality of piped water					X								X
		Green area per 100,000 population		X						X	X				X
		Green areas surface					X								X
		Green areas and public spaces						X							X
		Green area accessibility								X					X
		Number of trees per 100,000 population									X				X
		Basic service proximity									X				X
		Jobs-housing ratio									X				X
		Population density (per Km^2)		X							X				X
		Percentage of the city population living in medium-to-high population densities										X			X
		Built-up density									X				X
		Square meters of public indoor recreation space per capita									X				X

		Square meters of public outdoor recreation space per capita									X				X
		Percentage of public recreation services that can be booked online										X		X	
		Annual population change									X				X
		Population demographics									X				X
		Ratio of land consumption rate to population growth rate							X						X
		Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities							X						X
		Recreational facilities								X					X
		Mercer ranking in most recent quality of life survey		X											X
		Percentage of city population undernourished									X				X
		Percentage of malnourished children under five as a percentage of all citizens under five			X										X
		Family benefits public spending as a percentage of total city GDP			X										X
		Percentage green, open space increase or decrease over the past five years			X										X
		Average $ per $10,000 of total annual expenditure of city sanitation provider(s) spent on strategic, long-term (10+ years) planning activities			X										X
		Average household income (USD)									X				X
		Percentage of city population living within 0,5 Km of public outdoor recreation space											X		X
		Areal size of informal settlements as a percentage of city area			X						X				X
Governance	**Participation in decision making / Active citizens**	City representatives per resident	X												X
		Number of civic engagement activities offered by the municipality last year		X											X
		Availability of online city information and feedback mechanisms				X								X	

		Annual number of citizens engaged in the planning process per 100,000 population										X			X
		Online civic engagement				X								X	
		Presence of a direct participation structure of civil society in urban planning and management that operate regularly and democratically							X						X
		Public participation						X							X
		Proportion of corporate charitable giving within community as a percentage of city GDP			X										X
		Number of charities operating in the city per 100,000 population			X										X
		Percentage of major projects within the last year which included private sector consultation			X										X
		Percentage of city government major policy and plan changes within the past year sent out to public consultation			X										X
		Percentage of planning applications submitted to the city during the past five years on which emergency services agencies have been consulted			X										X
		Number of times the five most significant hazards identified in the city's local risk profile have been assessed by multi-stakeholders in the last five years?			X										X
		Number of times multi-stakeholder emergency responders meet and undertake joint activities (e.g., exercises, risk assessment, plan reviews) per year			X										X
		Percentage of public meetings dedicated to resilience in the city											X		X
		Percentage of city departments that are engaged in preparing for and responding to potential risks											X		X
	Public social services &	Child care availability	X							X					X
		Satisfaction with quality of schools	X												X

	Budgeting	Existence of electronic benefit payments (e.g., social security) to citizens		X										X	
		Existence of official citywide privacy policy to protect confidential citizen data		X											X
		Open data		X				X		X				X	
		Public sector e-Procurement								X				X	
		e-Public services adoption						X						X	
		Percentage of service contracts providing city services which contain an open data policy										X		X	
		Percentage of payments to the city that are paid electronically based on electronic invoices										X		X	
		Annual number of online visits to the municipal open data portal per 100,000 population										X		X	
		Percentage of city services accessible and that can be requested online		X		X				X		X		X	
		Average response time to inquiries made through the city’s non-emergency inquiry system (days)										X			X
		Average downtime of the city’s IT infrastructure										X		X	
		Percentage of the city area covered by municipally provided Internet connectivity										X		X	
		Percentage of building permits submitted through an electronic submission system										X		X	
		Average time for building permit approval (days)										X			X
		Number of mobile applications available based on open data		X										X	
		Use of social media by the public sector				X								X	
		Availability of electronic and mobile payment platforms				X								X	
		Online support for new city inhabitants				X								X	
		Application of services to support persons with specific needs				X								X	

		Existence of strategy, rules and regulations to enable the use of public data				X									X
		Expenditure of the municipal per resident in PPS	X												X
		Number of mechanisms in place to support local, small- and medium-sized businesses following a disaster			X										X
		Weeks between a small claims case (less than £10,000 / $15,500) being submitted to court and hearing (expressed in weeks)			X										X
		Emergency planning budget as a percentage of total city budget			X										X
		Number of times the emergency response centre capability has been tested (and successfully passed) in the last five years (for real or scenario)													X
		Annual expenditure on upgrades and maintenance of city service assets as a percentage of total city budget											X		X
		Annual expenditure on social and community services as a percentage of total city budget											X		X
		Total allocation of disaster reserve funds as a percentage of total city budget											X		X
		Annual expenditure on green and blue infrastructure as a percentage of total city budget											X		X
	Urban planning	Urban development and spatial planning						X		X					X
		Frequency with which disaster management plans are updated											X		X
		Percentage of essential city services covered by a documented continuity plan											X		X
		Annual expenditure on emergency management planning as a percentage of total city budget											X		X
		Percentage of city land area in high-risk zones where risk reduction measures have been implemented											X		X

		Percentage of damaged infrastructure that was “built back better” after a disaster											X		X
		Adoption of a consistent planning approval process with respect to EMF				X		X							X
		Number of years since oldest current building code was reviewed			X										X
		Number of years since city economic asset assessment (public and private)			X										X
		Percentage of city area for which a comprehensive exposure and vulnerability assessment has been undertaken within the past five years			X										X
		Years since the city’s climate change strategic plan was updated			X										X
		Number of years since the last city-wide review of the adequacy of the city’s protective infrastructure assets			X										X
		Number of years since last citywide critical asset assessment			X										X
		Number of years since the city evacuation plan was updated			X										X
		Number of years since city hazard maps have been updated			X										X
		Percentage of major city plans published in the last year that incorporate consultation with communities			X										X
		Percentage of census data available for planning			X										X
		Number of years validity of population projections			X										X
		Percentage of current land use and zoning plans that have been subject to a formal consultation process			X										X
		Percentage of current land use and zoning plans that have been subject to a formal consultation process with utility providers and transport agencies			X										X
		Percentage of current land use and zoning plans that have been subject to a formal consultation process with minority communities affected by the development			X										X

		Percentage of high-risk areas within the city where development is restricted or prohibited under planning guidelines			X										X
		Number of years since the city plan was updated			X										X
		Resilience plans		X				X		X					X
	Transparent governance	Satisfaction with transparency of bureaucracy	X												X
		Number of convictions for corruption and/or bribery by city officials per 100,000 population									X				X
		Proportion of population who believe decision making is inclusive and responsive, by sex, age, disability and population group							X						X
		Annual number of multi-stakeholder risk assessments											X		X
		Percentage of emergency responders in the city equipped with specialized communication technologies able to operate reliably during a disaster event											X	X	
		Percentage of city departments and utility services that integrate the results of risk assessment in their planning and investment											X		X
		Percentage of local major local government contracts and tenders (of more than $15.500) made public			X										X
		Proportion of city residents that agree corruption is somewhat or very common			X										X
		Percentage of emergency responders with arrangements which enable them to communicate in an emergency [e.g., MTPAS (UK), satellite phones, airwaves etc.]			X									X	
		Number of training and knowledge sharing agreements with international networks			X										X
		Percentage of non-sensitive city government documentation and data sets that are publicly available			X										X

		Percentage of major policy / regulatory decisions made within the last year that were the product of city-upwards, downwards (regional, national) government consultation			X										X
		Percentage of major policy / regulatory decisions made within the last year that were the product of cross-departmental government consultation			X										X
		Number of times the city's multi-stakeholder emergency management strategy has been tested in the last five years			X										X
		Satisfaction with fight against corruption	X												X

SHORT CURRICULUM VITAE

Maria Panagiotopoulou holds a Diploma in Rural and Surveying Engineering (2012) from National Technical University of Athens (NTUA). She also holds a Master of Science in Geoinformatics (NTUA, 2018). She has carried out her Doctoral Dissertation in NTUA and works on the fields of Smart, Sustainable, Resilient, and Inclusive Cities (S2RICs), public participation, and knowledge representation. She has participated in several national and international conferences and has published her research work in numerous scientific international journals. Her research interests focus on: Geographical Information Systems (GIS), WebGIS, Spatial Analysis, e-Planning, Sustainable Development and Spatial Planning, Urban / Regional Planning and Policy, Foresight Methodologies (Scenario Analysis), Evaluation in Spatial Planning, Multicriteria Analysis, Smart Cities and Communities, Participatory Approaches, Geographic Knowledge Representation, Geographic Ontologies.