National Technical University of Athens
School of Rural and Surveying Engineering
Department of Topography - Cadastre

Legal Requirements for Real Property Stratification

DOCTORAL DISSERTATION

for the title of Doctor of Philosophy in Engineering submitted in the School of Rural & Surveying Engineering, National Technical University of Athens

Dimitrios Kitsakis

Diploma in Rural & Surveying Engineering N.T.U.A.

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November 2019

Εθνικό Μετσόβιο Πολυτεχνείο
Σχολή Αγρονόμων Τοπογράφων Μηχανικών
Τομέας Τοπογραφίας - Κτηματολόγιο

Νομικές Προϋποθεσεις για την Διαστρωμάτωση Πολυεπίπεδων Ιδιοκτησιακών Δικαιωμάτων

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

για τον Επιστημονικό Τίτλο του Διδάκτορα Μηχανικού υποβληθείσα στη
Σχολή Αγρονόμων & Τοπογράφων Μηχανικών του Εθνικού Μετσόβιου Πολυτεχνείου

Δημήτριος Κιτσάκης

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Νοέμβριος 2019

« Η έγκριση της διδακτορικής διατριβής από την Ανώτατη Σχολή Αγρονόμων και Τοπογράφων Μηχανικών του Ε.Μ. Πολυτεχνείου δεν υποδηλώνει αποδοχή των γνωμών του συγγραφέα (Ν. 5343/1932, Άρθρο 202) ».

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This research was funded by a scholarship awarded by the Special Account for Research Grants, National Technical University of Athens.

Acknowledgements

This thesis concludes a long period in School of Rural and Surveying Engineering in National Technical University of Athens, dating back to 2005, when I was admitted for graduate studies. The journey of working on a post-graduate degree in NTUA, started late in 2013 and gave me the opportunity to conduct in-depth scientific research, the honour to meet good friends and collaborate with excellent scientists. In this section I would like to express my sincere gratitude to all those who have contributed, in any way, to the fulfilling of this research.

Words are poor to express my gratitude to my supervisor, Professor Efi Dimopoulou, for her exceptional and tireless guidance, encouragement, advice and support, during all stages of my research. Her scientific and technical suggestions, along with her human touch, have allowed hard and constructive work in an enjoyable working environment.

Professor Lambros Kitsaras, has provided valuable insight, recommendations and remarks on the legal issues related to this research, as well as advice and encouragement. I would like to specially thank him for participating to my advisory committee, representing a different scientific field.

Professor Andreas Georgopoulos, has provided me with valuable advice on scientific issues, as well as on systematically organising this research. I would like to thank him for embracing my idea for this interdisciplinary research, and supporting it by introducing me to my supervisor.

The members of the examination committee, for their interest in my research and for agreeing to examine this thesis.

Jesper Paasch for introducing me to the legal working group on 3D Cadastres, his excellent collaboration and scientific advice.

Professor Peter van Oosterom, who has honoured me by assigining me the coordination of the “Legal Foundations” chapter of the “3D Cadastres Best Practices Publication”.

Professor Chryssy Potsiou, for our five year collaboration in the knowledge area of Cadastre.

Tassos Labropoulos, for his collaboration, encouragement and advice during the course of my research.

My dear friends and members of the “3D Campus” research group, Katerina Athanasiou, Eftychia Kalogianni, Eva Tsiliakou and Ioannis Pispidikis.

Professor Abbas Rajabifard, Mohsen Kalantari, Behnam Atazadeh and the whole research group in the Centre for Spatial Data Infrastructures and Land Administration at the University of Melbourne for inviting and hosting me in Melbourne, and for their flawless cooperation during my visit.

The teaching staff of Law School of the National and Kapodistrian University of Athens, for assisting my research in Property Law, Cadastre Law, Environmental Law, and Planning and Urban Planning Law.

The Special Account for Research Grants of National Technical University of Athens, for the financial support of my research.

The staff of the School of Rural and Surveying Engineering in National Technical University of Athens, as well as of the Law School of the National and Kapodistian University of Athens.

My friends, for believing to me and my work, for their encouragement and their support.

Finally, my parents Labrini and Odysseas, and my sister, Maria. All my life, they have offered me endless and unconditional love, unwavering support, encouragement and advice, while showing inexhaustible patience to my anxiety and absence. I owe them more than I could ever put in words. Without them, this work would have never been completed.

To all, my most heartfelt thanks.

Publications

Peer-reviewed journals

Kitsakis, D. and Dimopoulou, E. (2013) "3D Cadastres: Legal Approaches and Necessary Reforms", Survey Review, Volume 46, No 338, September/ October 2014, pp. 322-332

Dimopoulou, E., **Kitsakis D.**, and Tsiliakou E., 2015. "Investigating correlation between legal and physical property: possibilities and constraints." Proc. SPIE 9535, 3rd International Conference on Remote Sensing and Geoinformation of the Environment. International Society for Optics and Photonics, 2015.

Floros, G., Tsiliakou E., **Kitsakis, D.**, Pispidikis G. and Dimopoulou E, 2015. "Investigating Semantic Functionality of 3D Geometry for Land Administration". In Advances in 3D Geoinformation (pp. 247-264). Springer International Publishing.

Kitsakis, D., Apostolou, C. & Dimopoulou, E., 2016. "Three dimensional cadastre modelling of customary real property rights", Survey Review, DOI:10.1080/00396265.2016.1252518

Chatzigianni, D., **Kitsakis, D.** and Dimopoulou, E. (2016) "Investigation of disputes' resolving over ecclesiastical and monastic land property in Greece using cadastral and land use data", Geojournal, Vol. 81, No 1, DOI: 10.1007/s10708-016-9706-2

Paasch, J., Paulsson, J., Navratil, G., Vučić, N., **Kitsakis, D.**, Karabin, M. and El-Mekawy, M. (2016) "Building a Modern Cadastre: Legal issues in Describing Real Property in 3D", Geodetski Vestnik, Vol. 60, No 2, pp. 256-268, DOI: 10.15292/geodetski-vestnik.2016.02.256-268

Kitsakis, D., Tsiliakou, E., Labropoulos, T., and Dimopoulou, E. (2017) Procedural 3D Modelling for Traditional Settlements. The Case Study of Central Zagori, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W3, pp. 369-376, doi: 10.5194/isprs-archives-XLII-2-W3-369-2017

Kitsakis, D. and Dimopoulou, E. (2017) "Addressing Public Law Restrictions within 3D Cadastral Context", International Journal of GeoInformation, 6 (7), pp. 182

Kitsakis, D. and Papageorgaki, I. (2017) Towards 3D Modelling of Public Law Restrictions in water bodies, European Water 60 (2017), pp. 395-401

Pispidikis, I., Tsiliakou, E., **Kitsakis, D.**, Athanasiou, K., Kalogianni, E., Labropoulos, T. and Dimopoulou, E. (2018) Combining Methodological Tools for The Optimum 3d Modelling of NTUA Campus, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4/W6, 57-63, https://doi.org/10.5194/isprs-annals-IV-4-W6-57-2018, 2018.

Kitsakis, D., Kalantari, M., Rajabifard, A., Atazadeh, B. and Dimopoulou, E. (2019) "Exploring the 3rd dimension within public law restrictions: A case study of Victoria, Australia", Land Use Policy 85, pp. 195-206

Kitsakis, D., Dimopoulou, E. (In press). Assessing the environmental impact of 3D Public Law Restrictions, Land Use Policy

Karabin, M., **Kitsakis, D.**, Koeva, M., Navratil, G., Paasch, J., Paulsson, J., Vučić, N., Janečka, K., Lisec, A. (2019) Layer approach to ownership in 3D cadastre – a subway case (submitted for publication)

Kitsakis, **D.**, Pispidikis, I., Athanasiou, K., Kalogianni, E. and Dimopoulou, E. (2019) Investigating the use of 3D Modelling and Geovisualisation for social housing. FIG Commission 3 Annual Meeting and Workshop 2019, Cluj-Napoca, Romania

Peer-reviewed conference papers

Kitsakis, D. and Dimopoulou, E. (2014) "Contribution of Existing Documentation to 3D Cadastre", in Proc. of 4th International FIG 3D Cadastre Workshop, 09-11 November 2014, Dubai, United Arab Emirates

Kitsakis, D., Apostolou, A. and Dimopoulou, E. (2015) "3D Cadastre Modelling of Customary Real Property Rights", Joint Workshop FIG Commission 3 & Commision 7 and Annual Meeting, 16-20 November, St. Julians, Malta *[The paper was awarded Best Workshop Paper by the FIG Commission 3]*

Kitsakis, D., Paasch, J., Paulsson, J., Navratil, G., Vučić, N., Karabin, M., El-Mekawy, S. and Carneiro, A. (2016) "3D Real Property Legal Concepts and Cadastre - A Comparative Study of Selected Countries to Propose a Way Forward", in Proc. of 5th International FIG 3D Cadastre Workshop, 18-20 October 2016, Athens, Greece

Kitsakis, D. and Dimopoulou, E. (2016) "Possibilities of Integrating Public Law Restrictions to 3D Cadastres", in Proc. of 5th International FIG 3D Cadastre Workshop, 18-20 October 2016, Athens, Greece

Kitsakis, D. and Dimopoulou, E. (2018) Determining the "true" three-dimensional environmental impact of Public Law Restrictions, 6th International FIG 3D Cadastre Workshop, Delft, The Netherlands

Karabin, M., **Kitsakis, D.**, Koeva, M., Navratil, G., Paasch, J., Paulsson, J., Vučić, N., Janečka, K. and Lisec, A. (2018) Layer approach to ownership in 3D cadastre – a subway case, 6th International FIG 3D Cadastre Workshop, Delft, The Netherlands

Kitsakis, **D.**, Kalogianni, E., Dimopoulou, E. and van Oosterom, P. (2018) "Requirements for Standardised Representation of Public Law Restrictions Based on LADM." In FIG Commission 3 Workshop and Annual Meeting, Naples, Italy, 1–20.

Reports

Kitsakis, D., Paasch, J., Paulsson, J-., Navratil, G., Vučić, N., Karabin, M., El-Mekawy, S., Koeva, M., Janečka, K., Erba, D., Alberdi, R., Kalantari, M., Yang, Z., Pouliot, J., Roy, F., Montero, M. and Alvarado, A. (2018) "3D Cadastre Best

Practices Chapter 1: Legal Foundations", In v. Oosterom, P. (Ed.) Best Practices 3D Cadastres – Extended version, FIG Publication

Kitsakis, D., Paasch, J., Paulsson, J-., Navratil, G., Vučić, N., Karabin, M., El-Mekawy, S., Koeva, M., Janečka, K., Erba, D., Alberdi, R., Kalantari, M., Yang, Z., Pouliot, J., Roy, F., Montero, M. and Alvarado, A.. 2016. "3D Cadastres Best Practices : Legal Foundations." Short version, p.: 1–10.

Others

Kitsakis, **D**., Tsiliakou, E., Labropoulos, T. and Dimopoulou, E. (2016) "3D Modelling of traditional settlements of Central Zagori", 8th Interdisciplinary Interuniversity Conference of the NTUA and NTUA MIRC, 22-24 September 2016, Metsovon, Greece (in Greek).

Pispidikis, I., Tsiliakou, E., **Kitsakis, D.**, Athanasiou, K., Kalogianni, E., Labropoulos, T. and Dimopoulou, E. (2017) "Development of WebGIS platform for NTUA campus", 25th ArcGIS User Conference, Athens, 11-12 May 2017 (in Greek).

Pispidikis, I., Tsiliakou, E., **Kitsakis, D.**, Athanasiou, K., Kalogianni, E., Labropoulos, T. and Dimopoulou, E. (2017) Navigation in 3D virtual web environment – Implementation in SRSE NTUA, 5th Panhellenic Conference of Rural and Surveying Engineers, Athens, Greece, 14-15 October 2017 (in Greek).

Pispidikis, I., Tsiliakou, E., **Kitsakis, D.**, Athanasiou, K., Kalogianni, E., Labropoulos, T. and Dimopoulou, E. (2018) Development of a 3D web GIS application for NTUA Campus, 25th ArcGIS User Conference, Athens, 10-11 May 2017 (in Greek).

Abstract

This research focuses on the multiple stratification of real property, in the form of overlapping real property rights and Public Law Restrictions (PLRs), the legal instruments that are used to support vertical segmentation of land, their limitations and the legal amendments required for the operation of stratified land rights and volumetric real property units.

Interrelation between the legal and the spatial component of real property units is made, in terms of the powers that are assigned to right-holders through real property rights and of the spatial boundaries within which such powers can be exercised. Advance from "indivisible" ownership concepts, deriving from Roman principles on land ownership, to the "excision" of ownership of navigable air space or of underground space for mineral activities, as well as the assignment of legal powers to third parties through limited real rights, depicts the need of legal instruments that circumvent the absolute character and the indivisible content of real property ownership. Further dissociation of surface parcel ownership from that of over (or under) lying structures, or of imposing volumetric Rights, Restrictions or Responsibilities (RRRs) is required by the increased spatial needs of modern societies and community living. Existing legal instruments, such as servitudes (easements), rights of superficies, emphyteusis, composite ownership concepts, or special real property rights, face limitations when applying to modern cases of real property stratification, thus highlighting the need of "enhancing" property law and cadastre legislation to support the vertical segmentation of real property and the assignment of volumetric real property rights.

This thesis is structured in eight chapters, which respond to its research aim. First, the cases requiring real property stratification are identified, followed by studying of existing legal instruments used for real property stratification. Then, legal issues related to volumetric real property units are identified, analysed and compared, in order to evaluate existing concepts of real property stratification and propose legal amendments that address their limitations.

Chapter 2 presents characteristic cases of overlapping land rights at international level. Depending on each country's level of development, the abundance of land and urban planning priorities, simpler or more complex cases of overlapping rights can be identified. Such cases may range from composite ownership concepts, such as apartment ownership, overlapping and interlocking structures, infrastructures and networks, to rights deriving from customary tenure. Public Law Restrictions (PLRs), also fall within this field, constituting non-materialised legal volumes where restrictions are imposed.

The third chapter of this thesis deals with the legal framework that supports 3D RRRs on land. It starts by describing the different types of classifying legal systems. The different aspects of each type of classification are depicted, while the distinction between Civil and Common Law jurisdictions was considered to serve the purposes of this work, as it does not allow grouping heterogeneous legal systems, in terms of land tenure systems, cadastral infrastructure and cadastral legislation. Presentation of the main features of limited real property rights used for real property stratification follows. These include, within the context of Civil or Civil law based jurisdictions, servitudes (easements), usufruct, the right of superficies, emphyteusis, composite

ownership rights, as well as special property rights and objects. Within the context of Common law, their equivalent concepts, such as easements, life-estates and leasehold are also presented. Issues of delimitation of real property units and of their boundaries are also taken into account in this chapter.

Chapter 4, delves into the relation between physical and legal space. Given that right holders are allowed to exercise specific powers to a specific space, the relation between legal and physical space is fundamental to land administration systems and it is reflected on the structure of different land registration systems. Integration of legal and physical space is aimed through various approaches, including the introduction of land objects (denoting a piece of land where homogeneous conditions exist within its boundaries), as well as through standardised models (e.g. the Land Administration Domain Model and its proposed legal specialisation, the Legal Cadastral Domain Model), or exploitation of 3D modelling techniques, such as Building Information Modelling, or 3D city modelling standards (e.g. CityGML).

Chapter 5 emphasises on the legal issues related to stratification of real property and 3D Cadastre, within extensive research among legal provisions of different countries internationally, both of Civil and Common law legal tradition (also including jurisdictions of mixed legal tradition). Provision to include jurisdictions both of deed and title registration systems was made, along with different types of cadastre purposes (legal, fiscal and multipurpose cadastral systems). Examination of legal issues related to 3D cadastre internationally, concluded to the main concerns regarding 3D regulation and management of real property which include the definition of real property, the terminology used to describe its spatial extent, the relation between stratified and traditional real property objects, the distinction of 3D real property objects from those deriving from employing limited real property rights and, the use of 3D property to support both legal and physical space. Public Law Restrictions that pertain volumetric connotation are also examined in this chapter.

Following the presentation of the different approaches regarding real property stratification, as well as the legal instruments employed by different legal systems, chapter 6 compares aforementioned concepts and legal instruments. *Definition of land* pertains, most commonly, the earth and the space above and below it, while ownership of land may be subject to land use-based limitations (e.g. mining or aviation). In several jurisdictions, reference is made to specific height and depth levels of real property ownership, instead of indivisible ownership columns. This notion is also reflected on national definitions of traditional “land parcels”. In order to address the limitations of “indivisible” land parcel ownership columns, several jurisdictions have introduced *individual 3D real property units*, in terms of delimited volumes of real property (instead of an indivisible volume extending above and below a land parcel). Different types of 3D real property units are available to each jurisdiction, while vocabulary and content of 3D real property units depends on each country, state or province. *Relation between 3D real property with traditional land parcels* is regulated by generic (non-specialised) restrictions, the establishment of statutory implied easements, or specialised provisions. Each case promotes different principles, such as individual agreements, or community living. *Distinction between 3D real property units and property units deriving from limited real property rights* is required to highlight their different operation and context; the former are used to extend the capacities of traditional real property units by addressing complex cases of stratified real property rights, while the latter operate ancillary, either in by

"excising" powers from the right of ownership, or allowing specific types of land exploitation (e.g. customary real property units). Stratification of real property also pertains Public Law Restrictions and regulations. These are either explicitly defined in terms of height, depth and volume, or implied, by reference to physical, or even to non-geometrical, qualitative characteristics. Despite the abundance of Public Law Restrictions and their registration and mapping, such restrictions are imposed on (traditional) land parcel level, thus limiting exploitation capabilities of the land parcel volume as a whole. In several Common law jurisdictions, the concept of volumetric easements is considered to be applicable; however, the specific types of statutory easements inhibits the exploitation of volumetric easements for Public Law Restrictions with 3D spatial connotation.

In chapter 7, "best practices" for real property stratification are identified, emphasising on the 3D partition of real property both for Private and Public Law purposes. As regarding real property rights related to Private Law, emphasis is given to the following aspects: (i) facilitation of investments, (ii) overcoming difficulties with overlapping building situations, (iii) allow transactions between 3D objects, (iv) "compatibility" and relation between stratified and traditional real property units, and (v) distinction from other types of real property units. Although limited real property rights are better adopted to traditional real property units, they face significant limitations in creating distinct real property volumes in multiple spaces within the same land parcel footprint. Moreover, limited real property rights face limitations regarding allocation of ownership rights on stratified real property units (since such rights may only "excise" specific powers from the owner of the surface parcel and allocate them to the limited right-holder). On the other hand, 3D real property units provide better insight on real property situations on multiple levels by different right-holders, and allow for more efficient management of real property. Common law jurisdictions seem to be better adjusted to the concept of real property stratification; the estate system that applies in Common law jurisdictions, which vests ownership to the state or the crown, is closer to the allocation of real property rights on multiple space volumes, compared to the Roman principles that apply to Civil Law jurisdictions. This is also reflected on the provisions regarding stratified real property units in Civil and Common Law based jurisdictions. The former restrict the use of 3D property units for buildings or constructions, while the latter leave room for non-feasible legal spaces as well. 3D stratification of PLRs constitutes a best practice by itself, since Land Administration systems aim to present the full range of RRRs that apply on land. 3D PLRs serve within this purpose in two ways. First, they allocate the exact volume of space that is subject to a restriction, while, second, leave the rest of the space available to exploitation. Although PLRs with 3D connotation already exist, such restrictions apply to surface parcels as a whole, mainly in the form of land expropriation. This increases bureaucratic and procedural workload, while also retains significant volumes of "exploitable" space, unexploited.

Finally, chapter 8 concludes this work by discussing the findings of the previous chapters and responding to the research questions formulated to address the aim of this thesis, while also proposing further research fields.

Περίληψη

Η παρούσα διδακτορική διατριβή εστιάζει στα ζητήματα διαστρωμάτωσης της ιδιοκτησίας σε πολλαπλά επίπεδα, είτε με τη μορφή επικαλυπτόμενων, αυτοτελών ιδιοκτησιακών αντικειμένων, είτε με τη μορφή περιορισμών από διατάξεις του Δημοσίου Δικαίου, οι οποίοι επιβάλλονται στον τρισδιάστατο χώρο. Παράλληλα, εστιάζει στα νομικά εργαλεία τα οποία χρησιμοποιούνται για να επιτευχθεί ο διαχωρισμός της γης σε επιμέρους «όγκους» ιδιοκτησίας, στους περιορισμούς που προκύπτουν κατά την διαδικασία αυτή, καθώς και στις απαιτούμενες παρεμβάσεις στο νομικό πλαίσιο περί την έγγεια ιδιοκτησία, ώστε να υποστηριχθεί η θεσμοθέτηση και η λειτουργία «στρωματοποιημένων» ιδιοκτησιακών δικαιωμάτων και τρισδιάστατων ιδιοκτησιακών οντοτήτων.

Στο πεδίο της ακίνητης περιουσίας, η ιδιοκτησία χαρακτηρίζεται από τη νομική και την χωρική της συνιστώσα. Η πρώτη αφορά στην εξουσίαση του ακινήτου, δηλαδή στις δυνατότητες που έχει ο δικαιούχος για χρήση, κάρπωση και διάθεση ενός ακινήτου. Η δεύτερη συνιστώσα αφορά στον προσδιορισμό και την οριοθέτηση του χώρου εντός του οποίου μπορούν να ασκηθούν οι δυνάμεις που απορρέουν από τη νομική συνιστώσα. Προκειμένου να εξασφαλιστεί το κοινωνικό συμφέρον και να εκφραστεί η κοινωνική λειτουργία της ιδιοκτησίας, επιβάλλονται στην έγγεια ιδιοκτησία περιορισμοί, τόσο ως προς τη χωρική διάσταση, όσο και ως προς το περιεχόμενο του τρόπου εξουσίασής της, δημιουργώντας έτσι «όγκους» ιδιοκτησίας. Αυτό, ερχεται σε αντίθεση με την παραδοσιακή αντίληψη του δικαιώματος της κυριότητας, όπως αυτή διατυπώνεται μέσω των αρχών του βυζαντινορωμαϊκού δικαίου, βάσει της οποίας η έγγεια ιδιοκτησία περιλαμβάνει το σύνολο της αέριας στήλης πάνω της, το έδαφος κάτω από αυτή, καθώς και το σύνολο των επικειμένων της. Η αντίληψη αυτή αποτελεί ατομικιστική προσέγγιση, και η αναγνώριση της κοινωνικής διάστασης της ιδιοκτησίας ξεκίνησε με την «περικοπή» από το έυρος της ιδιοκτησίας του χώρου που χρησιμοποιείται για μεταλλευτική δραστηριότητα, καθώς και για την διέλευση των εναερίων μέσων. Στο πλαίσιο της κοινωνικής λειτουργίας της ιδιοκτησίας, εισήχθησαν εμπράγματα δικαιώματα τα οποία περιορίζουν τον άμεσο και απόλυτο χαρακτήρα της κυριότητας (περιορισμένα εμπράγματα δικαιώματα), παραχωρώντας συγκεκριμένες εξουσίες προς τρίτους. Παρ' όλα αυτά, τα χρησιμοποιούμενα νομικά εργαλεία, για παράδειγμα οι δουλείες, τς συστήματα διαιρεμένης ιδιοκτησίας, τα δικαιώματα επιφανείας και εμφύτευσης, και τα ειδικά ιδιοκτησιακά δικαιώματα, αντιμετωπίζουν περιορισμούς όταν καλούνται να χρησιμοποιηθούν σε περίπλοκες περιπτώσεις επικαλυπτόμενων ιδιοκτησιακών δικαιωμάτων σε σύνθετες υπόγειες ή υπέργειες κατασκευές, καθώς και στην επιβολή περιορισμών Δημοσίου Δικαίου (για παράδειγμα διατάξεις για την προστασία του περιβάλλοντος). Καταδεικνύεται λοιπόν η ανάγκη ενίσχυσης της νομοθεσίας που ρυθμίζει τόσο τα ζητήματα της έγγειας ιδιοκτησίας, όσο και της κτηματολογικής καταγραφής των δικαιωμάτων αυτών, ώστε να υποστηριχθεί ο διαχωρισμός της ιδιοκτησίας σε διακριτούς, τρισδιάστατους όγκους, αλλά και η επιβολή τρισδιάστατων ιδιοκτησιακών δικαιωμάτων.

Το περιεχόμενο της διατριβής αυτής διαρθρώνεται σε οκτώ κεφάλαια. Αρχικά, εντοπίζονται οι περιπτώσεις για τις οποίες απαιτείται «στρωματοποίηση» των ιδιοκτησιακών δικαιωμάτων, καθώς και τα νομικά εργαλεία τα οποία αξιοποιούνται από τις διάφορες δικαιοδοσίες διεθνώς για τον σκοπό αυτό. Ακολουθεί αναγνώριση και ανάλυση των νομικών ζητημάτων που ανακύπτουν ως προς την δημιουργία τρισδιάστατων ιδιοκτησιακών οντοτήτων, και σύγκριση των διαφορετικών προσεγγίσεων

που ακολουθούνται σε κάθε δικαιοδοσία, ώστε να αξιολογηθούν οι υπάρχουσες προσεγγίσεις και να εντοπιστούν πιθανές τροποποιήσεις στη νομοθεσία, οι οποίες να αντιμετωπίζουν τους περιορισμούς που ανακύπτουν. Πιο συγκεκριμένα:

Το κεφάλαιο 2 παρουσιάζει συνήθεις, χαρακτηριστικές περιπτώσεις επικαλυπτόμενων ιδιοκτησιακών δικαιωμάτων διεθνώς. Τέτοιες περιπτώσεις περιλαμβάνουν σύνθετες ή διαιρεμένες ιδιοκτησίες (π.χ. σύσταση οριζοντίων ιδιοκτησιών), κατασκευές που επικαλύπτονται ή συμπλέκονται, δίκτυα υπόγειων ή υπέργειων υποδομών, καθώς και δικαιώματα εθιμικού δικαίου. Η πολυπλοκότητα της κάθε περίπτωσης εξαρτάται από την διαθεσιμότητα γης, τις υποδομές, καθώς και τις προτεραιότητες που θέτει η κάθε χώρα ως προς τον πολεοδομικό και χωροταξικό της σχεδιασμό.

Στο κεφάλαιο 3 εξεταζεται, σε διεθνές επίπεδο, το νομικό πλαίσιο στο οποίο στηρίζεται η διαστρωμάτωση πολυεπίπεδων δικαιωμάτων, περιορισμών και υποχρεώσεων. Αρχικά, περιγράφονται οι διαφορετικοί τρόποι κατηγοριοποίησης των διαφορετικων δικαϊκών συστημάτων και τα χαρακτηριστικά κάθε τύπου κατηγοριοποίησης. Για τους σκοπούς της παρούσας μελέτης, κρίθηκε καταλληλότερη η διάκριση μεταξύ Αστικού και Κοινού Δικαίου, καθώς διατηρεί τον διακριτό χαρακτήρα κάθε δικαιϊκής οικογένειας όσον αφορά το καθεστώς έγγειας ιδιοκτησίας, καθώς και της κτηματολογικής νομοθεσίας. Στη συνέχεια του κεφαλαίου, ακολουθεί η παρουσίαση των κύριων χαρακτηριστικών των περιορισμένων εμπραγμάτων δικαιωμάτων τα οποία χρησμοποιούνται στη δημιουργία επικαλυπτόμενων ιδιοκτησιακών αντικειμένων. Στο πλαίσιο του Αστικού Δικαίου, εξετάζονται τα χαρακτηριστικά δικαιωμάτων όπως οι πραγματικές δουλείες, η προσωπική δουλεία της επικαρπίας, τα δικαιώματα επιφανείας και εμφύτευσης, τα συστήματα διαιρεμένης ιδιοκτησίας, καθώς και τα ειδικά ιδιοκτησιακά δικαιώματα, τα οποία στηρίζονται σε κανόνες του εθιμικού δικαίου κάθε δικαιοδοσίας. Παράλληλα, εξετάζονται και τα χαρακτηριστικά των αντίστοιχων δικαιωμάτων του Κοινού Δικαίου, αναγνωρίζοντας τις διαφορετικές αντιλήψεις των δύο αυτών νομικών οικογενειών σχετικά με την ιδιοκτησία της γης και τα δικαιώματα που παραχωρούνται επ' αυτής. Το κεφάλαιο αυτό λαμβάνει επίσης υπόψη ζητήματα οριοθέτησης των τρισδιάστατων ιδιοκτησιακών αντικειμένων τα οποία δημιουργούνται από τα προαναφερθέντα εμπράγματα δικαιώματα.

Το κεφάλαιο 4 εξετάζει τη σχέση μεταξύ του φυσικού χώρου (δηλαδή του πραγματικού χώρου που καλύπτει ένα κτίσμα ή μια κατασκευή) και του νομικού χώρου (του άυλου χώρου εντός του οποίου ασκείται ένα δικαίωμα ή επιβάλλεται μία υποχρέωση ή ένας περιορισμός). Η σχέση αυτή αποκτά ιδιαίτερη σημασία για τα συστήματα διαχείρισης γης, καθώς ο φυσικός και ο νομικός χώρος δεν ταυτίζονται. Στο πλαίσιο της διαχείρισης γης, πραγματοποιούνται προσπάθειες ενοποίησης των δύο αυτών χώρων μέσω της ανάπτυξης προτύπων διαχείρισης γης (π.χ. Land Administration Domain Model, Legal Cadastral Domain Model), προτύπων τρισδιάστατης μοντελοποίησης πόλης (π.χ. CityGML), τεχνολογία Building Information Modelling (BIM) ή μέσω της εισαγωγής αντικειμένων γης (land objects), δηλαδή τμημάτων γης εντός των ορίων των οποίων ισχύουν ομοιογενείς συνθήκες ορισμένες από το νόμο.

Τα νομικά ζητήματα τα οποία σχετίζονται με τη διαστρωμάτωση των ιδιοκτησιακών δικαιωμάτων μελετώνται στο κεφάλαιο 5 της διατριβής αυτής. Η μελέτη επεκτείνεται στις σχετικές διατάξεις σημαντικού εύρους χωρών διεθνώς, περιλαμβάνοντας δικαιοδοσίες που εντάσσονται στην οικογένεια του Αστικού και του Κοινού Δικαίου, καθώς και σε δικαιοδοσίες όπου επικρατούν μεικτά δικαιϊκά συστήματα. Οι διαφοροποίηση των συστημάτων καταγραφής γης τα οποία εφαρμόζονται σε κάθε

δικαιοδοσία (όπως το σύστημα καταγραφής πράξεων και το σύστημα καταγραφής τίτλων), ελήφθησαν υπόψη κατά την επιλογή των υπό μελέτη δικαιοδοσιών, καθώς και το πλήθος των διαφορετικών σκοπών ανάπτυξης κτηματολογικών συστημάτων (π.χ. δημοσιονομικό/φορολογικό, νομικό ή πολυδιάστατο κτηματολόγιο). Εξετάζοντας τα προαναφερθέντα ζητήματα, οι βασικοί προβληματισμοί ως προς το νομικό πλαίσιο το οποίο υποστηρίζει τη δημιουργία και τη διαχείριση τρισδιάστατων ιδιοκτησιακών δικαιωμάτων, συνοψίστηκαν στα ακόλουθα: (i) ορισμός και διατύπωση του «ακινήτου», (ii) χρησιμοποιούμενη ορολογία για την περιγραφή των χωρικών χαρακτηριστικών των ακινήτων, (iii) συσχέτιση μεταξύ των επικαλυπτόμενων στο χώρο ακινήτων και των σκινήτων που βασίζονται στη θεώρηση του αδιάσπαστου δικαιώματος της κυριότητας καθ' ύψος και τις εξαιρέσεις της (μέσω των περιορισμένων εμπραγμάτων δικαιωμάτων), (iv) τη διάκριση μεταξύ των τρισδιάστατων ιδιοκτησιακών οντοτήτων από περιπτώσεις διαστρωμάτωσης δικαιωμάτων που προκύπτουν από την εφαρμογή περιορισμένων εμπράγματων δικαιωμάτων και, (v) τη χρήση των τρισδιάστατων ιδιοκτησιακών αντικειμένων για την επιβολή δικαιωμάτων, περιορισμών και υποχρεώσεων, τόσο στην περίπτωση του φυσικού αλλά και του νομικού χώρου. Στο κεφάλαιο αυτό, εντάσσεται και η μελέτη των περιορισμών με τρισδιάστατα χαρακτηριστικά, οι οποίοι προκύπτουν από τις διατάξεις του Δημοσίου Δικαίου.

Ύστερα από την παρουσίαση των διαφορετικών προσεγγίσεων που ακολουθούνται για τη δημιουργία επικαλυπτόμενων ιδιοκτησιακών αντικειμένων, καθώς και των εμπράγματων δικαιωμάτων που χρησιμοποιούνται στις διαφορετικές δικαιοδοσίες, ακολουθεί η σύγκριση των διαφορετικών προσεγγίσεων. Ως προς τον ορισμό του κατακόρυφου εύρους της γης και του ακινήτου, σημειώνεται η επίδραση των βυζαντινορωμαϊκών αρχών (βάσει των οποίων περιλαμβάνεται ο χώρος πάνω και κάτω από ένα γεωτεμάχιο, καθώς και τα επικείμενά του), με συγκεκριμένους τύπους εξαιρέσεων, όπως οι πτήσεις των αεροσκαφών, ή η εξόρυξη μεταλλευμάτων και ορυκτών. Παρ'όλα αυτά, σημειώνεται πως διατάξεις οι οποίες επιτρέπουν τη δημιουργία και την επιβολή ιδιοκτησιακών δικαιωμάτων καθ' ύψος, συναντώνται σε σειρά δικαιοδοσιών διεθνώς. Στο πλαίσιο αυτό, εισήχθησαν μορφές ανεξάρτητων τρισδιάστατων ιδιοκτησιακών αντικειμένων, με τη μορφή σαφώς οριοθετημένων όγκων ιδιοκτησίας (αντίθετα προς την επικρατούσα προσέγγιση της ενιαίας και αδιάσπαστης ιδιοκτησιακής οντότητας της στήλης υπέρ και υπό ενός εδαφοτεμαχίου). Οι τύποι των τρισδιάστατων αυτών ιδιοκτησιακών όγκων, η χρησιμοποιούμενη ορολογία και το περιεχόμενό τους, διαφέρουν ανάλογα με τις ιδιαιτερότητες που χαρακτηρίζουν κάθε δικαιοδοσία. Ως προς τη σχέση μεταξύ των τρισδιάστατων ιδιοκτησιακών αντικειμένων με την παραδοσιακή θεώρηση των ακινήτων (ως αδιάσπαστες στήλες ιδιοκτησίας), παρατηρούνται τρεις διαφορετικές προσεγγίσεις, οι οποίες καθορίζονται από τις προτεραιότητες που θέτει κάθε νομικό σύστημα (π.χ. προώθηση προσωπικών συμφωνιών μεταξύ ιδιωτών, ή ρύθμιση μέσω γενικότερων διατάξεων στο πλαίσιο της προώθησης της κοινωνικής συμβίωσης). Η πρώτη, περιορίζεται στην θέσπιση περιορισμών γενικού τύπου, προωθώντας την επίτευξη συμφωνιών μεταξύ των όμορων δικαιούχων. Η δεύτερη, προβλέπει τη ρύθμιση των σχέσων μεταξύ των γειτονικών ακινήτων μέσω ενός πλέγματος εξειδικευμένων κανόνων, εστιάζοντας στην προώθηση της κοινωνικής συμβίωσης. Τέλος, μια τρίτη, ενδιάμεση, προσέγγιση, προβλέπει τη θεσμική ρύθμιση συγκεκριμένων σχέσεων μεταξύ όμορων ακινήτων μέσω εξειδικευμένων διατάξεων (όπως, για παράδειγμα, περιπτώσεις φωτισμού-ηλιασμού, διέλευσης, και δομικής υποστήριξης ομόρων κατασκευών). Στόχος της προσέγγισης αυτής, αποτελεί η ικανοποίηση βασικών αναγκών της κοινωνικής συμβίωσης, ανεξαρτήτα από πιθανή διαφωνία μεταξύ των όμορων δικαιούχων σε ένα λιγότερο «ασφυκτικό» ρυθμιστικό πλαίσιο, το οποίο θα

βασίζονταν εξαντλητικά σε εξειδικευμένες διατάξεις. Η διάκριση μεταξύ των αυτοτελών, τρισδιάστατων ιδιοκτησιακών αντικειμένων από αυτά τα οποία προκύπτουν από τη σύσταση περιορισμένων εμπράγματων δικαιωμάτων, είναι απαραίτητη ώστε να τονιστεί η διαφοροποίηση στη χρήση και το περιεχόμενό τους. Τα μεν τρισδιάστατα ιδιοκτησιακά αντικείμενα, στοχεύουν στην αντιμετώπιση πολύπλοκων, επικαλυπτόμενων περιπτώσεων δικαιωματων, περιορισμών και υποχρεώσεων, διευρύνοντας τις δυνατότητες αξιοποίησης του χώρου σε σχέση με την παραδοσιακή θεώρηση της έννοιας του ακινήτου. Τα δε προερχόμενα από τη σύσταση περιορισμένων εμπραγμάτων δικαιωμάτων ιδιοκτησιακά αντικείμενα, βρίσκουν εφαρμογή είτε σε περιπτώσεις όπου απαιτείται ο περιορισμός ορισμένων εκφάνσεων του δικαιώματος της κυριότητας, είτε για να δώσουν τη δυνατοτητα εξειδικευμένων τρόπων αξιοποίησης των ακινήτων (π.χ. ειδικά ιδιοκτησιακά αντικείμενα, πραγματικές δουλείες). Στο πλαίσιο της διαστρωμάτωσης της ιδιοκτησίας εντάσσονται επίσης και οι περιορισμοί οι οποίοι προκύπτουν από τις διατάξεις του Δημοσίου Δικαίου. Αυτοί μπορεί να διατυπώνονται ρητά ως προς συγκεκριμένα τρισδιάστατα χατακτηριστικά (όπως το ύψος, το βάθος ή ο όγκος), είτε ως προς φυσικά χαρακτηριστικά, ποσοτικά ή ποιοτικά, χωρίς άμεση αντιστοιχία σε κάποιο γεωμετρικό μέγεθος. Παρά τον σημαντικό, και συνεχώς αυξανόμενο, αριθμό περιορισμών Δημοσίου Δικαίου με χωρικά χαρακτηριστικά, οι περιορισμοί αυτοί διατυπώνονται και επιβάλλονται με βάση την παραδοσιακή θεώρηση της γης και του ακινήτου (δηλαδή ως «αδιάσπαστη» οντότητα καθ' υψος και βάθος), περιορίζοντας έτσι τις δυνατότητες αξιοποίησης ή επιβολής περιορισμών σε συγκεκριμένους όγκους ιδιοκτησίας. Ορισμένες δικαιοδοσίες του Κοινού Δικαίου προβλέπουν την επιβολή περιορισμών με τρισδιάστατα χαρακτηριστικά, υπό την μορφή «ογκομετρικών δουλειών» (volumetric easements). Παρ''ολα αυτά, το πεδίο εφαρμογής του δικαιώματος αυτού είναι σαφώς οριοθετημένο και δεν προβλέπει την εφαρμογή του στις περιπτώσεις περιορισμών Δημοσίου Δικαίου με τρισδιάστατα χαρακτηριστικά.

Στο κεφάλαιο 7, αναζητούνται οι βέλτιστες πρακτικές κατακόρυφης διαστρωμάτωσης της έγγειας ιδιοκτησίας, για την εξυπηρέτηση των σκοπών τόσο του Ιδιωτικού όσο και του Δημοσίου Δικαίου. Αναφορικά με το πρώτο, έμφαση δίνεται στα ακόλουθα: (i) τη διευκόλυνση της επενδυτικής δραστηριότητας, (ii) την αντιμετώπιση περίπλοκων περιπτώσεων ιδιοκτησιακών δικαιωμάτων σε επικαλυπτόμενες κατασκευές, (iii) τη διευκόλυνση των συναλλαγών τρισδιάστατων ιδιοκτησιακών αντικειμένων, (iv) την εξασφάλιση «συμβατότητας» μεταξύ των διαφορετικών τύπων ιδιοκτησιακών αντικειμένων, και (v) την σαφή διάκριση, ως προς τη χρήση και το περιεχόμενο, μεταξύ των διαφορετικών μορφών ιδιοκτησιακών αντικειμένων. Όπως είναι λογικό, τα περιορισμένα εμπράγματα δικαιώματα είναι πλήρως προσαρμοσμένα στην παραδοσιακή θεώρηση της έγγειας ιδιοκτησίας, υστερούν όμως σημαντικά στις περιπτώσεις όπου απαιτείται διαστρωμάτωση του χώρου σε πολλαπλά επίπεδα, εντός του ίδιου εδαφοτεμαχίου. Επιπρόσθετα, αντιμετωπίζουν σημαντικούς περιορισμούς όσον αφορά στην εκχώρηση πλήρους κυριότητας σε συγκεκριμένο όγκο εντός ορισμένης ιδιοκτησίας (καθώς η επιβολή ενός περιορισμένου εμπράγματου δικαιώματος επιτρέπει μόνο τον περιορισμό συγκεκριμένων ενεργειών από το δικαίωμα της κυριότητας του εδαφοτεμαχίου, και την εκχώρησή τους στον δικαιούχο του αντίστοιχου περιορισμένου εμπράγματου δικαιώματος). Αντίθετα, οι τρισδιάστατες κτηματολογικές οντότητες, παρέχουν πληρέστερη εικόνα των ιδιοκτησιών οι οποίες βρίσκονται σε διαφορετικά επίπεδα, ενώ επιτρέπουν την αποτελεσματικότερη αξιοποίηση του χώρου. Οι διατάξεις που ρυθμίζουν την έγγεια ιδιοκτησία στα συστήματα τα οποία στηρίζονται στο Κοινό Δίκαιο, παρουσιάζονται περισσότερο συμβατά προς την διαστρωμάτωση των ιδιοκτησιακών δικαιωμάτων σε πολλαπλά επίπεδα. Εξάλλου, ο διαχωρισμός της

πλήρους κυριότητας (η οποία τελεί αποκλειστικά υπό το κράτος ή τον μονάρχη), και η εκχώρηση συγκεκριμένων επιπέδων εξουσίασης ενός ακινήτου σε ιδιώτες για ορισμένη χρονική διάρκεια, τα οποία προβλέπονται στις δικαιοδοσίες που διέπονται από τις αρχές του Κοινού Δικαίου, προσεγγίζουν περισσότερο τον διαχωρισμό της ιδιοκτησίας σε πολλαπλά επίπεδα σε σχέση με τις βυζαντινορωμαϊκές αρχές οι οποίες ρυθμίζουν το εύρος και το περιεχόμενο του δικαιώματος της κυριότητας, όπως ισχύουν στο Αστικό Δίκαιο. Η διαφοροποίηση των δύο αυτών προσεγγίσεων, αντικατοπτρίζεται και στο πνεύμα των διατάξεων που έχουν θεσπιστεί για την διαστρωμάτωση της ιδιοκτησίας στις δικαιοδοσίες που βασίζονται στις αρχές του Αστικού Δικαίου (π.χ. Νορβηγία, Σουηδία) και του Κοινού Δικαίου (π.χ. Αυστραλία, Καναδάς, Μαλαισία, Σιγκαπούρη). Οι μεν περιορίζουν το εύρος εφαρμογών των τρισδιάστατων ιδιοκτησιακών τους δικαιωμάτων και αντικειμένων σε κτήρια και κατασκευές, ενώ οι δε, παρέχουν τη δυνατότητα αξιοποίησής τους και σε νομικούς χώρους, που δεν αντιστοιχούν σε κάποιο φυσικό αντικείμενο ή τεχνητή κατασκευή. Η διατύπωση και χρήση τρισδιάστατων περιορισμών Δημοσίου Δικαίου αποτελεί, η ίδια, βέλτιστη πρακτική, δεδομένου ότι στόχος των Συστημάτων Διαχείρισης Γης αποτελεί η καταγραφή και η παρουσίαση του συνόλου των δικαιωμάτων, των περιορισμών και των υποχρεώσεων οι οποίοι επιβάλλονται πάνω στη γη. Ο ρόλος των τρισδιάστατων περιορισμών Δημοσίου Δικαίου σε αυτό τον στόχο είναι διττός καθώς, αφενός, επιτρέπουν την ακριβή οριοθέτηση του χώρου όπου επιβάλλεται μία ρύθμιση ή ένας περιορισμός εντός ενός εδαφοτεμαχίου, ενώ, αφετέρου, καθιστούν τον υπόλοιπο όγκο του εδαφοτεμαχίου διαθέσιμο προς αξιοποίηση. Παρά το γεγονός ότι περιπτώσεις περιορισμών Δημοσίου Δικαίου με τρισδιάστατα χαρακτηριστικά έχουν ήδη θεσπιστεί, οι περιορισμοί αυτοί ασκούνται με βάση τα αντίστοιχα εδαφοτεμάχια στο σύνολό τους (σαν «στήλη» εδάφους και αέρα κάτω και πάνω από την επιφάνεια του εδαφοτεμαχίου), κυρίως σε περιπτώσεις απαλλοτριώσεων, αυξάνοντας σημαντικά τον χρόνο και το κόστος της διαδικασίας.

Το 8ο κεφάλαιο, ολοκληρώνει την πορεία αυτής της ερευνητικής προσπάθειας παρουσιάζοντας τα συμπεράσματα που προέκυψαν, συσχετίζοντάς τα με τον ερευνητικό στόχο και τα ερευνητικά ερωτήματα που είχαν τεθεί. Παράλληλα, προτείνονται πεδία περαιτέρω έρευνας προς την κατεύθυνση της θέσπισης νομοθετικού πλαισίου ρύθμισης της διαστρωμάτωσης πολυεπίπεδων ιδιοκτησιακών αντικειμένων. Δεδομένου του «εθνικού» χαρακτήρα της νομοθεσίας και των ιδιαίτερων κοινωνικών, ιστορικών και πολιτιστικών και λοιπών παραγόντων που την διαμορφώνουν, δεν είναι δυνατή η δημιουργία ενός κοινού πλαισίου τρισδιάστατης κτηματολογικής νομοθεσίας διεθνώς, ούτε μπορεί να προταθεί μια κοινή «βέλτιστη λύση». Κάθε δικαιοδοσία καλείται να προσαρμόσει το νομικό της πλαίσιο με τέτοιο τρόπο ώστε να μπορέσει να αντιμετωπίσει τις συνεχώς αυξανόμενες ανάγκες της, τόσο όσον αφορά την ικανοποίηση των αναγκών της κοινωνικής συμβίωσης, όσο και την αγορά των ακινήτων της. Άλλωστε, το τρισδιάστατο Κτηματολόγιο δεν αποσκοπεί στην ανατροπή του υπάρχοντος νομικού πλαισίου, αλλά στην συμπλήρωσή του, με στόχο την επίτευξη των κοινωνικών, περιβαλλοντικών και οικονομικών επιδιώξεων.

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Abbreviations

Aerodrome Reference Point	ARP
African Charter on Human and Peoples' Rights	AfCHPR
Alberta Energy Regulator	AER
Alberta Geological Survey	AGS
American Convention on Human Rights	ACHR
Application Domain Extension	ADE
Basic Property Unit	BPU
Building Information Modelling	BIM
Bundes-Bodenschutzgesetz (Federal Soil Protection Act)	BBodSchG
Cadastral Unit	CU
Cadastre and Land Registry Knowledge Exchange Network	CLRKEN
Canadian Environmental Assessment Act	CEEA
Civil Code	CC
Common Data Environment	CDE
Computer Aided Design	CAD
Constructive Solid Geometry	CSG
Cultural Resource Information Systems	CRIS
Department of Environment, Land, Water and Planning	DEWLP
Department of Planning and Community Development	DPCD
Digital Cadastral Database	DCDB
Environmental (Socioeconomic) Impact Assessment	E(S)IA
Environmental Impact Statement	EIS
Environmental Protection Agency	EPA
Erbbaurecht-Verordnung	Erbbau-VO
European Convention on Human Rights	ECHR
European Union	EU
Federal Aviation Administration	FAA
Fédération Internationale de Géomètres	FIG
Geographic Information Systems	GIS
Industry Foundation Classes	IFC
International Civil Aviation Organization	ICAO
International Comparative Legal Guides	ICLG
Land Administration Domain Model	LADM
Land Registry Services	LRS
Landmarks Preservation Commission	LPC
Legal Cadastral Domain Model	LCDM
Legal Property Object	LPO
Level of Detail	LoD

National Building Information Modelling Standard	NBIMS
National Building Specification	NBS
National Environmental Policy Act	NEPA
National Environmental Policy Act	NEPA
New South Wales	NSW
Non-Directional Beacon	NDB
Objeto Territorial Legal	OTL
Obstacle Limitation Surfaces	OLS
Obstacle Limitation Surfaces	OLS
Physical Property Object	PPO
Public Law Restriction	PLR
Remotely Piloted Aircrafts	RPA
Remotely Piloted Aircrafts	RPA
Research and Development	R&D
Resource Management Act	RMA
Right Restriction Responsibility	RRR
Special Real Property Object	SRPO
Surface Mining Control and Reclamation Act	SMCRA
Surveying and Planning through Electronic Applications and Referrals	SPEAR
Terrain Obstacle Database	TOD
Transfer of Development Rights	TDR
Underground Master Plan	UMP
Uniform Common Interest Ownership Act	UCIOA
Uniform Common Interest Ownership Act	UCIOA
United Kingdom	UK
United Nations Educational, Scientific and Cultural Organization	UNESCO
United States	US
United States Geological Survey	USGS
Universal Declaration of Human Rights	UDHR
Unmanned Aerial Vehicles	UAV
Water Framework Directive	WFD
Wohnungseigentumsgesetz	WEG
World Intellectual Property Organization	WIPO

1. Introduction

Land constitutes the most significant asset for life and development. It is the residence of people, animals and plants, the fundamental resource for agricultural activities, the source of raw materials, and the background for all types of activities. Consequently, the notion of recording rights on land to record systems held by the state and accessible in public was developed, yet from 4000 B.C. in Mesopotamian civilizations.

This relates to the powers that a holder of land may exercise, and on the limitations of such powers, which, eventually, lead to the concepts of "property", "ownership", and "rights on land". Dale & McLaughlin (1999), regard property as the buildings associated with land, or, more specifically, the legal rights attached to the land. Ownership constitutes the fundamental legal right which can be imposed on land, assigning to its holder the strongest and most extensive power that can be exercised on land. Property rights specify the ways that land can be owned, used and managed, in terms of content, modes of acquisition and loss, as well as of the protection that is given to such rights under the law (Georgiadis, 2012). The significance given to the right of property, is reflected by its inclusion among human rights, and reference to its protection is acknowledged in international and regional legal instruments, as well as on stipulations of numerous national constitutions (Golay & Cismas, 2010). Characteristic references can be traced to the Universal Declaration of Human Rights (UDHR) (Art. 17), the European Convention on Human Rights (ECHR) (First protocol, Art. 1), the American Convention on Human Rights (ACHR) (Art. 21), the African Charter on Human and Peoples' Rights (AfCHPR) (Art. 14), the Commonwealth of Independent States Convention on Human Rights and Fundamental Freedoms (Art. 26) and the Arab Charter of Human Rights (Art.25).

Land pertains an inherent spatial connotation, which delineates the boundaries where each right holder can exercise his/her property rights. Definition of the horizontal boundaries of land property is relatively easy; legal boundaries can be realised through survey measurements, or by reference to physical or artificial objects on the land's surface. However, the situation is not that simple when it comes to defining the vertical extent of real property, both in terms of legal definition and in physical delineation through survey measurements or by reference to objects. Legal stipulations defining the vertical extent of ownership are based on the Roman principle "*cujus est solum es usque ad coelum et ad inferos*", while stipulations based on the principle "*superficies solo cedit*" promote indivisible ownership to the vertical column of space above and below a land parcel. However, mineral ownership as well as aviation, come to oppose aforementioned principles. Abramovitch (1953), investigates the various views regarding interpretation of the "*cujus est solum est usque ad coelum et ad inferos*" principle, focusing on the field of aviation. This work, concludes that this maxim allows surface parcel owners to effectively use their property without interference of flights, but only to the extent that such flights hamper the enjoyment of land (Abramovitch, 1953). Besides, stipulations dissociating aviation and mining from surface parcel ownership can be traced in several jurisdictions, either in property laws, or in aviation and mineral laws and codes. However, aviation and mining do not constitute the sole cases where the "indivisible" and "unlimited" concept of land ownership is challenged. Multiple cases of vertical subdivision of land have emerged in the course of time, to accommodate the growing needs of contemporary societies. Urbanisation has increased the need in land for residential and commercial purposes, as well as for the development of public utilities. Additionally, community living and environmental protection have

introduced various types of restrictions on land use, many of which are based on three-dimensional characteristics and apply to 3D space (Gkeli, Ioannidis, & Potsiou, 2017; Dimitrios Kitsakis & Dimopoulou, 2016). Advances in rock mechanics, excavation and support of underground structures allow re-conceptualisation of land exploitation and planning, by integrating aerial and subsurface space to urban and rural planning. Kaliampakos & Benardos (2008), note that advances in underground projects' development may broaden the range of underground space use by relocating surface land uses or activities, in which installation is difficult, impractical, less profitable, or even environmentally undesirable on the ground level. Exploitation of underground and aerial space for a broad range of uses is evident in several countries. Apart from utility networks, development of large underground infrastructures such as shopping centres, warehouses and storage tanks, tunnels, parking spaces sports and others can be traced in countries with high population density (Kishii, 2016; Vähäaho, 2016; Wallace & Ng, 2016; F. Zaini, Hussin, & Raid, 2017; Z. Zhang, Tang, Gong, & Huan, 2017). Bartel & Janssen (2016), highlight that conflicts in the exploitation of underground space are complex and multi-dimensional, thus highlighting the need of integrating underground space within spatial planning procedures. Exploitation of underground space of Helsinki in Finland has started since the 1960's (City of Helsinki, n.d.), while the Underground Master Plan of Helsinki has been approved the City Council since 2010 (Vähäaho, 2014). Within the overall strategy for long-term economic strategy and the urban sustainability, the development of underground master plan is studied in Singapore (Delmastro, Lavagno, & Schranz, 2016; Zhou & Zhao, 2016).

Development of complex constructions above and below the land's surface, extending on multiple parcels on different height or depth levels, confronts contemporary methods of real property stratification. Property rights are used to dissociate surface parcel ownership from this of constructions on top (or below) the land's surface, or to "excise" powers from the land owner and assign them to another individual. Such rights are servitudes (or easements), the right of superficies, emphyteusis, composite ownership rights, especially condominium/apartment ownership concepts, indirect ownership and special real property rights and objects, as well as their equivalents in other legal families. Each of these rights has specific content, serves specific purposes, and is subject to specific limitations regarding their use. Most notably, apart from composite ownership rights[1], they fail to form multiple, individual real property units on different levels of height and depth above or below land's surface. Demsetz (1967), claims that emerging societal needs that derive from technological and market development cannot be accommodated within existing property rights concepts, thus resulting in the need of developing new property rights. The need of reconceptualising ownership and to introduce new forms of property is also noted by Praduroux (2017). Within the Cadastre field, this can be envisaged through intense stratification of real property, which is restricted by the legal principles which define the vertical extent of real property and the absolute character of ownership right. 3D Cadastre falls within this research field, aiming to complement contemporary concept of real property rights, by providing the legal instruments to subdivide and manage real property in 3D space (Jesper M. Paasch et al., 2016). 3D Cadastre is not restricted to stratification of rights on multiple height or depth levels referring to modern constructions, but may also comprise Public Law Restrictions (PLRs)

[1] Which however face different limitations as regarding to their exploitation in real property stratification.

(Kitsakis & Dimopoulou, 2016, 2017; Navratil, 2012), as well as rights deriving from customary law (Kitsakis, Apostolou, & Dimopoulou, 2016), or for the protection of traditional settlements (Kitsakis, Tsiliakou, Labropoulos, & Dimopoulou, 2017).

Given these, the limitations and the capabilities of existing concepts of real property stratification need to be identified, to assist the understanding of the problems and the factors related to stratification of real property legislation and provide insight to those jurisdictions interested in moving towards a 3D Cadastre legislation.

1.1 Research motivation

3D Cadastres are discussed since the late 1990's (P. J. M. van Oosterom, 2018), while 3D Cadastre related legislation in Australia dates back in the 1960's (Andreone, 2011). However, there is slow progress on introduction of national, full 3D cadastral systems[2]. This is mostly attributed, on the one hand, to technical and, on the other hand, on legal and administrative aspects (Jantien Stoter, 2004a; Jantien Stoter & van Oosterom, 2006; Jantien Stoter, Van Oosterom, & Ploeger, 2012).
Technological development in the 3D GIS and 3D modelling fields allows for accurate 3D real property units' modelling as well as 3D querying (Givord, 2012). However, real property legislation, especially in jurisdictions where Civil Law applies, poses restrictions on the establishment and management of RRRs that apply on 3D space (Kitsakis & Dimopoulou, 2014). The Roman principles[3] on which national real property laws are based, only provide for the establishment of limited real rights on land[4], thus restricting real property stratification. Regardless the case, interest from legal professionals on the field of 3D Cadastre remains limited (Banut, 2011; Kitsakis et al., 2016; Paasch et al., 2016; Paasch & Paulsson, 2014). Legal professionals' lack of interest in 3D Cadastre issues mainly derives from (Kitsakis & Dimopoulou, 2017):

- the existence, until recently, of limited cases that would require a 3D cadastral approach;
- the use of limited real rights and condominium concepts;
- the establishment of specific legislation to regulate large-scale underground infrastructures.

Despite the above mentioned arguments, existing concepts of real property stratification cannot unambiguously establish and regulate Rights, Restrictions and Responsibilities (RRRs) on land that address societal needs as:

- High rise complex structures are most common in modern urban environment (a) to address the lack of space for accommodation and utilities, (b) to reduce high land values and (c) to reduce cost deriving from horizontally expanded urban environment, in terms of health, safety and utilities.
- According to the "*numerus clausus*" principle, limited real rights are restricted in number and have specific content. Stratification of real property through

[2] The first full operating 3D Cadastre system can be traced in Shenzhen, China, while aspects of 3D cadastre can be traced on Australia (states of New South Wales, Queensland and Victoria), Singapore and The Netherlands.
[3] The extent of the right of real property ownership and its content, are based on the Roman principles "*superficies solo cedit*" and "*cujus est solum es usque ad coelum et ad inferos*". Discussion on the impact of such principles on real property stratification is made in following sections of this thesis.
[4] Given that the "*numerus clausus*" principle applies on limited real rights, real property stratification cannot be achieved through the introduction of a new limited real right under agreement among the involved parties (Kitsakis et al., 2016).

statutory limited real rights exploits servitudes (or easements), rights of superficies and apartment ownership or condominium units. Although each of these concepts can be used in simple cases of real property stratification, they fail to accommodate successfully the most complex ones. Additionally, they are mostly related to physical structures, therefore, cannot apply to non-material legal spaces.

- Limited real rights are established to each of the involved land parcels as a whole, even if only a volumetric part of the parcel is affected. This inhibits economic exploitation of land, while establishment of limited real property rights does not allow the owners of subsurface volumes to use them as collateral (Karabin et al., 2018).
- Case specific legislation regulates only large-scale underground infrastructures, so it cannot be extensively used in other cases of rea property development at lesser scale.

In their research, (Paulsson & Paasch, 2011), investigate the number of legal topics regarding 3D Cadastre publications. They conclude that legal aspects constitute a small portion of the research related to 3D Cadastre, highlighting the lack of a standardised 3D Cadastre terminology, as well as the use of legal aspects merely as a background on technical research topics.

The theoretical departure of this thesis lies on the role of legislation in defining the physical space against which Rights, Restrictions and Responsibilities (RRRs) are imposed. This thesis seeks to identify the limitations that are imposed by legislation on real property stratification and the amendments required to overcome such limitations. The aim of this research can be summarised to:

"*Identify the legal impediments regarding stratification of real property and RRRs, in order to identify the legal amendments that address detected impediments*".

In order to respond to the above research aim, the following *research questions* were defined:

1. Which are the cases that require real property stratification?
2. Which are the capabilities and the restrictions deriving from current legal structures regarding real property stratification?
3. Which should be the features of 3D real property units?
4. How should legal framework be amended to support 3D real property units?

In order to respond to the research questions defined, the following *research objectives* were formulated:

1. Review of cases of vertically overlapping RRRs internationally.
2. Study on the legal instruments used for real property stratification.
3. Analysis of the legal issues on 3D real property units, based on applied legislation and international literature.
4. Critical analysis of legal instruments used for real property stratification.
5. Evaluation of existing concepts and proposal of legal amendments that facilitate real property stratification.

1.2 Research process

This section presents the methodological steps applied in this research. In the first step, the background of the examined topic is presented, setting the primary research question. Definition of the research question dictates the aim and the research questions of this research, so that research objectives can be drawn.

In order to fulfil the research objectives, detailed review of international literature and legislation was conducted (research objectives 1-2). International literature was reviewed to trace the types of real property stratification, including cases of overlapping rights deriving both from Private, Public and customary law.

To fulfil research objective 3, detailed analysis of international legislation and research towards 3D real property stratification was employed. The characteristics that 3D real property units should acquire are examined, considering legal provisions in countries where 3D Cadastre legislation has been established and international research proposals.

To meet research objective 4, implementation of comparative analysis on the examined jurisdictions was required. Such analysis also provided input for the evaluation of the compared cases, so that examined legal instruments could be evaluated and proposal of legal amendments to be exported (research objective 5). It was decided not to select and compare some distinct examples of each legal order. Instead, this work attempted to review the variety of real property stratification aspects and approaches globally. Legal orders were classified to legal families, so that distinctive common features of each legal order could be identified and to facilitate the analysis and the comparative process.

1.3 Methodology

1.3.1 Comparative Law

Comparative Law describes the comparison between various laws (Michaels, 2011). In many cases, comparatists refer to comparative law using different terminology since it merely constitutes a comparative procedure (Frankenberg, 1985; Pieters, n.d.; Vrellis, 1988), and not a distinct branch of law, e.g. property law.

Zweigert and Kötz (1998) consider knowledge as the primary goal of comparative law. They also acknowledge other functions such as achieving of international understanding, contribution to law-reform in developing countries, or the development of own legal systems. Pieters (n.d.), discusses the functions of law comparison and the methodological steps to be applied. He ascribes nearby, intermediate and long term goals related to comparative law functions, based on those defined by Zweigert and Kötz (1998). According to his study, nearby goals involve knowing and understanding national law of foreign countries, better understanding of own legal systems and challenging national legal prejudice, classification of national legal systems, use of accurate translation tools and, finally, decomposition of legal concepts in a way that allows meaningful communication among the involved parties despite terminological differences. Intermediate goals pertain legal education, interpretation of national, international and supranational rules of law and correct application of foreign law. Within distant goals, he includes

finding *de lege ferenda*[5] solutions, development of law in international and supranational level, harmonization and unification of laws, development of a common law and identify common basic principles (Pieters, n.d.).

Van Hoecke (2015), aims to present a comparative law "toolbox" that could be used in any type of legal comparison. To this aim, he has identified in literature the following comparative law research methods[6]:

- The functional method, which is based on the assumption that every society faces similar problems which, however, are addressed using different solutions with, often, similar results (Zweigert & Kötz, 1998).
- The analytical method that aims to analyse complex legal concepts and rules, looking to detect common parts and differences. It can be used to rank the legal systems that are compared based on their fitting with a defined "ideal type".
- The structural method, which focuses on the analysis of the framework of the law or of the elements reconstructed through an analytical approach.
- The historical method that examines changes of the examined legal systems over time.
- The law-in-context method, which also takes into consideration during comparative process other aspects such as culture, economy, psychology, religion etc.
- The common-core method. This method looks for common-core in the concept of harmonizing parts of the law.

Depending on the research question, apart from different methods, also different levels of comparative law can be applied (Hoecke, 2012; Pieters, n.d.).

- Based on the extent of the comparison to an entire legal system, or to some specific parts, *macro* and *micro* level of legal comparison can be used. Macro-comparison focuses on comparing entire legal systems, while micro-comparison emphasises on comparing specific institutions and specific problems[7].
- The level of underlying general and professional legal cultures (and traditions) goes deeper, considering the background against which legal systems are understood and operate.
- Differences in the law in practice and law in action need also to be considered, as diverging rules and doctrinal structures may lead to similar practical solutions and vice versa.

[5] *De lege ferenda* or *lex ferenda* are Latin expressions meaning "concerning the law that is to come" or "future law", used to denote legislative improvements required (Martin, 2003).

[6] According to (Hage, 2014), there is no single way of conducting comparative law research. It relates it to the purpose that it is performed, to the view of the researcher on the examined domain and the research question itself.

[7] Romano (2016), argues that both these theories are affected by a problem of infinite regress, as any object of enquiry is at the same time too broad and too narrow. Therefore, he suggests their complementary exploitation through the use of a meso analysis.

- *Surface* level or *deep* level comparative research may be required, depending on the examined jurisdictions' doctrinal constructions and if such constructions allow for surface level comparison of rules and concepts, or deeper level comparison, in terms of underlying views in theories of meaning and interpretation, is required.
- Doctrinal framework and its relation to underlying legal culture, considering both the conceptual legal frameworks that have influenced private law at international level (common law, the French Code Civil and the German *Bürgerliches Gesetzbuch*) and the application of law based on local culture.

Comparison is a process where concepts different in belief, circumstance or traditional are treated as equals (Glenn, 2007). Law comparison constitutes a complex task that requires high language skills, and understanding both of the legal concepts of the examined jurisdictions and of foreign cultures (Hussa, 2014; Pieters, n.d.). Therefore, it is not definite that resorting to interpretations or stipulations which are based on foreign legal orders can provide equally reliable results (Kitsaras, 2001).

Linguistic issues are of significant importance on performing legal comparison. Foreign legal structures as applying to one jurisdiction need to be perceived by the comparatist as they operate within his jurisdiction, and translated in a way that cannot be confused with different legal structures that apply to another jurisdiction or with legal structures that use similar terminology (Pieters, n.d.). Influence of the legal culture of a researcher while conducting a legal comparison needs to be considered since it can distort the comparative procedure and undermine its scientific validity (Pieters, n.d.). Michaels (2009), defines *homeward bias*, as one of the main problems of legal systems' comparative evaluation expressed either through prioritisation of one legal system's solutions to a problem, or through defining questions that best fit to a specific legal system. Therefore, terminology used requires to be neutral, in terms of not referring to a legal order among the compared ones. Language also poses restrictions within comparative analysis, as it limits the sources that are available to conduct a legal comparison. Legal documents are written in national language, therefore researchers are able conduct legal comparison among jurisdictions where languages that they are familiar with are spoken (Hoecke, 2012).

Legal comparison also requires understanding of foreign legal culture, so that puzzling features of the role and the rule of law within given societies are considered (Nelken, 2004). Each country has developed during the years its own legal tradition, despite similarities deriving from common influences, cultural interchange and economic interdependence (Glenn, 2007; Nelken, 2004). However, this term remains difficult to define, while it is used referring to multiple ideas which are not sufficiently separated (Michaels, 2009; Nelken, 2004; Silbey, 2010). This may lead to further complications regarding law comparison as it is open to stereotypic views about the purported view of the examined law (Michaels, 2009).

Understanding foreign culture is also very important for conducting legal comparison, as it sets the framework within which a law has been established and operates. It is a very important aspect as even if a law is replaced by another one, if the latter does not accord with national cultural characteristics, it will not be able to

operate properly and serve public needs (Whytock, 2009)[8]. As with legal culture, there is no exact definition of culture thus leading to similar complications when referring to legal culture.

Hussa (2014), highlights the twofold problem of comparative interdisciplinary study of law, involving on the one hand lawyers stepping outside the boundaries of law in other disciplines and, on the other hand, of non-lawyers venturing outside their specialist field to comparative law (Hussa, 2014).

Within this research, the risk of exploiting of comparative law by a non-legal professional is acknowledged. In order to minimise possible drawbacks, extensive research was conducted on the specifications of the different legal systems, along with the collaboration of legal and cadastre professionals from different jurisdictions. Besides, surveying professionals are, to an extent, familiarised with legislation as study of land legislation is among the occupations of surveying profession. Examination of the legal aspects of 3D Cadastre under technical perspective, provides a different point of view, combining technical and legal background and of minimised bias regarding legal system, thus securing exogenousity of the comparative process. Furthermore, different requirements and specifications are highlighted, related to the implementation of land and cadastre laws in practice, based on a professional surveyor's viewpoint.

1.3.2 Terminology

Terminology constitutes one of the main hindrances on 3D Cadastre legal research. Several researchers identify this problem, especially during the last years (Kitsakis & Dimopoulou, 2014; Kitsakis et al., 2016; Kitsakis et al, 2018; Paasch, 2012; Paasch et al., 2016; Paulsson, 2007). For an elaborate research on the classification of real property rights and public regulations, based on their content, please refer to (Paasch, 2012). In order to avoid misconceptions and maintain consistency, when no specific reference is made, terminology used in this thesis is based on the ISO-recognised international standard Land Administration Domain Model (LADM) (ISO 19152:2012). Exception is made regarding the definition of land parcel; LADM Spatial Unit class (which is the equivalent to land parcel) is formed to be compatible with real property stratification. Consequently, the definition provided by Henssen (1995) will be used (which remains prevalent in cadastral and property laws internationally), so that its limitations under the context of real property stratification can be identified. Therefore:

3D real property unit, is a "*spatial unit against which (one or more) unique and homogeneous*[9] *rights (e.g. ownership right, lease or other land use right), responsibilities or restrictions are associated to the whole entity, as included in a Land Administration system*" (FIG Working Group on 3D Cadastre, 2014). The terms 3D real property, 3D property unit or 3D property are used interchangeably in this thesis, retaining the same meaning.

[8] However, the extent of understanding the impact of foreign culture to an examined legal comparison and, therefore, foreign law is open to question (Hage, 2014).

[9] *Homogenous* means that the same combination of rights equally apply within the whole 3D spatial unit. *Unique* means that this is the largest spatial unit for which this is true. Making the unit any larger would result in the combination of rights not being homogenous. Making the unit smaller would result in at least 2 neighbour 3D parcels with the same combinations of rights (FIG Working Group on 3D Cadastre, 2014).

Land parcel, is "*a continuous area of land within which unique and homogeneous interests are recognised*" (Henssen, 1995). In terms of cadastral registration and mapping, a land parcel is the footprint of the above-defined area on land or on the cadastral map. Where no specific reference is made, the terms parcel, surface parcel, or immovable property are used under the same meaning.

Right, is "*an action, activity or class of actions that a system participant may perform on or using an associated resource*" (Lemmen, 2012).

Restriction, is a "*formal or informal entitlement to refrain from doing something*" (Lemmen, 2012).

Apart from terminology, language constitutes a significant barrier on cross-national research. This also applies in this thesis, in which the legal framework on real property stratification of more than fifteen countries was examined; the majority of the examined countries are not English speaking, therefore direct access to national legislation was made either through English translations by competent national authorities, when available, or through published international research in English language. The author notes that has put his best effort to render the original meaning of each legal statute in English language, however possibilities of misinterpretation cannot be ruled out.

1.4 Structure of the study

This thesis is divided in eight chapters. This section concludes the first chapter of this work, introducing the subject and its background, the methodology that is followed and its limitations. The second chapter presents characteristic cases that require real property stratification at international level. In the third chapter, the legal framework supporting real property stratification in presented. First, classification of legal systems is conducted, in order to allow comprehensive presentation of their characteristics and facilitate analysis and comparison between different systems. In the second part of the chapter, the most common types of limited real property rights used to stratify real property are presented, including praedial servitudes (or easements), the personal servitude of usufruct, the right of superficies, composite and indirect ownership concepts, as well as special real property rights and objects. The forth chapter of this thesis investigates the relation between physical constructions (physical space) and their legal counterparts (legal space). Emphasis is given on systems of land registration, while the concept of land objects is presented. Standardisation and modelling of stratified land rights by international standards are also presented in this chapter. Reference to the well-known Land Administration Domain Model (LADM), along with its proposed legal extension, the Legal Cadastral Domain Model (LCDM) is made. Exploitation of Building Information Modelling (BIM) techniques and of the 3D digital urban environment model CityGML for 3D Cadastre purposes concludes the forth chapter of this thesis. In the fifth chapter, emphasis is given to the legal issues regarding development of 3D real property units, based on international literature. Investigation pertains jurisdictions where 3D cadastre systems are established and operating, jurisdictions where real property rights are used in real property stratification, as well as jurisdictions where research towards introduction of 3D cadastral systems has been proposed. Investigated jurisdictions are based on the classification between Civil and Common Law, which better reflects the differences between proprietary systems and real property rights. The sixth chapter elaborates

on the findings of chapter 5 and compares between the different approaches followed in each jurisdiction regarding real property stratification. The seventh chapter examines the advantages and the limitations of the identified characteristics of the legal instruments used for real property stratification. The eighth chapter concludes this work, responding to the research questions which were defined, based on the five research objectives that were set in chapter one.

2. Cases of overlapping rights on land

Stratification of land dates back to ancient time. From Roman *insulae*, to the Kandovan cave dwellings in Iran, people tried to exploit land both in height and depth. It is not surprising that regulations on the maximum building height trace back in the time of the Roman emperors Augustus and Nero (Boozer, 2013). In the course of time, the increased number of urban population along with the advances in construction technology, have resulted in further exploitation of land in height and depth, in order to address needs for accommodation and infrastructures. In islands and areas that were influenced by foreign legal and cultural systems, scarcity of land has led to customary vertical exploitation of land. However, it is not the vertical exploitation of land that led to the need of developing statutory 3D real property legislation, but the growing complexity of proprietary relations on multi-level real property units, combined with real property legislation's inclination towards the "indivisibility" of real property on the vertical direction. According to Stoter & Salzmann (2003), 3D real property situations include constructions built on top of each other, under and above ground infrastructures, cables, pipelines and other utility networks, and apartments. Enrichment of the above cases with restrictions imposed by Public Law is noted by several researchers (Givord, 2012; Kaufmann & Steudler, 1998; Kitsakis & Dimopoulou, 2016; Navratil, 2012; Zevenbergen & De Jong, 2002), since archaeological, environmental and other types of regulations affect the vertical extent of land exploitation. This chapter presents the most characteristic cases of vertical exploitation of real property, as well as those "stretching" current legal practices regarding their formation and cadastral registration (Ho, 2014).

2.1 Condominium

Accommodation is among the first needs that stratified real property aimed to address. Development of multi-storey buildings, as already mentioned, dates back to the Roman times. Condominium ownership constitute a composite ownership right[10] and comprise, apart from an apartment's volume, a share to the common parts of the building and separate volumes of space that serve as appurtenances of the apartment unit (such as storage rooms and parking spaces). Condominium schemes are well-established and constitute a functional and reliable concept (Paulsson, 2008). Complex situations, such as overhanging private spaces above public ones, are dealt by specialised statutes, which, however, denote that limitations still exist (Fig. 1).

[10] For more detailed description of condominium (and composite ownership) characteristics, please refer to section 3.2.5.

Figure 1. (Left) Stoa, (right) private space overhanging from public space.

2.2 Complex overlapping and interlocking structures

This case refers to all different types of constructions that horizontally overlap, or to complex interlocking structures, such as constructions built on top of other constructions, which are owned by separate individuals (Fig. 2). Similar cases can be traced in buildings of complex architecture, or of real property units that extend on multiple levels within a building (Fig. 3).

Figure 2. Building constructed on top of another building (Jantien Stoter, Van Oosterom, and Ploeger 2012).

Figure 3. Left: Real property extending on multiple levels within a building (Atazadeh et al., 2016), Right: Buildings with complex architecture (Interlace building) (reddit, 2016).

2.3 Under and above ground infrastructures and networks

Infrastructures and networks constitute characteristic cases of real property stratification globally. Common cases of underground infrastructures comprise shopping centres, parking space, subway and railway lines and stations, while advances in construction and excavation technology pave the road for expansion of underground infrastructures to include commodities' storage facilities, storage of oil, fuel, explosives, and waste treatment (Kaliampakos, Benardos, & Mavrikos, 2016). Apart from the above mentioned major underground infrastructures, utilities and networks, such as electricity, communication and sewerage, are developed below the land's surface, while networks may be traced to the space above real property, such as electricity and telecommunication networks. Formation of the above mentioned objects, requires the establishment of unambiguous real property rights regarding their spatial extent and content. Besides, conflicts with rights assigned to surface parcels emerge. Establishment of specific legislation regulating land issues regarding the development of major underground projects is usually employed. However, this

implies long-term procedures, which may also include litigation, while they are case specific, therefore they cannot be extended to other cases of real property stratification. It is noted that, even in such cases (where specific legislation is established) reference is made to whether the surface parcel owner may object to the construction of the development (based on the impact of such development to the exploitation of the surface parcels), but the depth, or height, of surface parcel ownership is not explicitly defined (or it is implied, by reference to common land exploitation practices in the surrounding region).

2.4 Customary tenure and special rights

Customary tenure and special real property rights and objects can be traced in specific localities within a jurisdiction. Customary rights and objects do not follow statutory provisions on real property stratification, but are based on "custom", meaning local values and practices mixed with foreign influences. As regarding to real property exploitation, customary rights allow the subdivision of the "column" of space above and below the surface parcel to individual property units, e.g. Special Real Property Objects (SRPO) in several of the Aegean islands in Greece.

Special rights exist in several jurisdictions, regulating proprietary relations which derive from the specifications of local practice, according to the principles and the values of each national legal order. Presentation of characteristic cases of special rights and customary real property objects can be traced in section 3.2.7.

2.5 Public Law Restrictions

Restrictions imposed by Public Law (PLRs) may also create vertical "layers" of RRRs in space. PLRs are related to the social function of property thus restricting the broad range of powers that land owner may exercise to their land parcels. To the field of Land Administration, Public Law's effect has grown over the years, both due to the need of regulating vertically overlapping, conflicting activities and to secure public benefit. To this aim, law obliges land owners to tolerate on their land, constructions owned by others (Ploeger & Stoter, 2004). Such effect does not directly derive from land laws, but from legislation pertaining urban planning, mineral activities, archaeology, underground water, pollution, environment, aviation, infrastructures, utilities and constructions that require multi-surface land management. Given the growing number of Public Law regulations, intense vertical exploitation of real property, lack of centralised recording of PLRs as well as their 2D based definition, real property related development can get complicated, delayed or, in complex cases, even jeopardised.

The effect of the 3D aspects of PLRs should not be underestimated. Despite their three-dimensional character, PLRs are not land parcel-based, thus they are more difficult to be dealt with, within land parcel-based cadastral systems. Separation of mineral ownership from surface parcel ownership was among the first regulations of Public Law with three-dimensional effect, in order to assure proper exploitation of underground mineral resources and avoid conflicts that would derive if mineral ownership followed surface parcel ownership. Similarly applies in case of underground antiquities, especially those that is decided to be preserved *in-situ* (remain buried). Protection of buried antiquities requires that land use restrictions are imposed on the volume where antiquities are located, extended by a safety zone, instead of declaring protected archaeological zones in horizontal plane. Environment protection is also related to stratified PLRs. Pollution of soil and groundwater cover

specific volumes of space, while depending on their physical and chemical characteristics, they affect their surroundings along with all habitats, animal life and flora. Height or volumetric restrictions are also related to noise, vibration and ambient air pollution, given that propagation of noise and of air pollutants is affected by three-dimensional parameters and varies on different height levels. To these, restrictions imposed on civil aviation need to be added. Such restriction include not only constructions' height restrictions in the vicinity of airports, but also restrictions on the flight of unmanned air vehicles (UAV). Finally, PLRs impose restrictions on urban planning and on height, depth or volumetric characteristics of constructions, to facilitate community living and establishment of public utilities. Schematically, the range of 3D PLRs that may apply on land is presented in Figure 4.

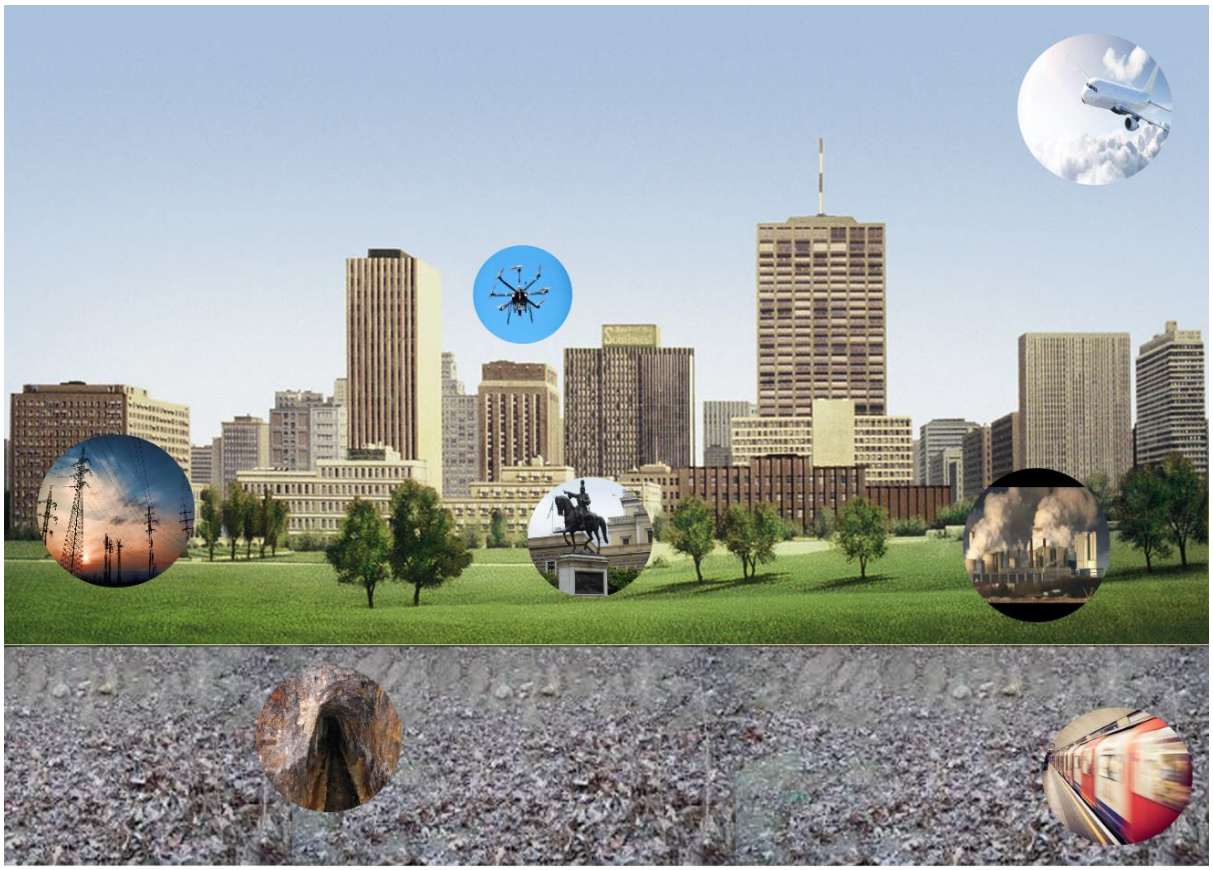


Figure 4. Schematic representation of types of PLRs on land (Kitsakis et al., 2018).

3. Legal framework supporting 3D RRRs

This section presents the legal instruments used for real property stratification purposes in different jurisdictions. It first starts with classification of legal orders to legal families. Several approaches of classification are presented, based on international literature. Classification in legal families within this work does not aim to limit the research extent on defining and examining distinct examples of each class. Research extends to the maximum possible jurisdictions, in order to trace the variety of approaches on real property stratification and 3D Cadastre. Classification is used to facilitate the comparative process and group the exported deductions.

The next step emphasises on presenting the main features of limited real property rights used for real property stratification purposes. In this case, classification in legal families is used to distinct between jurisdictions of Civil and of Common Law. However, this distinction is used to serve the structure of this thesis, and different aspects of limited real property rights within countries of the same jurisdiction are presented, thus depicting the varying approaches in real property stratification.

3.1. Legal families worldwide

Classification of legal systems allows for a more comprehensive presentation of their characteristics and facilitates analysis and comparison between the different legal system groups. Definition of the criteria on which classification is based, is fundamental for the classification process to be successful (Zweigert & Kötz, 1998). Within the concept of legal classification, definition of criteria may affect classification results, given the dynamic character of law and the impact of, among others, historical, cultural, sociological and religious characteristics in national legislation. Depending on the selected criteria, classification may result in groups that under different perspective would be considered as highly inconsistent (Hoecke, 2012). Varga (2012), traces references on classification of laws, yet since 1531. In his work, he provides a detailed review of the variety of classification proposals during the years, reflecting the different perspective of each comparatist. Some of the criteria used include [based on (Varga, 2012)]:

- Language and species (Esmein, 1905)
- Race (Sauser-Hall, 1913)
- Line of development (under concept of written law and codification, in contrast with customary law which was developed through legal practice and religious laws) (Lévy-Ullmann, 1922)
- Generic roots (Martinez-Paz, 1934)
- Substance (Arminjon et al., 1950)
- Ideology or philosophical worldview and technique of law (David, 1950)
- Style of a legal system [including (i) historical development, (ii) predominant and characteristic mode of thinking (iii) distinctive legal institutions (iv) the kind of legal sources and the way that these are handled (v) ideological attributes] (Zweigert and Kötz, 1998)
- Adherence to the rule of law (Bose, 1962)

- Political systems (focusing on the overarching systems of capitalism and socialism) (Kulcsár, 1961; Gorla, 1963; Eörsi, 1973)
- Historical characteristics (Mamlström, 1969)
- Systems of social organisation, under the concept of administration of all social interactions that take place either between individuals or between individuals and institutions (Mattei, 1997).
- Cultural spheres (Husa, 2004).

Despite the variety of groups developed based on the above mentioned criteria, legal systems of each class can be further subdivided in subgroups that repeat divisions based on a different criterion. For example, Civil (Romano-Germanic) and Common Law constitute individual classes in the classification of David & Brierley (1978), while are subclasses of Western class in the classification of Mattei (1997). Husa (2004) ponders if a new direction needs to be followed instead of constructing classifications, noting that current classifications suffer by lack of neutrality (as they are based on Western views that include Common and Romano-Germanic Law) and are of static nature. Comparison between legal doctrines has been used for centuries; however, development of systematic comparative methods emerged after the establishment of distinct, codified, national private laws (Michaels, 2011). Focus of classification processes on Private Law is another factor that impacts on classification of legal systems. According to Hoecke (2012), no overall classification can be achieved within Private Law and further specification is required, for example to Land Law, Family Law etc. Hence, private law oriented classifications are questioned by modern comparatists, e.g. (Hoecke, 2012; Husa, 2004; Pieters, n.d.),. Figure 5, schematically depicts the complexity and the interrelation of classes and subclasses based on the literature of classification criteria presented by Zweigert & Kötz (1998).

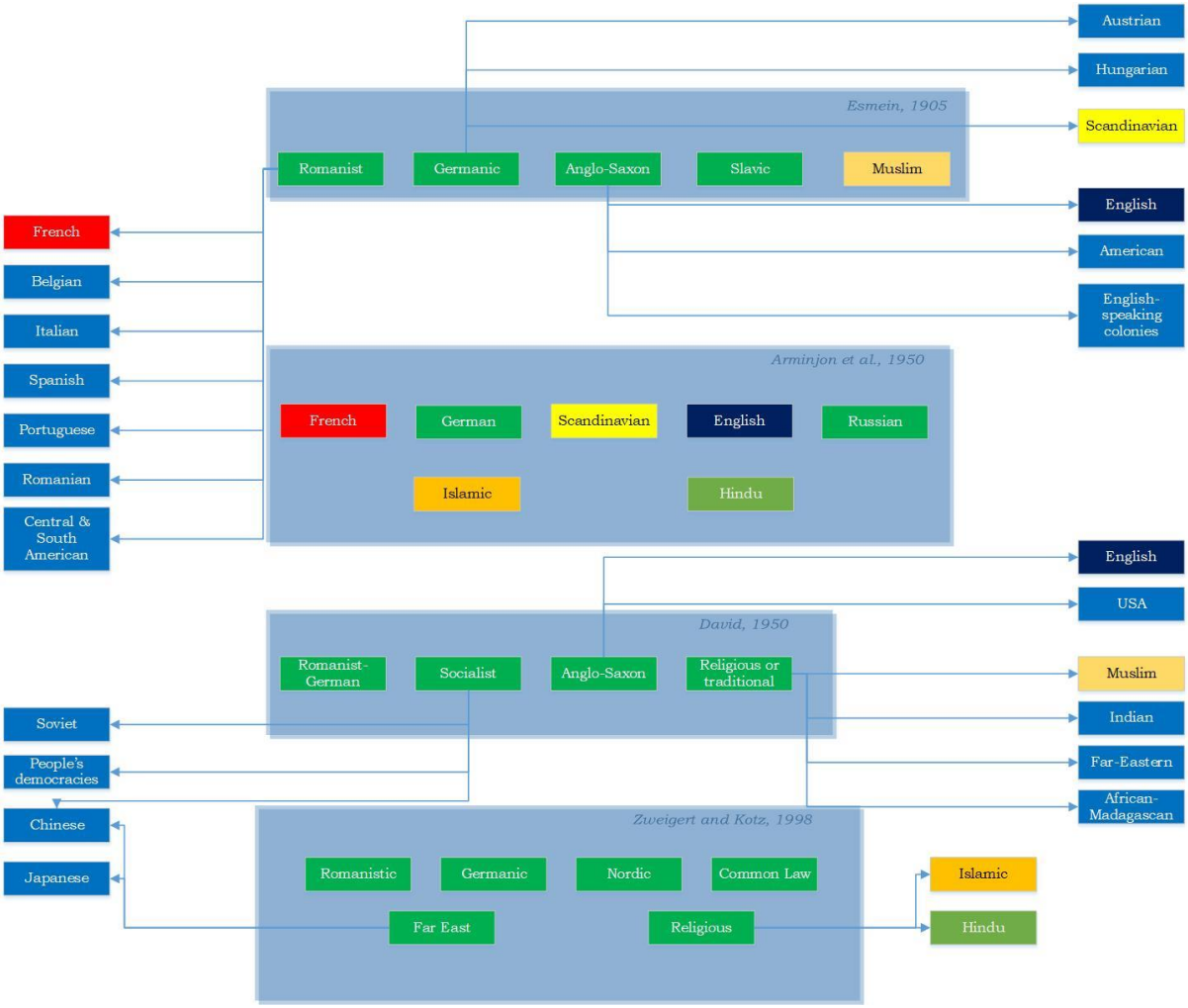


Figure 5. Classification of legal families to classes and subclasses.

This thesis does not aim to take sides for or against the research proposals on classifying legal systems. Besides, no taxonomy may claim to serve every comparative purpose (Mattei, 1997). 3D Cadastre pertains characteristics both of Public and Private Law. Real property is regulated within Property Law, while 3D real property does not constitute a new concept, but aims to expand the capacities of contemporary real property objects (Paasch et al., 2016). Therefore, it can be assumed that the establishment and the management of 3D real property units falls into the reign of Private Law. Given this, grouping of the jurisdictions that are examined in this thesis requires that the classification used is based on Private Law. Classification could further emphasise on Property Law, especially on legislation regulating 3D real property units, i.e. jurisdictions with or without established legislation supporting 3D space partition. Such a classification would require to group together highly heterogeneous countries, in terms of land tenure systems, cadastral infrastructure and cadastral legislation. Trite though it may be, classification between Civil and Common Law can efficiently serve the purpose of this thesis. Such a classification also contributes grouping of "mixed-Law" jurisdictions that share characteristics from different legal families, e.g. Quebec, Louisiana or Israel. Potential subclasses, for example Civil Law jurisdictions can be further divided

to Germanic, Romanist, Nordic and Chinese Law[11]. Existence of such subgroups is acknowledged in this research, but it is not within the scope of this thesis to undergo in-depth analysis of different legal families' subgroups. Presentation of characteristic examples of different subclasses is attempted, so that the different notions within a legal family's subgroups can be perceived. Figure 6, presents the geographical allocation of legal systems globally.

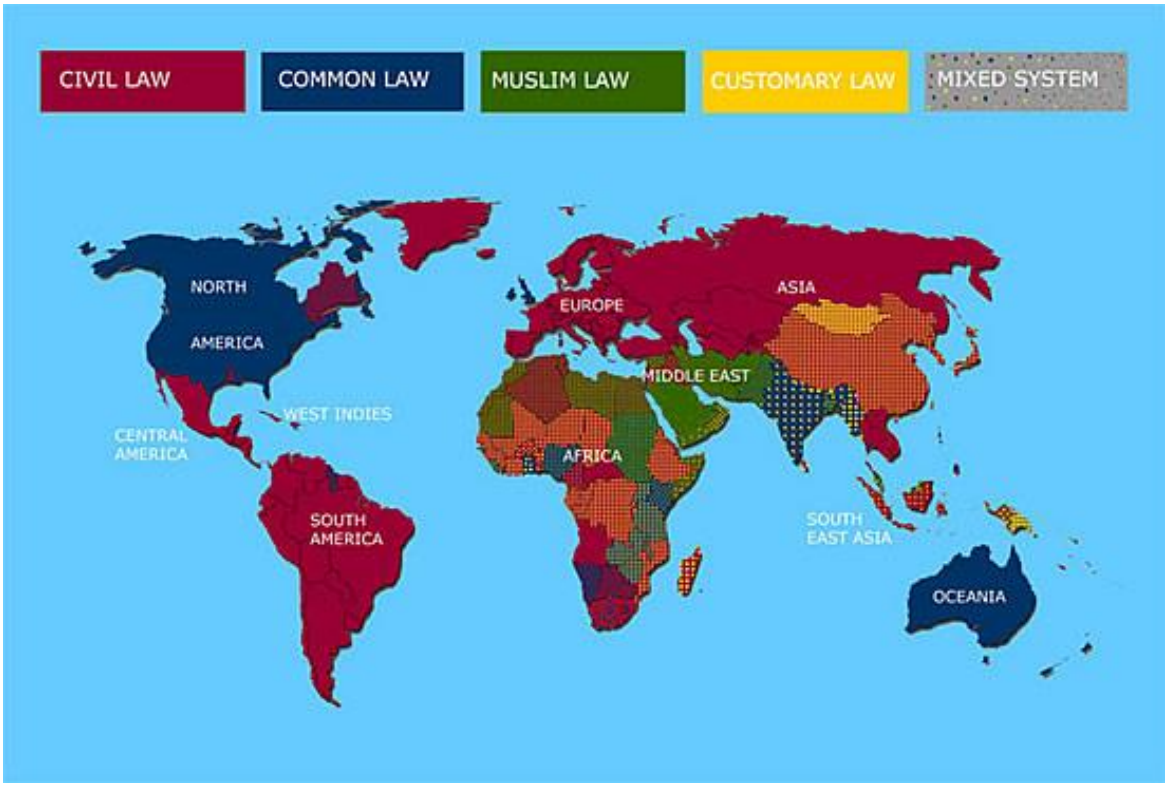


Figure 6. Legal systems of the world (University of Ottawa, 2016)

3.2 Real property rights and real property stratification

Although systematic research and debate on the establishment of 3D Cadastre legislation dates back to the late '90s (P. J. M. van Oosterom, 2018), stratification of real property is applied long earlier through the establishment of limited real property rights. Limited real property rights restrict the right of ownership so that their holder may exercise specific actions on real property. The number and the content of limited real property rights is defined by legislation, based on the "*numerus clausus*" principle[12] ensuring foreseeability and predictability of rights, both for the involved parties and the real property market, also securing rights' protection (Akkermans, 2017). This means that establishment of a real property right different from those defined in legislation, would induce additional cost to acquire information on the content of such a right and of the real property objects that are subject to it. Limited real rights may derive from Civil Law, Land Codes, specific legislation or customary

[11] According to the latest literature Nordic and Chinese legal families are considered as individual legal families, the former lying between Common and Civil Law, and the latter as a mixture of Civil and Customary Law.

[12] Depending on the legal system, there can be traced explicit stipulations limiting the number of limited rights to those defined by law, stipulations defining limited real rights but not explicitly rejecting the existence of other limited real rights or, no provision on limitation of the number of limited real rights (although many of these legal systems operate as if such limitation existed) (Akkermans, 2017).

law. The rest of this section presents the most common types of limited real rights that are used for stratification of real property, including praedial servitudes (or easements), the personal servitude of usufruct, the right of superficies and condominium (or apartment) rights. It is noted that this section by no means aim to make a comprehensive analysis of each of the presented rights, but to present their fundamental features, under the prism of real property stratification. Depending on the legal system, not all of the above mentioned rights apply to all jurisdictions.

3.2.1 Servitudes (easements)

Servitudes[13] allow their holder to use another's land in a specific way or to object on specific uses of such land. Depending on each national civil code, servitudes can be classified in praedial (or real) and personal, based on their establishment in favour of the owner of a specific land parcel or of an individual. Civil Law based jurisdictions mainly define servitudes as an encumbrance imposed on a real property in favour of another real property owned by a different owner (e.g. French Civil Code, sec. 637; German Civil Code, art. 1018; Greek Civil Code, art. 1118; Polish Civil Code, art. 285; Spanish Civil Code, art. 530; Swiss Civil Code, art. 730). The owner of the former is required either not to exercise specific rights on his/her property, or to allow the owner of the latter to exercise specific rights on the servient parcel (Dutch Civil Code, 5:71; German Civil Code art. 1018; Greek Civil Code, Art. 1119; Polish Civil Code, art. 285; Spanish Civil Code, art. 533; Swiss Civil Code, art. 730).

National civil codes stipulate the content of servitudes by reference to the rights of the dominant and the restrictions on the servient land parcel, and may also explicitly refer to the available types of servitudes (e.g. French Civil Code, Title IV, Chapters I-III; Greek Civil Code, Art. 1120; Spanish Civil Code, Title VII, Chapters II-III). Servitudes have been extensively used for real property stratification, especially in case of development, access, repairing and maintenance of above or below surface utilities and infrastructures. Servitudes encumber land parcels as a whole, although they can be exercised in a specific part of the servient land parcel and to the least inconvenience of the owner of the servient parcel (Dutch Civil Code, 5:74; Greek Civil Code art. 1125, German Civil Code, art. 1020, Swiss Civil Code, art. 737, Spanish Civil Code, art. 545; Swedish Land Code, Chap. 14 sec. 6). Legislation does not stipulate any restrictions on the number of servitudes (easements) that can be established on a land parcel. However, given that servitudes (easements) encumber a land parcel's right of ownership, establishment of a new servitude (easement) applies to the "remaining" non-encumbered ownership. Therefore, newly servitudes (easements) are not equal to their prior ones. Conflicts either with other servitudes (easements) imposed on the same land parcel, or with a mortgage, are regulated based on time precedence (Triantos, 2000; Swiss Civil Code, art. 812).

Common Law jurisdictions use the term "easement" in a description from the dominant parcel's perspective (Akkermans & Swadling, 2012). Easements are defined as rights enjoyed by an owner of land (dominant tenement) to the benefit of another land (servient tenement) (Martin, 2003). The owner of the land is restricted from exercising his rights on land through restrictive covenants which operate as "negative easements" (The Law Commission, 2008). Similarly to the distinction of

[13] "Servitude" is the English term used in Civil Law or Civil Law based jurisdictions, e.g. France, described from the perspective of servient land (Akkermans & Swadling, 2012). However, the term "easement" may also be used as well in some Civil Law translations, e.g. Sweden.

Civil Law servitudes in praedial and personal, Common Law easements can be classified in appurtenant easements and easements in gross, depending on the existence of a dominant (benefited) and a servient (burdened) parcel, or only of a servient (burdened) parcel respectively. The latter are mainly established in favour of specific authorities, including transmission companies, water corporations, gas companies, municipalities or other government authorities[14] (Eames-Mayer & Matthews, 2008). In several Common Law jurisdictions, such as the United States, Canada and Australia, easements (or covenants) can be used, apart from provision of services, to promote the purposes of private organisations or state agencies concerned with heritage preservation and conservation, over privately-owned land parcels (conservation easements, covenants) (Atkins et al., 2004; Owley, 2015; Victorian Law reform Commission, 2010). Property owners may retain specific types of rights on land, e.g. right to subdivide land, while agreeing to donate, lease or sell some of their rights for the protection of historic, cultural, or archaeological sites and for the preservation of land for ecological goals (Bureau of Archaeological Research Division of Historical Resources, n.d.). Conservation easements are usually named after the type of resource that they aim to protect, for example historic preservation easements and open space or scenic easements (Bureau of Archaeological Research Division of Historical Resources, n.d.). Atkins et al. (2004), summarise the requirements deriving from conservation easements to the following:

- preservation of identified conservation values;
- protection of habitat for plant and animal species, including rare and endangered species;
- maintenance of areas that have been restored due to past destructive land practices;
- requirements for protection and maintenance of historic structures;
- protection of scenic corridors or other aesthetic values;
- restrictions on types of industrial activities;
- restrictions on subdivision;
- specifications permitting some uses and prohibiting or limiting other uses;
- requirements for the management of forest land in accordance with specific forestry and conservation standards and practices;
- requirements for sustainable agricultural practices;
- restrictions on the use of pesticides;
- protection for areas adjacent to streams, lakes and other water bodies.

Conservation easements constitute an alternative, cost-effective land protection approach compared with land acquisition, but also an approach that retains the economic exploitation of land, to a specific extent, in a concept easier accepted by land owners as well (Fishburn et al., 2009). Within this context, conservation easements can be exploited as policy tools for resource use and conservation (Wiebe & Meizen-Dick, 1998), while Owley (2015) is sceptical of the role of private organisations in heritage protection using conservation easements.

Servitudes (easements) encumber a land parcel as a whole, although they are exercised to a specific part of it (Akkermans, 2008). Although it is not explicitly

[14] The terms "(statutory/public) right of way" are also used to describe an easement where no dominant tenement exists, e.g. British Columbia in Canada (Land Title Act, sec. 218), (National Telecommunications and Information Administration, 2003)

stipulated in legislation, exercise of a servitude (easement) is not limited to the earth's surface, but it may extend, if needed, to the space above or below it as well. However, several Common Law jurisdictions, e.g. New Zealand and the states of New South Wales and Queensland in Australia, explicitly provide for easements with volumetric characteristics, which can be restricted in height and depth (Queensland Land Act, sec. 362; New South Wales Conveyancing Act, Schedule 8B; (T. F. D. Gulliver, 2015).

Existing types of servitudes (or easements) differ not only among Civil and Common Law based jurisdictions, but also among countries of the same jurisdiction. Taking into account the types of servitudes (or easements) defined in national civil codes and documentation describing the types and content of easements in Common Law jurisdictions (Alberta Land Titles, 2002; Department of Sustainability and Development, 2013; Registrar of Titles and Registrar of Water Allocations, 2009; Land Titles Act (Singapore), 1993), those related to 3D space can be tentatively grouped in the following categories:

- *Public utilities*. In this case, servitudes (or easements) serving public benefit are created for the construction, repairing and maintenance of a public utility. In most cases, they are regulated by specific legislation, e.g. as prescribed in French Civil Code art. 650, Spanish Civil Code art. 550, Land Code of Russian Federation art. 23. Ownership of utilities, e.g. cables or pipelines, constitutes separate property from the land on which they are situated. In Civil Law jurisdictions, this is provided by national civil codes. For example, Swiss Civil Code art. 676 denies the right of vertical accession to pipes, cables and conduits "*located outside the parcel of land which they serve*", stipulating that they constitute property of the utility plant from which they come or to which they lead. Similarly, Dutch Civil Code, art. 5:20, excludes ownership of networks from surface parcel ownership; networks belong to the person who has installed them or to his legal successors. In Common Law jurisdictions, public utility easements are regulated by specific legislation e.g. telecommunication, electricity, pipelines laws. Such laws stipulate the rights of each public utility provider on the servient parcel or parcels, and include, among others, rights of way, drainage or sewerage, supply with water, gas, electricity, telecommunication or other services (e.g. National Telecommunications and Information Administration, 2003; Registrar of Titles and Registrar of Water Allocations, 2009; The Law Commission, 2008).
- *Retention of light, air and view*. According to these servitudes (or easements), the owner of the servient parcel is restricted from exercising his right to make constructions that may obstruct admission of light, enjoyment of view or the free flow of air in the servient parcel. This type of servitudes (or easements) are known both in Civil (e.g. Quebec, Louisiana, Greece, France, Spain) and Common Law (Alberta Land Titles, 2002; Department of Sustainability and Development, 2013; Foster, 1988; Registrar of Titles and Registrar of Water Allocations, 2009; Property Law Act (New Zealand))[15]. The purpose of such types of servitudes (or easements) can be served more efficiently if applied within city scale context, and systematically organised based on the specific building and environmental requirements, instead of agreements among

[15] In Queensland, only easements for light and air exist, since easements on view are considered as non-acceptable (Registrar of Titles and Registrar of Water Allocations, 2009).

individual, neighbouring owners. Therefore, such servitudes (or easements) are related to Public Law Restrictions (PLR) regulating building construction regulations, zoning, urban planning, Unmanned Aerial Vehicles (UAV) flights and protection of landscapes and vistas regulations (for more details, refer to sec. 5.6)

- *Overhanging eaves.* This type of servitude (or easement) allows the owner of the dominant parcel to project the eaves of his building that protrude to the servient parcel. Such type of easements can be traced both in Civil (e.g. Greece) and Common Law (Alberta, New South Wales, Queensland, Victoria) jurisdictions[16].

- *Prohibition to build or build only up to a fixed height.* This type of servitude (or easement) is established either to prevent construction of a building on the servient parcel, or to restrict it on a fixed height, e.g. Greek CC, art. 1120; French CC art. 689; Louisiana CC, art 699. It can be used in order to protect the view from the dominant parcel, although it differs from servitude (or easement) of retention of view, since retention of view restricts the owner of the servient parcel to exercise his right to build in his property, but up to a specific height (this that does not affect dominant parcel's view) (Yiannopoulos, 1982). Such servitudes (or easements) are also related, but should not be confused, with urban planning, zoning and construction regulations that may prohibit building on specific parcels, define specific maximum building heights or allow for transfer of unused development rights from one urban planning zone to another. For example, Greek construction regulations do not allow the establishment of servitudes which restrict the extent of constructions more than applying construction regulations (New Building Regulation, art. 9)

- *Support of buildings.* By this servitude (or easement), the owner of buildings or structures lying on the dominant parcel has the right to enjoy support by an adjoining building lying on the servient parcel, e.g. Greek CC, art. 1120; Registrar of Titles and Registrar of Water Allocations, (2009). Servitudes (or easements) for support of buildings, are distinct from the right of support of land (that is incident to land in its natural state, not including structures), and does not require to be established by an easement (NSW Law Reform Commission, 1997; Property Law Act (Queensland), sec. 179).

- *Other servitudes.* In several jurisdictions, legislation may provide that owners are permitted to establish other servitudes (or easements) as they deem convenient, under specific conditions. Such regulations may be traced on the French (art. 686) and Spanish Civil Code (art. 594). It is required that servitudes (or easements) apply "*to a tenement and for a tenement*" (French Civil Code, art. 686) and do not contradict to any public policy (French Civil Code, art. 686; Spanish Civil Code, art. 594). Norwegian legislation also does not provide for limitations on the types of servitudes that may be imposed on

[16] However each jurisdiction uses different terminology to describe this kind of servitude (or easement), e.g. easement for eavesdrop (Registrar of Titles and Registrar of Water Allocations, 2009) or right to project eaves and gutterings over a property boundary (Alberta Land Titles, 2002), easement of overhanging eaves (Department of Sustainability and Development, 2013), easement for overhang (New South Wales, Conveyancing Act Schedule 8)

real property (Feys, 2006). Introduction of other types of servitudes depends on the interpretation of the "*numerus clausus*" principle by national courts or special legislation. Characteristic examples include the introduction of the rights of emphyteusis and of perpetual use in France (Akkermans, 2017), and the re-establishment of the right of superficies in Greece regarding state owned land (Law 3986/2011). Servitudes (or easements) may also derive from agreements between interested parties, modifying regulations of the Law of Neighbours (Georgiadis, 2012). For example, the owner of a servient parcel may agree to tolerate emissions exceeding common use from the dominant parcel or affect the use of his land; alternatively, the servient parcel could be agreed not to emanate any emissions on the dominant one.

Common Law jurisdictions do not provide explicit restrictions on the types of easements that can be created. Several jurisdictions have issued detailed documentation presenting available permitted easement types, e.g. (Alberta Land Titles, 2002; Department of Sustainability and Development, 2013; Registrar of Titles and Registrar of Water Allocations, 2009). However, such enumeration is not considered to be exhaustive, allowing for different types of easements to be created. Besides, easements of different nature from already existing types, are usually not recognised by law (Akkermans, 2017; Clarke & Köhler, 2005; Registrar of Titles and Registrar of Water Allocations, 2009).

3.2.2 Usufruct

Usufruct is the personal servitude (or easement) that allows its holder the use and enjoyment of an immovable owned by another for a specific period of time, usually the life of the right's holder (usufructuary). Usufructuary's power of use can be limited, in case that restrictive conditions regarding the exercise of the usufruct have been agreed between him and the bare (or naked) owner. In several jurisdictions, e.g. Germany, if no such an agreement is made, usufruct constitutes the right that most closely resembles to ownership (Akkermans, 2008)[17]. Since right of disposal remains on the bare owner, the usufructuary cannot encumber the land by establishing other limited rights on it. Although the right of usufruct is not transferable, usufructuaries may cede this right to another person [German Civil Code, art. 1059, Greek Civil Code, art. 1166, Swiss Civil Code, art. 758(1)], lease, or even sell it (French Civil Code, art. 595, Spanish Civil Code, art. 480). Regardless the case, the usufruct is extinguished based on the conditions agreed between the usufructuary and the bare (or naked) owner. If no such an agreement has been made, civil code stipulations on the termination of usufruct apply, e.g. death of the usufructuary, consolidation of usufruct and bare (or naked) owner to the same person, or renunciation of the usufructuary. Termination of a right of usufruct entails that the bare owner enjoys absolute ownership of the immovable real property, free of the restrictions deriving from the establishment of the usufruct.

A usufruct may encumber an immovable as a whole, or may be apply to a portion of land, in favour of one or more usufructuaries, e.g. Greek Civil Code, art. 1144; Civil Code of Louisiana, art. 541. Regardless the case, establishing a usufruct on a thing,

[17] Art. 578 of the French Civil Code, also provides that things under usufruct are enjoyed by the usufructuary in the same manner as by the owner himself.

requires that its substance is preserved[18]. This condition is explicitly stipulated in several national civil codes (German Civil Code, art. 1036 (2); Greek Civil Code, art. 1142; Dutch Civil Code, 3:207; Polish Civil Code, art. 267, par. 1; Civil Code of Quebec, art. 1120; Civil Code of Louisiana, art. 539; French Civil Code, art. 578; Spanish Civil Code, art. 467; Swiss Civil Code, art. 769).

The right of usufruct mostly resembles to Common Law's life estate (Kinsella, 1994). The holder of a life estate interest (life tenant) has the right to possess an immovable real property and receive any revenues that may derive from it. Life estates last during life tenant's lifetime and can be disposed to another person. However, in such a case it is in force only during the lifetime of the original life tenant (*life estate pur autre vie*). Apart from the life tenant, a remainderman (or reversioner), holds the remainder interest after the creation of the life estate. When the life estate interest is extinguished (i.e. the death of the life tenant), the remainderman (or reversioner) acquires fee simple title for the immovable real property. In contrast with the usufruct concept, disposal of life tenancy by the original grantee to another person entails that the latter assumes all the rights and obligations related to the life estate interest (McClean, 1963).

3.2.3 Right of superficies

The right of superficies is used to dissociate ownership of a land parcel from constructions built on or, in some jurisdictions, below it in order to deviate from the *superficies solo cedit* principle. National terms used to define the right of superficies, include *droit de superficie* (France), *erbbaurecht* (Germany), *droit de superficie/ baurecht* (Switzerland), *superficies* (Canada, province of Quebec), *opstalrecht* (The Netherlands), *tomträtt* (Sweden). Translation of national terminology in English language also varies using terms such as *building lease* (Glock, n.d.; Schmid, Hertel, & Wicke, 2005), *building right*, or *site leasehold* (U. Jensen, n.d.; Swedish Land Code, Chap. 13).

According to the French Civil Code, the right of superficies can be described as a right of ownership over buildings and plantations, different and independent of the ownership of land (based on the translation of the French Civil Code by Rouhette & Rouhette-Berton, 2006). Similarly, Greek Law 3986/2011[19] defines the right of superficies as a right in rem that allows a natural or a legal person to make constructions on state-owned land and exercise on such constructions, or on already existing constructions on land, all powers deriving from the right of ownership[20]. Swiss Civil Code (art. 779) defines right of superficies (building right), as an easement that entitles a third party to erect or maintain a construction above or below ground. Similarly, German definition regards the right of superficies as a burden on a piece of land that provides the person who benefits from the creation of this right, the right of having a building upon or under the surface of the land (Akkermans, 2008). Swedish Land Code (Chap. 13, sec. 1) describes the right of superficies (site leasehold) as a right of user of a property unit during an indefinite period, for a certain purpose, in return for monetary ground rent. Civil Code of Quebec (art. 1110)

[18] According to the Dutch Civil Code (art. 3:207) and the Spanish Civil Code (art. 467), this condition may not apply if the bare owner and the usufructuary have agreed otherwise.

[19] As amended by Law 4092/2012.

[20] According to the introduction of Greek Civil Code (23.02.1946), the right of superficies was abolished in Greece. Rights of superficies pre-existing the introduction of the Greek Civil Code remained in force, although it is not allowed new ones to be established.

defines superficies as resulting from the "*division of the subject of the right of ownership of an immovable*", "*the transfer of the right of accession*" or "*the renunciation of the right of accession*"[21].

Duration of the right of superficies varies. Swedish rights of superficies may exist for an indefinite time period, while restrictions on maximum or minimum duration may be stipulated, e.g. art. 779 (l) of the Swiss Civil Code sets a maximum time period of 100 years, whereas Law 3986/2011 in Greece sets maximum duration up to 99 years, along with a minimum duration of 5 years (art. 19, sec. 2). Duration of the rights of superficies may also be defined by agreement between the involved parties.

As mentioned above, the right of superficies provides ownership right on buildings, plantations or constructions situated on another's land. Interpretation of these objects (buildings, plantations, constructions) needs to be conducted under the broad sense, including all types of constructions or installations already built or not yet constructed, by the time the right of superficies was established (Akkermans, 2008; Perakis, 2012). Therefore, the right of superficies can be considered to include both the right to build on another owner's land, and the right of ownership on built constructions (Akkermans, 2008).

Establishment of a right of superficies may be restricted to particular types of real property. Specifically, both Greek Law 3986/2011 (art.18) and Swedish Land Code (Chap. 13, sec. 2) limit the right's field of application to state-owned land, while provision is made so that real property belonging to foundations can also be subject to the right of superficies after Government permission. Swedish legislation also makes specific provision prohibiting the granting of rights of superficies (site leasehold) in a part of a property unit or in several property units conjointly (Land Code, Chap. 13, sec. 2).

Constructions built under the right of superficies constitute separate immovable objects and can be registered as such, e.g. Swiss Civil Code, art, 779; Law 3986/2011 of Greece, art. 19; Regulation on the right of Superficies (Erbbau-VO (Erbbaurecht-Verordnung) (Germany), par. 14; Swedish Land Code, Chap. 23, sec. 8). Therefore, other real property rights may be imposed on them, while they are transferrable and inheritable. However, specific restrictions apply on the real property rights that may be imposed on the rights of superficies as, despite their resemblance to the right of ownership, superficies remain a right inferior to ownership. Within this concept, a right of superficies cannot be burdened by another right of superficies, e.g. Sweden (Land Code, Chap. 13, sec. 1) and Greece (L. 3986/2011, art. 19), or by usufruct, e.g. Greece (L. 3986/2011, art. 19). Even in case that this is not explicitly prohibited, constructions' ownership passes to the holder of the newly created right (Akkermans, 2008).

In Common Law jurisdictions, the concept that most resembles to that of the right of superficies is *leasehold estate*, or *term of years absolute*[22] (Perakis, 2012).

[21] Although based on the French Civil Code, where separation between ownership of land and constructions on it is implied according to the art. 553 ("*All constructions, plantings, and works upon or within a tract of land are presumed made by the owner, at his expense and as belonging to him, unless the contrary is proved*"), The Civil Code of Quebec explicitly refers to the right of superficies in articles 1110-1118.

[22] Akkermans (2008), and (Erp & Akkermans, 2010) compare Common Law leasehold estate to Civil Law rights of emphyteusis and superficies.

Leasehold estate confers exclusive possession of land to the lessee for a determined period of time. Provided that the lease is of long duration, leasehold estate cannot be regarded significantly inferior to freehold title (Sparkes, n.d.), which is the most extensive entitlement that an individual may acquire within Common Law. Leasehold estates are created according to an agreement between the involved parts that sets the terms of their relation (Akkermans, 2008). Given the nature of leasehold, it can be often misinterpreted with license agreements. This leads to the need of defining whether an agreement between the involved parties provides exclusive possession to the right holder (Akkermans, 2008). According to Sim & Powell-Smith (1968), the intention of the parties "*as inferred from all circumstances*" is required to distinguish a lease from a license. Establishment of a leasehold estate, requires that its ending is certain and well defined (Sim & Powell-Smith, 1968). Several leasehold interests may exist over the same piece of land, while the holder of a right of leasehold may as well dispose of his right within a subsidiary lease, on condition that such disposal does not exceed the duration of the primary leasehold. Consequently, there are various forms of land tenure that may exist simultaneously over a single parcel of land (Xiaoyang Zhang, 1999).

3.2.4 Emphyteusis

Emphyteusis is a real property right that can be traced in several Civil Law and Civil Law based jurisdictions, such as France, Quebec, Spain and The Netherlands. This right allows its holder to hold and use an immovable owned by someone else, in exchange of annual ground rent (canon) (Akkermans, 2008; Jesper M. Paasch, 2011; Ploeger & Bounjouh, 2017; Jantien Stoter, Ploeger, & van Oosterom, 2012). National terms for emphyteusis rights are translated in English language as *long lease*, *building lease*, *long-term lease, land lease, leasehold* and *emphyteutic lease* (Milo, 2006; J. Paasch, 2012; Ploeger & Bounjouh, 2017; Ploeger & de Wolff, 2012; Smits, 2006; Storme, 2004). Rights of emphyteusis are established either by a contract or by will. Depending on jurisdiction, duration of such rights may be for a specific period of time or may apply in perpetual. For example, french Rural and Maritime Fisheries Code (art. 451-1), sets a minimum period of 19 years and a maximum of 99 years for the granting of emphyteusis rights. Similarly applies in the Civil Code of Quebec, which sets a minimum period of 10 years and a maximum of 100 years (art. 1197). On the contrary, the Dutch Civil Code does not set any limitations regarding the duration of the emphyteusis; according to article 5:86, the involved parties are to regulate its duration in the notarial deed by which emphyteusis is established. Other limited real rights may also be established against land held under the right of emphyteusis, including mortgages. In France, the holder of the right of emphyteusis also enjoys the right of accession during the emphyteusis (Rural and Maritime Fisheries Code, art. 451-10). In The Netherlands, buildings already constructed on land are also included within the emphyteusis, as well as those erected after its establishment although only as use rights (Akkermans, 2008).

Emphyteusis provides its holder the right to use and enjoy an immovable, as well as to benefit from the fruit that it produces, thus it can be compared to the personal servitude of usufruct. Indeed both rights provide their holder almost identical powers over an immovable. However, the right of emphyteusis is not connected to its holder in his personal capacity, compared to the personal character of usufruct; therefore, it is not related to the holder's lifetime (Akkermans, 2008). According to (Jesper M. Paasch, 2005), the power provided by this right, both on the land on the

constructions, is so strong that it can be comparable to the right of ownership. Dutch emphyteusis (*erfpacht*) retains another characteristic of usufruct, meaning the restriction of non-alteration of the immovable's function [Dutch Civil Code, art. 5:89 (2)], unless the owner provides his consent. Similar provisions can be traced also in the Civil Code of Quebec (art. 1195), that explicitly requires that the right holder does not endanger the existence of the immovable, and undertakes to make constructions, works or plantations thereon that increase its value in a lasting manner. On the other hand, such a restriction does not apply to the French emphyteusis (*emphytéose*). In The Netherlands, emphyteusis has been extensively used, under different typologies, for different types of use and duration, especially in municipally owned land (Ploeger & Bounjouh, 2017), including housing, agricultural, commercial and industrial purposes. The variety of situations, traced in Dutch literature, where emphyteusis rights are used, along with their objectives, lessors and lessees is summarised in (Ploeger & de Wolff, 2012).

In France, emphyteusis has been left out of the Civil Code, to be later allowed by court decisions and was re-introduced by the Rural and Maritime Fisheries Code (Y. Chang & Smith, 2015). Different typologies of the French emphyteusis can be traced in other legal documents, such as the General Local Authorities Code (Code Générale des Collectivités Territoriales) and the Code of Construction and Habitation (Code de la Construction et de l' Habitation). The type of emphyteusis right to be established, is dictated by its purpose. For example, an administrative emphyteutic lease (*bail emphytéotique administrative*) can be applied to immovables of the public domain that are destined to public benefit purposes. Construction lease (*bail à construction*) operates similarly with the emphyteusis right, but imposes on the right holder the obligation to build (Code of Construction and Habitation, art. 251-3). Finally, rehabilitation leases (*bail de rehabilitation*) operate similarly to construction leases, under specific restrictions to support social housing purposes (Akkermans, 2008).

3.2.5 Composite ownership

Composite ownership types are of "binary" nature, constituting of rights on land and on a part of a building constructed on such land. National terminology to describe composite ownership types differs, including terms such as *condominium*, *apartment right*, *horizontal property*, *strata title,* and *commonhold*. In this section, the term condominium is preferred, as it is a commonly used term worldwide and it does not specify on particular use types of the involved property units. Condominium concepts are among the most popular across the globe for the horizontal and vertical subdivision of land parcels into privately-owned units (Rosen, 2016). The notion of condominium is based on an, indivisible, tripartite structure (C. Van der Merwe, 2015) including, indivisibly, (i) individual ownership on a specific condominium unit within a building, (ii) shared ownership of the parcel and the building's common parts (e.g. garden, roof, elevator, or any other structures or building parts that are not related to building's apartments), and (iii) membership to the owners' association. Condominium is a term mostly used within Civil Law jurisdictions (along with horizontal property and apartment right), as well as in the United States and a number of Canadian provinces. On the other hand, the majority of Common Law jurisdictions use the term strata title. Within a condominium concept, the apartments of a building acquire the characteristics of individual land parcels since they can be separately owned, conveyed, transferred or mortgaged (Kerr, 1963). The majority of condominium legislation internationally was introduced during the period

of 1920-1970 (Andreone, 2011; C. G. Van Der Merwe, 2002; C. van der Merwe, 2016) for accommodation purposes. However, in several jurisdictions condominium concepts are also used for commercial or industrial purposes, e.g. Germany, Austria, Switzerland and Denmark (Mytrofanova, 2002 according to Jenny Paulsson (2007)).

Condominium concepts can be further classified in two categories, *unitary* (or *user right*) and *dualistic* (or *ownership right*) systems. This classification is based on the component that is considered of most importance within the condominium scheme (C. van der Merwe, 2016). Unitary systems regard co-ownership of the land and the constructions on it, as the most significant element of the condominium scheme. Ancillary to it, a right of exclusive ownership of an apartment is provided to each owner (C. van der Merwe, 2016). Unitary condominium systems can be traced in Austria, Croatia, Italy, Switzerland, The Netherlands and Norway (Jenny Paulsson, 2007; C. van der Merwe, 2016). Dualistic system, on the contrary, provides each owner individual ownership of an apartment along with co-ownership of the common property parts. This system is more popular to the rest of European countries, China, Russia, the United States and South American countries.

Regardless the type of condominium concept that applies in each jurisdiction (unitary or dualistic), the object on which ownership right applies, needs to be unambiguously defined[23]. As regarding apartment ownership, the boundaries separating individual apartments[24] or separating apartments from common property, are usually defined by reference to floors, walls and ceilings. Nevertheless, depending on the specifications of the legal instrument used to establish the condominium, the following approaches can be traced in national condominium laws.

- Boundaries in the middle of floors, walls and ceilings. In this case, the boundary between individual and common property lies on the middle of the building structure, for horizontal structural elements (e.g. floors and ceilings), precluding elevated floors or suspended ceilings; in case of vertical structural elements (e.g. walls, windows, doors and balustrades), middle is considered the midpoint between the exposed surface of the vertical structural element and the relevant building part (Fig. 7-top)

- Boundaries as the interior or exterior face of floors, walls and ceilings. In case of floors or ceilings, interior faces reach up to the upper surface of elevated floors or the underside of suspended ceilings, including any internal coverings and attached fixtures (Fig. 7-bottom left). Similarly, boundaries on exterior faces, run the exterior of any wall or other external part of the building (Fig. 7-bottom right).

- Other location used to define boundaries. In such case, a different location from the above mentioned is used to define the boundaries of individual and common property areas, e.g. Victoria (Subdivision (Registrar's Requirements) Regulations, 2011). For example, in the United States (Uniform Common Interest Ownership Act, 2014; Uniform Condominium Act, 1980), boundaries can be defined by reference to the plane of the unfinished floors, walls or ceilings. The space included within these boundaries, including all spaces,

[23] In accordance with the *specialisation principle* that requires real property rights to relate to a specific, unambiguously identified object (i.e. land) and subject (person-right holder).

[24] Alternative definitions depending on jurisdiction can be used such as *lot, section, private portion* or *unit.*

partitions and improvements, is regarded as part of the individually owned unit. Special reference is made on fixtures that are designated to serve a

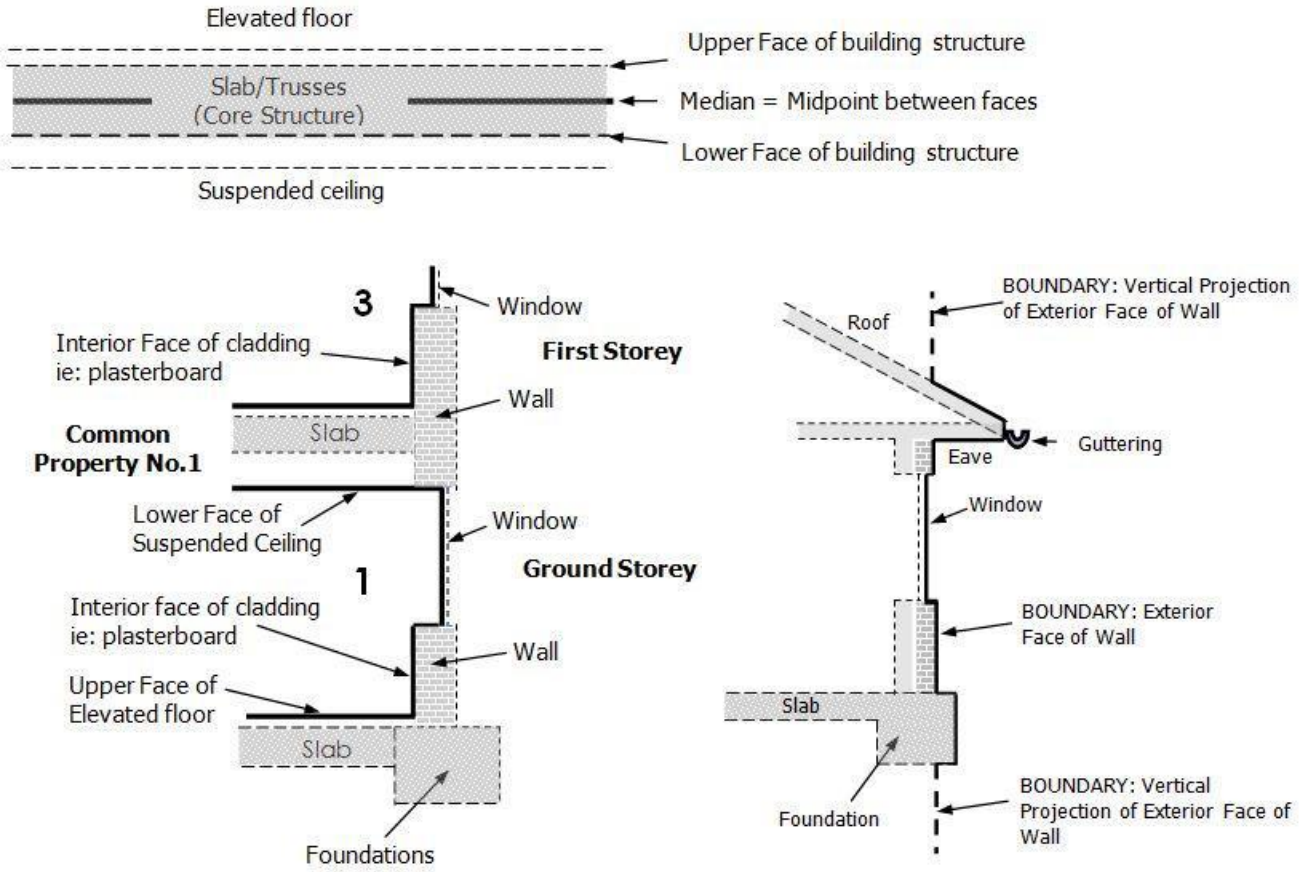


Figure 7. (Top) Median, (bottom left) Interior surface, (Bottom right) Exterior (Government of Victoria 2011)

specific property unit but are located outside its boundaries. These, constitute limited common elements, exclusively allocated to the unit they serve. In Queensland, the boundaries of exclusive use areas can be defined by referring to structural features (in case that the area of exclusive use consists of more than three sides, out of which all but one are at right angles), using survey marks to mark corners, or by delineating or dimensioning the boundaries (Department of Natural Resources and Mines, 2013). In Alberta, Condominium Property Act (sec. 9) stipulates that the only portion of a floor, wall or ceiling that forms part of the condominium unit is the finishing material that is in the interior of that unit. In Sweden, boundaries include the area necessary to allow practical use of an apartment (for example, hammering nails on the walls) (3D Cadastre Questionnaire, 2014). Condominium units' boundary definition with no reference to floors, walls, or ceilings is also provided in condominium laws of several European countries, especially regarding parking spaces, e.g. Germany, Austria and The Netherlands (C. van der Merwe, 2016). For example, according to the German Act on the Ownership of Apartments and the Right of Permanent Residency (Wohnungseigentumsgesetz, WEG) [sec. 3 (2)], the surface area of parking spaces may be identifiable by permanent markings.

Common parts within a condominium concept can be defined either by explicit reference to the objects considered as common property, or exclusively. In the latter case, common property includes everything that is not individually owned (Jenny Paulsson, 2011) and it is mainly followed by Common Law jurisdictions (e.g. US, UCIOA; California Civil Code, sec. 6542; NSW Strata Schemes Development Act, sec. 4; Alberta Condominium Property Act, sec. 1(f); Queensland Body Corporate and Management Act, sec. 10). Detailed reference on the elements that constitute common property can be mainly traced on Civil or Civil Law based[25] jurisdictions such as Greece (Law 3741/1929, art. 2), Quebec (Civil Code, art. 1044), France (Law 65-557, Chap. 1, art. 3) and Switzerland (Civil Code, art. 712b). Different perception is followed by the Tenements (Scotland) Act. According to sec. 3, rights of common property are attached to the units not included in an apartment (flat). Common property rights are attached on such units as pertinent rights to the apartment they serve. Common property along with structural elements that ensure the structural integrity of a building, such as foundations or load-bearing walls, beams and columns [Tenements (Scotland) Act, Schedule 1], constitute "scheme property" which is under collective maintenance and management (C. G. Van Der Merwe, 2002). However, outer building walls pertain to the ownership of the apartment which they delineate (C. G. Van Der Merwe, 2002). Similarly, owners of the top and bottom apartments also extend to the roof over and the ground below them respectively [Tenements (Scotland) Act, sec. 2]. In case that specific parts of the common property are allocated to the exclusive service of one or more, but not all, apartments of a condominium, these constitute *limited common property* or *exclusive use area*. Unless different arrangement is provided by the documentation establishing the condominium scheme, limited common property is considered common property; however, expenses related to limited common property are covered by the apartments that benefit from it. Such rights are mainly traced in the United States' UCIOA (sec. 2-108, Comment 1; sec. 3-107, Comment 1), South Africa (Sectional Titles Act, art. 1), Louisiana (Louisiana Condominium Act, par. 1121-103), Strata Schemes Management Act (sec. 142), Alberta (Condominium Property Act, sec. 50), British Columbia (Strata Property Act, sec. 1) and several European countries. In Germany, although exclusive use areas are not sanctioned by statute, they are recognised by the German Federal Court and can be registered to the land register (C. G. Van Der Merwe, 2002).

Ownership of common property vests in each owner that holds apartment ownership rights, either proportionately (based on apartment's value or area compared to the value or area of the whole building), or on the basis of one share per apartment. An exception to the common property ownership concept can be traced in the UK condominium concept (commonhold), where common property is owned not by the individual apartment owners, but from the commonhold association (which, however, consists of individual apartment owners).

[25] However, exceptions can still be traced. For example, Condominium Act of Louisiana (par. 1121.103) defines common property (*common elements*) as "the portion of the condominium property not a part of the individual units". Similarly, German Act on the Ownership of Apartments and the Right of Permanent Residency (*Wohnungseigentumsgesetz, WEG*) defines common property as "*the plot of land as well as those parts, facilities and installations of the building which are neither separately owned property nor property owned by a third party*" (sec. 1).

Owners' associations are legal bodies acting on behalf of all owners within a condominium, responsible for the management of condominium schemes (Jenny Paulsson, 2007). Terminology used in different jurisdictions differs including *commonhold associations* (UK), *strata corporations* (British Columbia), *cooperatives* (USA), or *condominium corporations* (Alberta). Usually, each apartment's share within the owners' association is based on the apartment's share on the common property. However, depending on the document establishing the condominium, the share of an apartment on common property may differ from its share within the owners' association. For example, Uniform Common Interest Ownership Act (UCIOA) of the United States allows share allocations to be made on different basis (Sec 2-107, Comment 2). Apartment value, is the most common basis for the assessment of each apartment's share in an owners' association. However, condominium legislation may also provide for other features to be used for assessing apartments' shares, such as area (South Africa, Sectional Titles Act 1986), any other type of formula selected during the drafting of condominium establishment documentation (United States, Uniform Common Interest Ownership Act, sec. 2-107, Comment 2; Louisiana, Louisiana Condominium Act, sec.1122.106), or even equal distribution of shares among the apartments that a condominium consists of (Scotland, Tenements (Scotland) Act, Schedule 1, Rule 2; UCIOA).

Apart from three-dimensional cubic spaces defined by reference to floors, walls and ceilings, a condominium may consist of unenclosed ground space, airspace, or spaces filled with water as well. Such provisions can be traced in UCIOA, while provision of condominiums consisting of air space can be found in Louisiana Condominium Act. Condominium may also be used to divide the utilisation of physical formations, e.g. caves, or even to divide parcels with no constructions (*bare land condominiums*) on them, e.g. Manitoba, The Condominium Act; (British Columbia, 2016); California Civil Code, sec. 6542; Alberta, Condominium Property Act, sec. 1-y (ii).

Sandberg (2001), argues that condominium can as well be used in case of underground buildings or "linearly" built structures. In Civil Law jurisdictions, legislation may provide for condominium units for purposes other than residence; for example, German Act on the Ownership of Apartments and the Right of Permanent Residency (Wohnungseigentumsgesetz, WEG) stipulates that title to units (*Teileigentum*) in respect of non-residential areas within a building can be created (sec. 1). However, provision for the establishment of bare land condominiums is not common. Such a provision can be traced also in the Dutch Civil Code (art. 5:106, 2) that allows a bare plot of land to be split on several apartment rights[26]. On the contrary, in Sweden condominium is restricted only for accommodation purposes (Jenny Paulsson, 2012).

In Greece, apart from horizontal properties, another type of composite ownership is *vertical ownership*, based on Decree-Law 1024/1971. Vertical ownership requires at least two buildings to be constructed on a land parcel. Vertical ownership allows for separate ownership of a building or buildings, indivisibly with a co-ownership share on the land parcel. Vertical ownership can be further subdivided in apartments under condominium legislation, constituting a *composite vertical ownership*. The

[26] According to art. 5:106 (4) of the Dutch Civil Code, an apartment right may also refer to specific parts of the bare land plot.

difference between condominium and vertical ownership lies both on the number of buildings constructed on a land parcel, and on the object of exclusive ownership (Georgiadis, 2012): in the former case, condominium requires only one building while in vertical ownership more than one buildings are required on the land parcel; in the latter, a floor (or an apartment) is exclusively owned (in case of condominium), while in vertical ownership, exclusive ownership concerns one or more buildings (or an apartment of such building) (Georgiadis, 2012).

3.2.6 Indirect ownership

Condominium concepts have been developed in order to overcome both the limitations deriving from the *superficies solo cedit principle* regarding multi-surface ownership, and those deriving from, pre-existing, indirect types of ownership (Kenin, 1962; Sherry, 2009), such as tenant-ownership, limited companies or housing co-operative structures (Jenny Paulsson, 2007). All forms of indirect ownership constitute of a collective entity that holds the ownership of a development and grants rights of occupancy to its members. The type of indirect ownership right, dictates the type of:

- the collective association (owners' association, company, private or non-profit housing society),
- the participation of individuals to such associations (shares or blocks of shares) and
- the rights of each member of the owners' association on the real property (apartment ownership or exclusive use, participation to building management, conveyance right, mortgaging).

Indirect ownership concepts have been developed to support accommodation purposes. They are very popular in Scandinavian countries but can also be traced in many countries globally, such as the United States, Canada, Latin America and African countries. Since indirect ownership concepts are mainly focused on accommodation purposes, they will not be further elaborated. Specification on the characteristics of indirect ownership can be traced, indicatively, in (Bengtsson, 1992; McStotts, 2004; Jenny Paulsson, 2007; C. van der Merwe & Nedelmann, 1996).

3.2.7 Special real property rights and objects

Given the specifications of each country, and the needs to subdivide real property in strata, special real property rights have been introduced. Such rights may be statutory or customary, developed through historical, cultural, religious or other types of influence. The following subsections present characteristic cases of unique, national cases of 3D real property rights and 3D real property objects, as compiled by Kitsakis & Dimopoulou (2014) and Kitsakis et al., (2016).

3.2.7.1 Waiving right of accession-reverse accession

In Belgium, a land owner is allowed to waive his right of accession, which is regarded as building right (*Real Property Law - National Report Belgium*, 2004). In case that another party has erected constructions on land where the right of accession is waived, then this party is considered to be the perpetual owner of the constructions (Vandehouwe & Pieters, 2010). Waiving of the right of accession is not stipulated in Belgian legislation; it derives from a decision made by the Supreme Court of Belgium, that regards waiving of the right of accession as a building right [Arr.Cass., 1987-88, 1230 (according to (*Real Property Law - National Report Belgium*, 2004)].

In contrast with Belgium that allows a land owner to waive his right of accession, Swiss Civil Code (art. 673) provides for *reverse accession*, allowing the owner of constructions of land to acquire ownership of the land parcel. Reverse accession can be applied in case that the value of constructions on the land parcel plainly exceeds the value of land.

3.2.7.2 Qualitative obligation

In The Netherlands, a restrictive covenant can be used in order to impose the owner of a land parcel the obligation of tolerating something on his land. Such a restrictive covenant is binding the future owners of the land parcel (Ploeger & Stoter, 2004) and it is defined by the term *qualitative obligation* (*kwalitatieve verplichting*) (Ploeger, van Velten, & Zevenbergen, 2005). Qualitative obligation right is regulated under the Law of Obligations within the Dutch Law and it is established upon registration of a notarial deed (Dutch Civil Code, 6:252) similarly to the procedure required for the establishment of limited real rights. In Dutch literature, this type of right is characterised as a servitude without a dominant parcel, compared to personal servitudes (Milo, 2006; Jesper M. Paasch, 2005) Milo, 2006). According to (Jesper M. Paasch, 2005), it is difficult to classify this right among real and personal rights whereas, based on its practical consequences, it is claimed that qualitative obligation can be regarded as a real right.

3.2.7.3 Agreement of joint possession

In Finland, Code of Real Estate (Chapter. 14, sec. 3), provides within the chapter on special rights registration, the *agreement of joint possession*. This is an ownership arrangement where involved owners define the separate parts of an estate or a building that will be owned by each one (Ralli & Weckström, n.d.).

3.2.7.4 Perpetual usufruct

Polish Civil Code, stipulates within its list of real property rights the right of *perpetual usufruct* (*Użytkowanie wieczyste*) (Szafarz, n.d.). Perpetual usufruct provides its holder a broad set or rights, comparable only to the right of ownership (Szafarz, n.d.). According to Polish legislation, perpetual usufruct can be established only on specific types of land, owned by the State Treasury or by local authorities, for a specific duration and for a specific purpose (Radel, 2008). Buildings or constructions existing prior to the establishment of perpetual usufruct, or that have been erected afterwards, are owned by the holder of the perpetual usufruct, while they are subject to other limited real rights (Radel, 2008). After the establishment of perpetual usufruct, the powers of the land owner are significantly constrained. The land can neither be encumbered nor sold to any party, other than the State Treasury, local authority, or to the holder of the perpetual usufruct himself (Szafarz, n.d.).

3.2.7.5 Special Real Property Objects (SPRO)

Special Real Property Objects (SRPO) are specific forms of real property created under customary law. “Custom” is a role of conduct, obligatory by those within its scope, established by long usage (World Intellectual Property Organization (WIPO), 2013). Customary law derives from a combination of, among others, historical, cultural, social or religious influence within a region. Despite their deficiencies, such as non-codification or their incompetence to be controlled through public administration, customary rights provide functional tenure security in local communities by constituting well known and widely used procedures for land allocation, boundary demarcation, adjudication and dispute resolution (Cousins & Hornby, 2006). Currently, customary rights mostly apply in the African and Asian countries, while

withering within the Western ones. However, even in the latter, regions where customary rights apply, especially involving real property, can still be traced (Dimitrios Kitsakis, Apostolou, et al., 2016).

In Greece, customary law ceased to apply since the introduction of the Civil Code of 1946. However, customary real property rights applying to 3D space, pre-existing the establishment of the Civil Code, are still in force and are mainly traced in the Aegean and the Ionian islands (Arvanitis, 2014; Papaefthymiou, Labropoulos, & Zentelis, 2004) (Papaefthymiou et al., 2004; Arvanitis, 2014, p.15). Within the context of the Hellenic Cadastre, these specific types of real property, established by customary law, are defined as Special Real Property Objects and include the following (Efi Dimopoulou, 2015):

- *Anogeio*
  Real property object lying over a land parcel with no share on surface parcel ownership (figure 8a).
- *Katogeio*
  Real property object that includes ownership only of a land parcel, while the rest of the structures on land constitute “anogeio” objects (figure 8e).
- *Anogeiokatogeio*
  Combined case of “anogeio” and “katogeio”.
- *Yposkafo*
  Construction built below another parcel, usually dug into the earth (figure 8b).
- *Arches*
  Property objects extending over a street or a road (figure 8c).
- *Syrma*
  Construction built on the seashore to draw boats during winter (figure 8d).
- *Wells and drillings*
- *Tanks*
- *Pumping stations*
- *Aqueducts*
- *Windmills*

- *Domes*

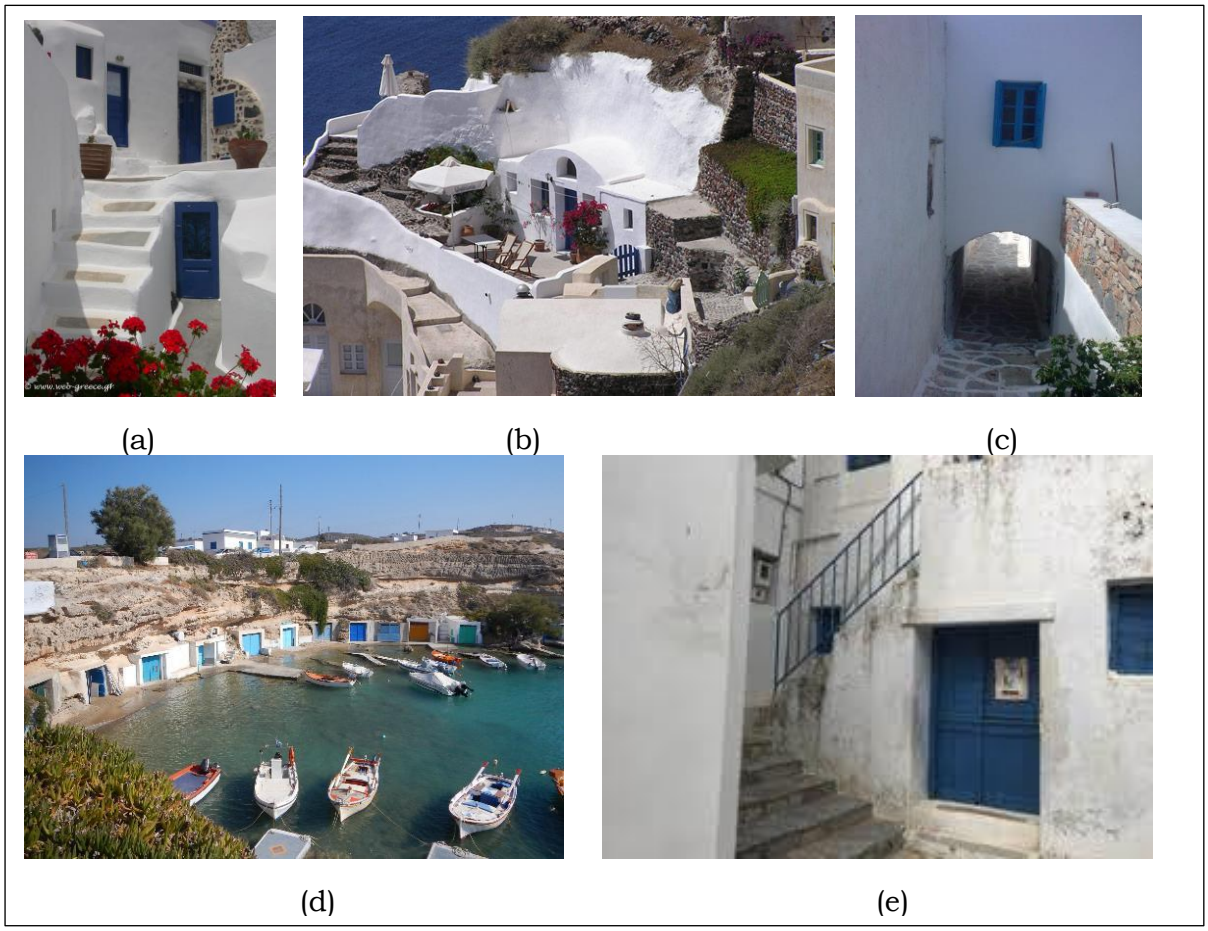


Figure 8. Characteristic cases of SRPO in Greece.

In case of SRPO, the owner of the surface parcel is not necessarily the owner of the buildings on it, as would apply according to the *superficies solo cedit* principle, while the boundaries of SRPO do not follow those of their underlying land parcel (Ministry of Reconstruction of Production Environment and Energy (Greece), 2013). For the purposes of cadastral registration, the three-dimensional character of SRPO is

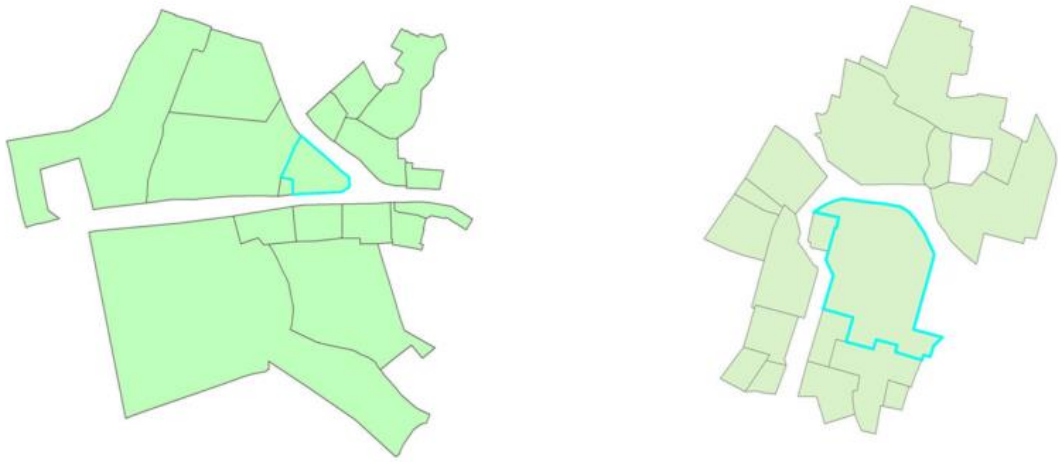


Figure 9. Presentation of SRPO in Greek cadastral maps (courtesy of Hellenic Cadastre).

reduced in 2D representation using special symbology, to present them either as surfaces or as points on the cadastral map (Tsiliakou & Dimopoulou, 2011) (Figure 9).

4. Relation between physical and legal space

Land recording and mapping carry a long history, dating from ancient Mesopotamia and Egypt (Fig. 10). During the years, different types of tenure and land rights have been developed, based on the cultural, religious, economic and historical characteristics of each society. The evolution of the relation between people and land, from tribal communities to the feudal period and then from the industrial revolution to capitalism and socialism is described by (L. A. Ting, 2002). This work also highlights the impact of individuals' economic imperative, as well as the updated role of local communities on the management of their surrounding environment.

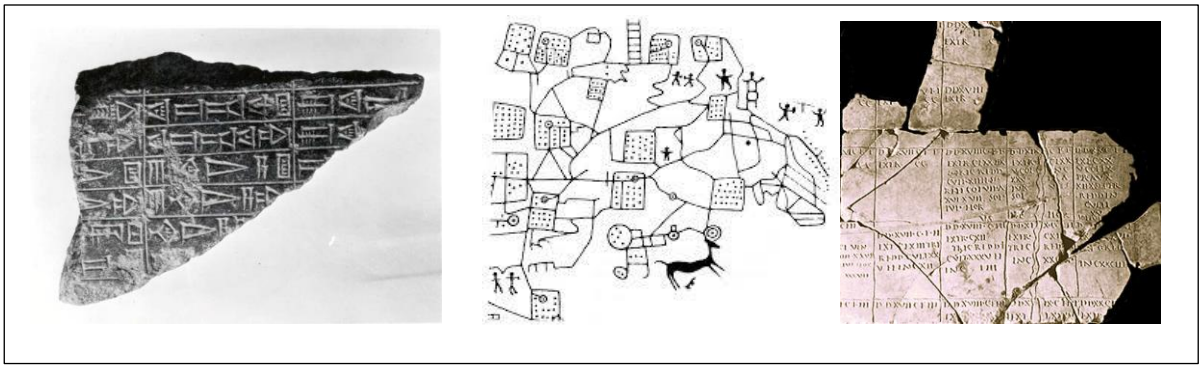


Figure 10. Cadastral recordings of ancient Mesopotamia (left), Egypt (centre) and Rome (right) (https://www.metmuseum.org, 2018; J. Wallace, 2007; https://en.wikipedia.org, 2018)

4.1 Classifications of land registration systems

Land registration systems play significant role in registration of stratified real property units, as they dictate the required scale and resolution of spatial data, their thematic and geometrical attributes, the administrative organisation of cadastral authorities, the types of recorded data and the maintenance costs of cadastral infrastructure (Jantien Stoter and van Oosterom, 2006). This section presents some of the types of land registration systems that are traced in literature, so that aspects of technical and administrative components of registering stratified real property units can be identified.

Land registration systems can be classified in several ways. One of the most common distinctions is between *title registration* and *deed registration*. Henssen (1995), describes title registration systems to be recording the legal consequence of a transaction, in contrast with deed registration systems where the legal document describing an isolated transaction is recorded. Title registration provides direct and comprehensive information regarding the rights of a beneficiary over a land parcel. On the contrary, within a deed registration system, the ostensible owner is required to trace his ownership to a good root of title (Henssen, 1995). The main principles of both title and deeds registration systems, including their advantages and drawbacks are presented in detail by (J. A. Zevenbergen, 2002). Depending on their purpose, cadastral systems can be distinguished in *fiscal* and *legal*. The former are developed to support real property taxation, dating back to the Napoleonic era, while the latter focus on securing real property rights on land. According to Bogaerts & Zevenbergen (2001), fiscal cadastres are simpler than legal ones because they do not need to be so frequently updated; fiscal cadastres require to be annually updated, while legal cadastres need daily update. Additionally, accuracy requirements of a fiscal cadastral map can be reduced if real property tax is based on valuation (land value). On the

contrary, legal cadastres require high-precision cadastral maps, so that the extent of a real property right is unambiguously defined. Emphasising on the guarantee and indemnity of registration systems, they can be distinguished in *positive* and *negative* systems (J. A. Zevenbergen, 2002). The former guarantee titles registered, while the latter are limited in guaranteeing mistakes in keeping the registers, but do not provide any guarantee regarding the actual title registered (J. A. Zevenbergen, 2002). Another classification, based on the type of cadastral registration and the level of the involvement of authorities, is between *systematic* and *sporadic* systems (J. A. Zevenbergen, 2002). Such classification can be made in case of newly introduced cadastral systems. Classified based on boundary schemes, *general boundary systems*, based on general physical features, and *fixed boundary* systems, based on precise surveyed boundaries can be distinguished (Henssen, 1995; J. A. Zevenbergen, 2002). Lyons et al. (2002), according to (R. Bennett, 2007) classify registration systems based on the interests recorded on titles, to *above the line systems* (interests that are recorded on titles and are guaranteed by the state) and *below the line systems* (interests are not recorded on the title but on disparate databases, without state guarantee). J. Zevenbergen (2004) applies systems' classification to static and dynamic by Kast & Rosenzweig (1970) to land registration, distinguishing *static* and *dynamic* models of land registration. Static models emphasise on the entities that are recorded (e.g. owners, rights and parcels), while dynamic models focus on describing the main functions that cadastral systems need to fulfil (adjudication, transfer and subdivision) (J. Zevenbergen, 2004).

4.2 Land Objects

Although real property RRRs in most cases relate to physical objects on the ground, they constitute part of the legal domain that can be described as a standardised system of group or individual behaviour in specific areas, based on formalised rules, regulations or court decisions (Jesper M. Paasch, 2007). The variation between literally defined legal space and its corresponding physical space is reflected on registration systems, resulting to ambiguous spatial referencing of legal objects, and deficiencies in real property registration and presentation on cadastral maps (Kalantari et al. 2008). Technological advances on geosciences, and especially geoinformation technology, fuelled scientific interest towards correlation between physical and legal space.

The concept of *land object* was introduced by Kaufmann & Steudler (1998), to denote a piece of land where homogeneous conditions exist within its boundaries. Land objects can be further classified in *legal land objects* and *physical land objects*. The former are created when RRRs are imposed on a land object by Private or Public Law, while in case of the latter, no juridical parameters are imposed. Land objects' concept has proved very attractive to researchers on land administration systems, due to its flexibility to integrate modern cadastral developments, interests and commodities (R. Bennett 2007; Kalantari et al. 2008; Karki, Mcdougall, and Thompson 2010). Bennett (2007), on his laborious work on the development of a framework for understanding and organising the management of RRRs for sustainable development, introduces the concept of the "*property object*". The property object is an extension of the land object that describes RRRs in detail, by using five attributes: (i) RRR's objective, (ii) the action that is regulated by an RRR (iii) the spatial extent on which an RRR applies, (iv) the duration that an RRR applies and (v) the people impacted by the

application of an RRR (R. Bennett, 2007). An enhanced model of land objects is also proposed by Kalantari et al. (2008), who support the replacement of physical parcels, as fundamental units of land administration systems, by *legal property objects* so that the broad range of RRRs and land related information could be incorporated to the cadastral fabric. The use of land parcels as the fundamental entity of cadastral systems provided a variety of advantages, such as the efficient organising and indexing of land-related information in land registration systems. Additionally, it facilitates registration and presentation of private law-based rights which constitute the basic records of cadastral systems (Kalantari et al. 2008). The legal property object emphasises on the legal attributes imposed within a specific space, in order to register non-parcel based interests of both Private and Public Law (Kalantari et al. 2008; Karki, Mcdougall, and Thompson 2010a). Spatial-unit model is also provided within Korean resurveying project. Spatial unit objects have been introduced to represent 3D objects and underground structures within Korean resurveying project, aiming to relate 3D rights on land with high accuracy information on buildings and underground facilities (B. M. Lee, Kim, Kwak, Lee, & Choi, 2015).

Aien, Kalantari, Rajabifard, Williamson, & Wallace (2013), note the lack of an integrated cadastral model able to maintain both physical and legal objects and propose a conceptual 3D cadastre data model that exploits semantic data to integrate legal objects to their physical counterparts. Instead of extending virtual 3D city models to support legal cadastral objects, the opposite approach is followed, i.e. extending core cadastral data model to support physical models (Aien, Rajabifard, Kalantari, & Shojaei, 2015). This model uses the concepts of Legal Property Object (LPO) and the Physical Property Object (PPO), proposed by Kalantari et al. (2008). The conceptual model of integrating legal and physical objects' models within the proposed cadastral data model is presented in Figure 11.

Transition to “land object-based” cadastral systems remains premature due to the extensive legal, technical and administrative amendments that would be required to the well-established parcel-based model. However, the emerging role of cadastral systems as tools providing multi-purpose, land-related information clearly depict the need of cadastral systems to evolve, by extending to the third dimension and to be related to broader legal and social interests on land (Intergovernmental Committee for Surveying and Mapping, 2015).

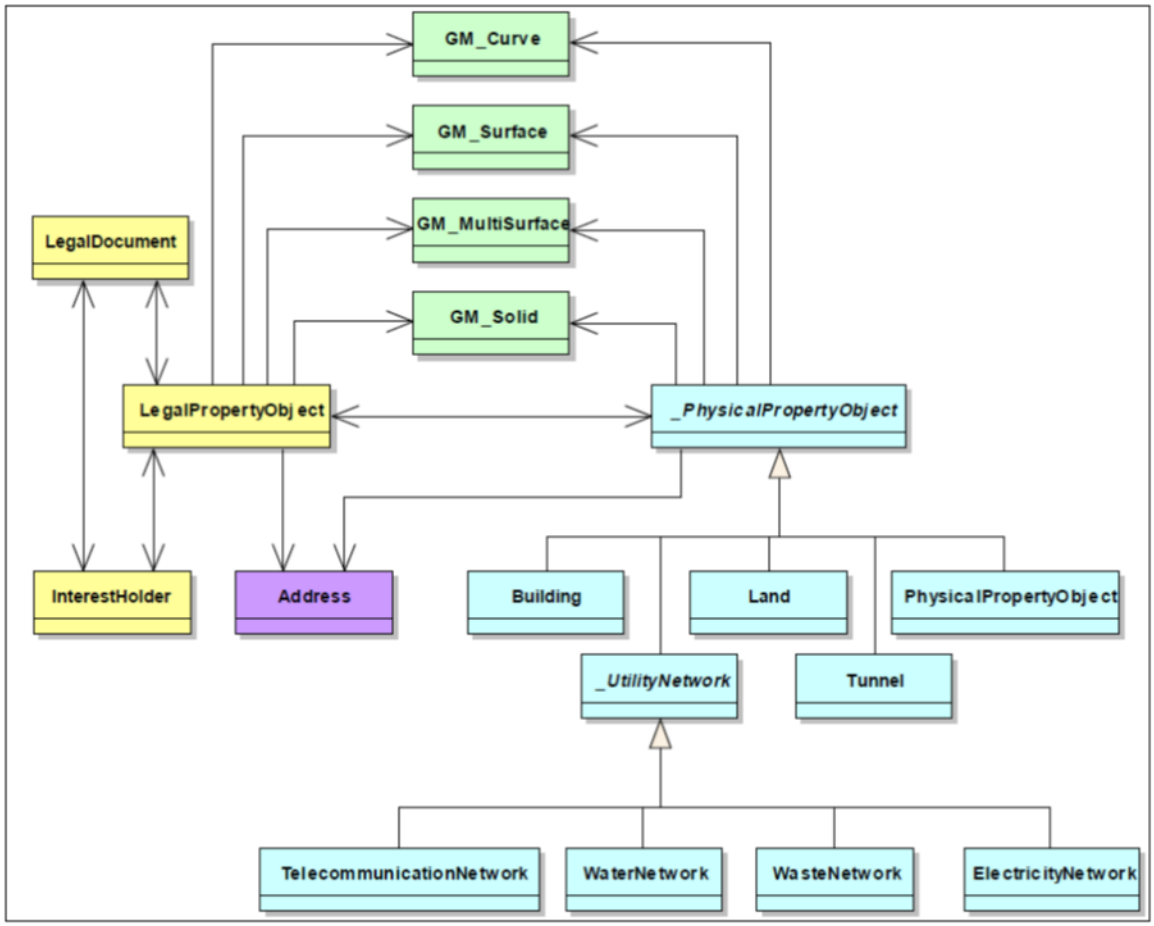


Figure 11. Conceptual model of integrating the legal and physical objects in the 3DCDM model (Aien et al. 2015).

Land objects can be traced in the countries of Latin America. However, explicit reference is only made in Argentinean legislation, while in the rest of the Latin American countries land objects exist within substantive and ancillary legislation, although not explicitly defined as such (Diego Alfonso Erba & Piumetto, 2012). National Cadastral Law of Argentina, defines a territorial object as any portion of land that, by nature and means of access, is finite and homogeneous (Diego A. Erba & Graciani, 2011). The same law defines legal territorial objects (*Objeto Territorial Legal-OTL*) as territorial objects generated by a legal cause (Diego A. Erba & Graciani, 2011). Legal causes may include property titles (in case of real property transactions), laws or ordinances (in case of ownership restrictions, creation of reservation areas, or the demarcation of urban areas) or even international treaties (Dimitrios Kitsakis et al., 2018). Legal territorial objects constitute a flexible solution, assigning legal interests to their corresponding spatial entities (Kalantari et al., 2008). Compared to land parcel, a land object can be considered to include a broader variety of land

entities, since it does not pertain only Private Law rights. Furthermore, legal land objects need not necessarily to be land parcels, as provided in art. 10 of the National Cadastral Law of Argentina (Diego A. Erba & Graciani, 2011). Legal land objects are easier represented since they are related to a specific legal description (Diego Alfonso Erba & Piumetto, 2012). However, legal descriptions may be defined based on non-geometrical characteristics (for example restrictions based on soil permeability for groundwater protection), or may even be implied (as in case of landscape protection), introducing difficulties on 3D objects' registration and modelling (Kitsakis et al., 2019). Given that land objects, and especially legal land objects, are closely related to Public Law Restrictions (PLR), further elaboration on this issue can be found in section 5.6.

4.3 Land Administration Domain Model (LADM)

Standardisation has grown very popular during the last decades as it provides efficiency and facilitates communication based on common terminology (Lemmen, 2012). Kerwer (2005), notes that standards are better adopted to national frameworks compared with international legislation, due to their voluntary nature, the moderate formalities required for their introduction, their interoperability, and the motivation of compliance they encourage. Standards regulate an extensive number of fields including metrology, telecommunications, food technology and information technology (International Organization for Stadardization (ISO), 2019). In the field of Land Administration, Lemmen (2012) identified the need for "*domain specific standardisation to capture the semantics of the land administration domain on top of the agreed foundation of basic standards for geometry, temporal aspects, metadata, and also observations and measurements from the field*" (p. 11). His research resulted to the development of the Land Administration Domain Model (LADM) that has been adopted as an international standard in 2012 (ISO 19152), while a variety of research on the development of national profiles based on LADM can be traced in literature (Bydlosz, 2013a; Choon, Zulkifli, Ujang, & Chin, 2015; Hespanha, 2012; Janecka & Soucek, 2017; Jenni, Lopez, Stefan, & Pérez, 2017; Zulkifli, Rahman, Jamil, & Hua, 2014). Currently (2018), LADM is under revision process to adjust to the growing users' requirements. LADM is a conceptual schema that comprises of three packages and one subpackage, representing four core classes (Lemmen, 2012):

- Party package, representing parties (core class LA_Party);
- Legal/Administrative package, representing rights, restrictions and responsibilities (core classes LA_RRR, LA_BAUnit);
- Spatial Unit Package, representing spatial units (core class LA_SpatialUnit);
- Surveying and Spatial Representation Subpackage, subpackage of the Spatial Unit Package.

Each of the LADM classes comprises of specialisations that include specific attributes, while code lists are used to express potential values of each attribute,

ensuring that the model is flexible to adapt to local, regional or national terminology (Lemmen, 2012). An overview of Version C of LADM, is presented in Figure 12.

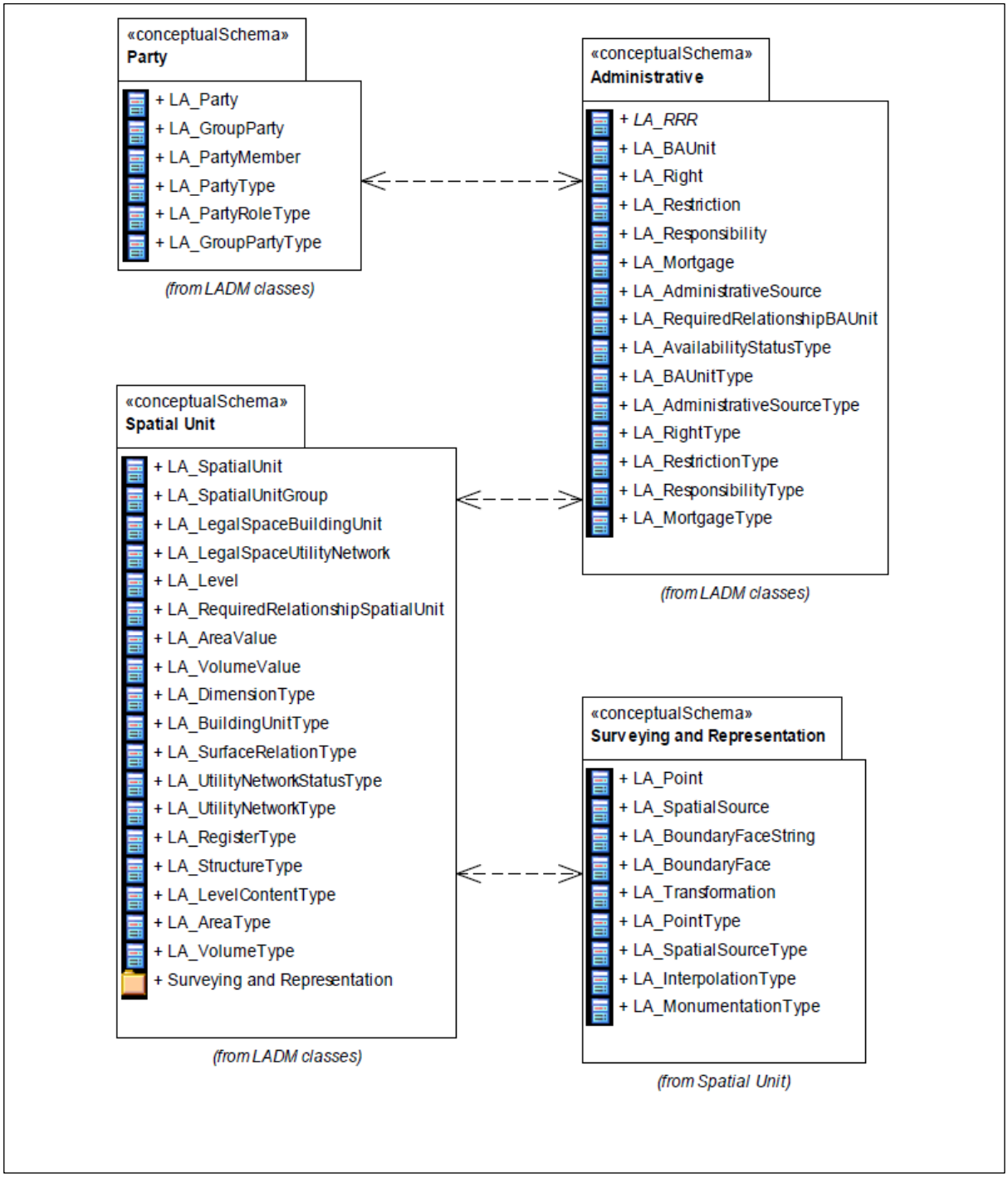


Figure 12. Overview of LADM Version C classes (ISO 2011c, according to (Lemmen 2012)).

In terms of real property stratification and 3D Cadastre purposes, LADM is designed so that 3D real property units are sufficiently supported. Spatial unit class (LA_SpatialUnit) includes attributes regarding the spatial unit's dimension (0D, 1D, 2D or 3D), relation to land surface (above or below) and volume (LA_DimensionType, LA_SurfaceRelation and LA_VolumeType respectively) (Lemmen, 2012). For the 3D representation of spatial units, boundary faces are used, maintained as an individual

class of the Surveying and Representation Subpackage. Spatial unit class can be further specialised in building units (LA_LegalSpaceBuildingUnit) that refer to the legal (non-material) space of the physical entity, and utility networks (LA_LegalSpaceUtilityNetwork) describing a utility's topology (Lemmen, 2012). The model can be further extended with external data sources outside its scope, such as land use and valuation (Lemmen, 2012). Apart from the various country profiles that have been developed based on LADM, adjustment of the model to serve different scientific fields is explored by researchers worldwide, in order to allow systems' interoperability and to take advantage of the systematic organisation approach of land-related data. In the light of LADM revision process, (Kitsakis et al., 2018) investigate integration of Public Law Restrictions (PLRs) within the LADM context, considering proposed modelling approaches under concept of ensuring modelling efficiency, UML models' complexity and extensibility. (Zhuo, Ma, Lemmen, & Bennett, 2015) use LADM to integrate Chinese legal framework of land and housing information, developing corresponding packages, classes and attributes, showing the impact of different levels of land-related legislation (Constitution, land laws, local laws, regulations and standards) to the development of corresponding packages, classes and attributes. Immovable cultural heritage also affect Land Administration, imposing a number of restrictions or responsibilities on land, while extending in height and/or depth. In this context, Gogolou & Dimopoulou (2015), identify the need to utilise Land Administration standards in cultural heritage management and propose a LADM-based model for the standardisation of Greek cultural heritage. To facilitate the management of 3D cadastral objects, (Ying, Guo, & Li, 2011) have developed a prototype, topological 3D object model, based on LADM (Fig. 13).

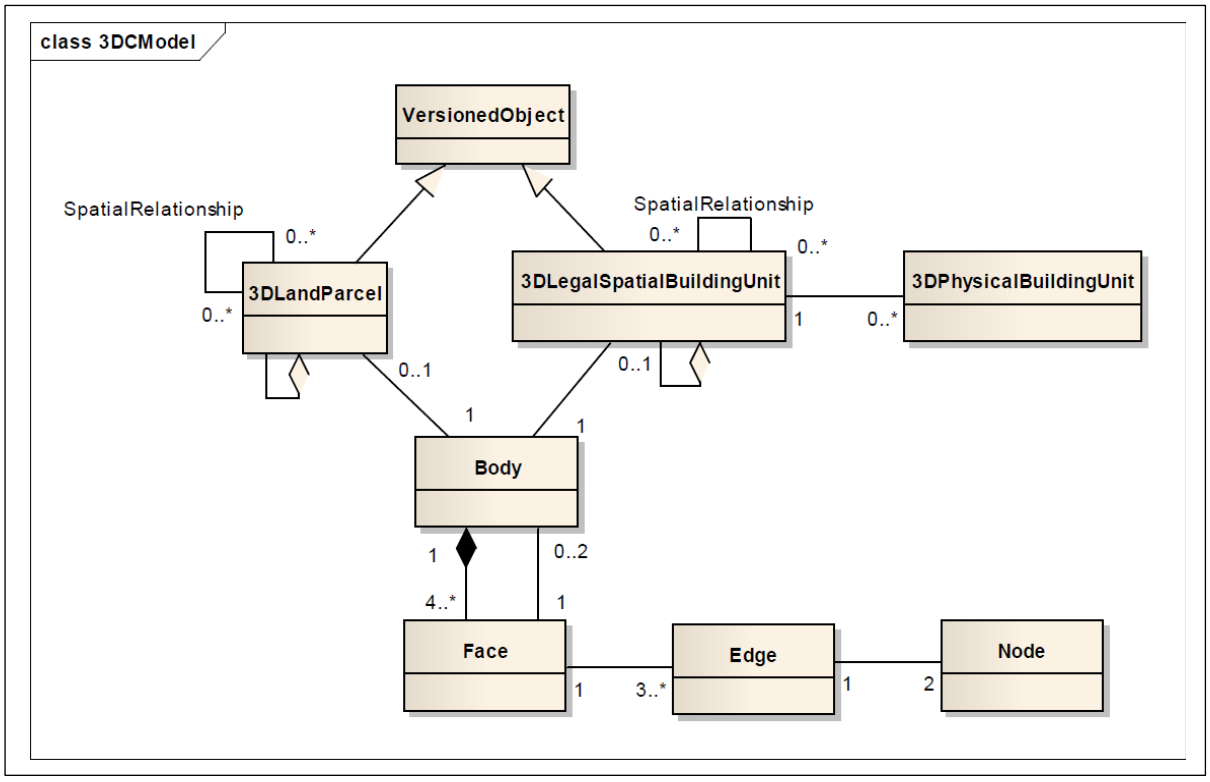


Figure 13. Data model of the prototype system developed by (Ying, Guo, and Li 2011)

Mapping between LADM classes and prototype object classes is made, while topological queries and 3D object editing, e.g. merge or split, are supported as well. Development of a 3D National Spatial Data Infrastructure has been decided by the Republic of Korea (Jeong et al., 2012). Recording of 3D information regarding buildings, structures and facilities is prescribed by the special cadastral resurvey law (B. M. Lee et al., 2015). An LADM-based 3D extension to cadastral registration in Korea is presented by (Jeong et al., 2012). (B. M. Lee et al., 2015), propose a new 3D Korean LADM profile to replace the already existing 2D-based one including 3D attributes and 3D rights, in accordance with the requirements set by the cadastral resurvey law. Kim & Heo (2017) identified the controversy between the 2D-based Korean cadastral system and the 3D enabled land registration system and propose a 3D underground cadastral data model, based and related to the LADM. Apart from 3D constructions, their proposed model takes into account restrictions deriving from Public Law as well such as, non-physical, protected or restricted volumes around underground parcels.

4.4 Legal Cadastral Domain Model (LCDM)

LADM aims to organise land related data into a standardised and interoperable way, facilitating data exchange. However, data exchange between different countries may prove a complicated task due to terminological differences between national concepts. Each country uses different terms to describe the same, or similar, real property rights while, in other cases, similar terms are assigned different content in each jurisdiction. Within this context, Jesper Mayntz Paasch (2012), developed the Legal Cadastral Domain Model (LCDM) to set a terminological framework to classify real property rights and public regulations. LCDM operates in tandem with LADM, expanding its legal profiles and code lists. In order to avoid misconceptions based on national terminological differences, LCDM classifies real property rights and public restrictions based on their content (Figure 14).

LCDM classes are based on the "Person-Ownership-Land" schema. This schema is similar to the "Person-Right-Parcel" schema described by Henssen (1995), emphasising on the impact of the various private and public land-related rights to the right of ownership, affecting its content and extent (Paasch, 2004; Paasch, 2012, p.18). Rights are first classified in those that benefit and those restricting real property ownership. The second tier of classification (both of benefitting and restrictive rights) distinguishes rights that are created by private agreements or court decisions, and rights imposed by the state, such as by legal statutes and regulations.

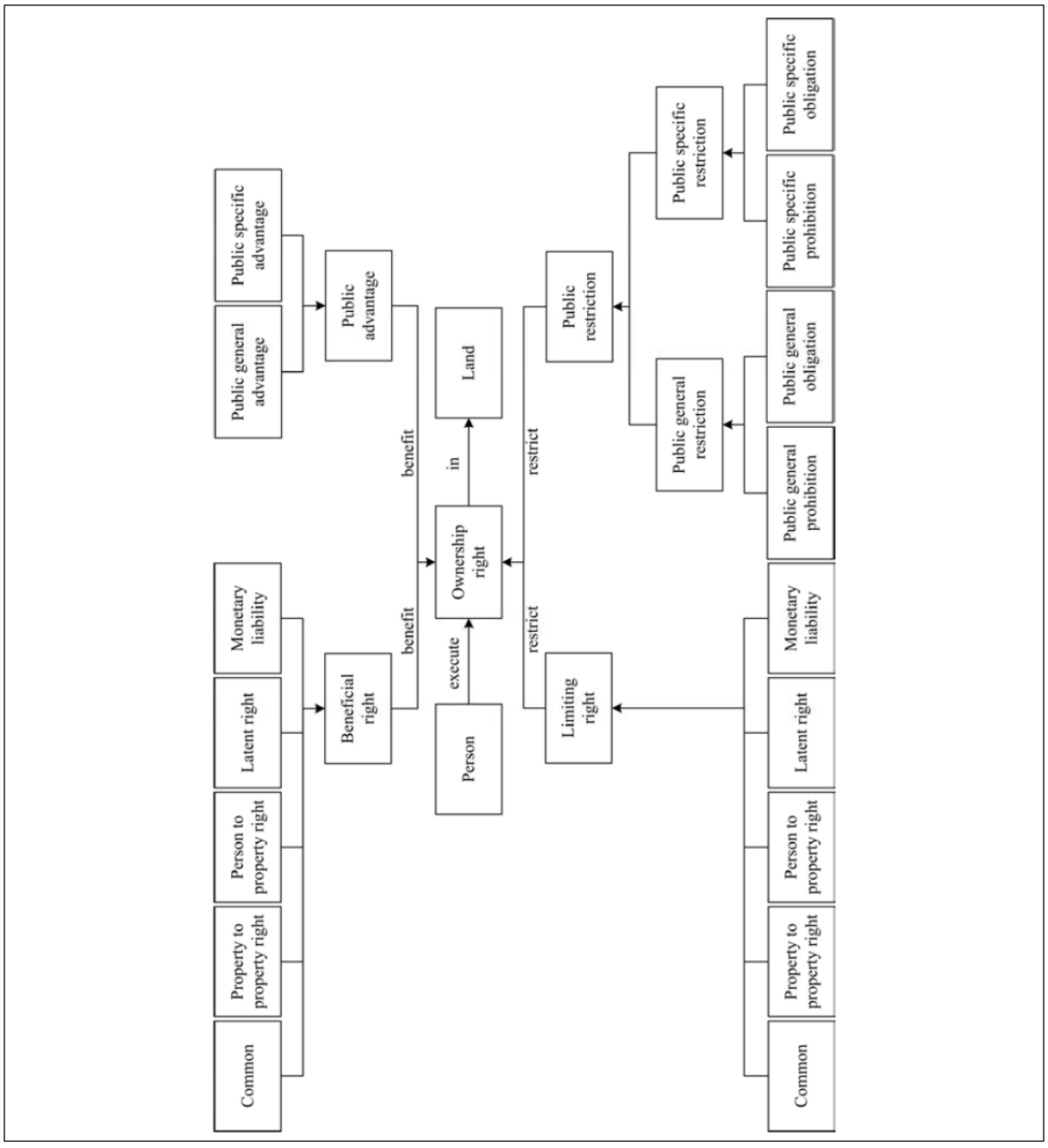


Figure 14. The Legal Cadastral Domain Model (Jesper Mayntz Paasch 2012).

Above mentioned rights are further classified based on *who* is executing a relation to real property ownership, *what* a relation to real property ownership consists of, and *if* a right has or has not been executed (Jesper Mayntz Paasch, 2012). LCDM classes are defined as following (Table 1) (Jesper Mayntz Paasch, 2012):

	Class	Definition
Beneficial to real property ownership	*Real property right classes*	
	Common	Real property to land relation executed in land legally attached to two or more real properties. Owners of the participating real properties execute co-ownership rights in the land at issue.
	Property to property right	Right executed by the owner of real property in another real property, due to his ownership.
	Person to property right	Right executed by a person to use, harvest the fruits/material of, rent or lease the real property in whole or in part, including the claim against a person.
	Latent right	Right not yet executed on a real property.
	Monetary liability	A latent, financial security for payment.
	Beneficial right	Right beneficial for the use and enjoyment of real property.
	Public regulation classes	
	Public general advantage	Change in legislation beneficial for certain types of real property at a general level, e.g. properties within urban areas, properties being subject for industrial forestry or properties containing cultural monuments.
	Public specific advantage	Publicly granted permission to perform activities for a limited and defined set of real properties, other- wise regulated by a public specific obligation or public specific prohibition, thereby restoring parts of the owners use right
	Public advantage	Publicly imposed action which is beneficial to ownership and use of real property
Limiting real property ownership	*Real property right classes*	
	Limiting right	Right limiting the use and enjoyment of real property.
	Common	Real property to land relation executed in land legally attached to two or more real properties. Owners of the participating real properties execute co-ownership rights in the land at issue
	Property to property right	Right executed by the owner of real property in another real property, due to his ownership
	Person to property right	Right executed by a person to use, harvest the fruits/material of, rent or lease the real property in whole or in part, including the claim against a person.
	Latent right	Right not yet executed on a real property.
	Monetary liability	A latent, financial security for payment.
	Public regulation classes	
	Public restriction	Publicly imposed restriction prohibiting or mandating certain activities on real property.
	Public general restriction	Publicly imposed restriction prohibiting or mandating certain activities on certain types of real property at a general level, e.g. properties within urban areas, properties being subject for industrial forestry or properties containing cultural monuments.
	Public specific restriction	Publicly imposed restriction on doing certain activities or demanding certain obligations for a limited and defined set of real properties, based on specific legislation.
	Public general prohibition	Publicly imposed prohibition affecting certain types of real property at a general level, e.g. properties within urban areas, properties being subject for industrial forestry or properties containing cultural monuments.
	Public general obligation	Publicly imposed restriction demanding certain activities on certain types of real property at a general level, e.g. properties within urban areas, properties being subject for industrial forestry or properties containing cultural monuments.

	Public specific prohibition	Publicly imposed restriction prohibiting certain activities for a limited and defined set of real properties, not to be performed by the real property owner.
	Public specific obligation	Publicly imposed restriction demanding certain activities from the real property owner, for a limited and defined set of real properties, based on specific legislation.

Table 1. Definition of LCDM classes (Jesper Mayntz Paasch (2012), adjusted).

Classification of real property rights within the LCDM is not affected by their spatial extent. Therefore, LCDM may serve the purposes of real property stratification within a 3D Cadastre context. (Liedholm, Paulsson, & Paasch, 2014) use LCDM to classify conflicting rights in Swedish mining areas including national interests (such as state rights on valuable substances, restrictions regarding protected areas, cultural areas and national defence areas), municipal rights, and individual parties' rights (such as mining rights). (Niukkanen, 2014) explores the compatibility of the Finnish real property rights' registration system to LADM and LCDM. Both models are considered suitable to describe the Finnish cadastral system. Special reference is made on the legal concept of real property in Finland, and special Finnish real property interests that create implementation issues of the Finnish country profile (Niukkanen, 2014).

4.5 Building Information Modelling (BIM)

Building Information Modelling (BIM) has emerged from the need of complete, parametric, 3D building simulation, to facilitate planning, design, construction and management of structures. Literature provides several definitions of BIM, although none is used authoritatively (P. A. Jensen & Jóhannesson, 2013; Kimsey, 2010; Kjartansdóttir, Ingibjörg Birna Mordue, Nowak, Philp, & Jónas Thór, 2017) (Kimsey, 2010; Jenssen and Jóhanesson, 2013; Kjartansdóttir et al., 2017). Mordue (2015), compiles some of the most common BIM definitions used by national and international standardisation organisations, professional institutes and BIM-software developers. Depending on each organisation's definition, BIM is regarded as a type of software, a virtual model or a process (Mordue, 2015). Emphasis is given on the plurality of information that BIM consists of, and it is described either as building's *functional* and *physical* characteristics, or as information from *all phases of a building's life-cycle*. BIM definitions may also refer to the *sharing* nature of building information between different stakeholders and BIM's aim to serve as a basis for building management and decision making. According to (Azhar, Khalfan, & Maqsood, 2012) from the technology perspective, BIM is a project simulation that consists of the 3D models of the project components, linked to information regarding project's planning, design, construction or operation, whereas when dealt under the virtual process perspective, BIM incorporates within a single model all aspects, disciplines and systems related to a structure. (Eastman, Teichloz, Sacks, & Liston, 2011), regard BIM as a human activity, and define it as a "*modelling technology and associated set of processes to produce, communicate, and analyse building models*". Given the variety of information and the multiple use of BIM models, the term n-D modelling or Virtual Prototyping Technology are also used instead of BIM (Azhar et al., 2012).

BIM technology is the outcome of research on computer tools for interactive 3D design that has started during the 1960's, and has led to the development of object-based, parametric 3D modelling (Eastman et al., 2011; Yan & Demian, 2008).

Polyhedral forms for viewing purposes quickly evolved to solid modelling, represented either as a collection of connected surface elements (boundary representation approach, b-rep), or as a set of functions between primitive polyhedra (Constructive Solid Geometry approach, CSG). Each approach is characterised by unique advantages such as versatility of object editing (CSG approach) or visualisation, measuring and detection of spatial conflicts (B-rep approach); current parametric tools and building models use both representations, depending on their purpose (Eastman et al., 2011). Computer Aided Design (CAD) systems were developed since the mid-1960's. In the next decades CAD systems have grown very popular among engineering industry (Yan & Demian, 2008). Emphasis was given on 2D object modelling due to the lack of computing power and cost of 3D object modelling (Eastman et al., 2011). A crucial step towards transition to BIM systems, apart from developments in computer technology and database management, was the development of parametric modelling. Parametric models are structured based on specific conditions that are imposed on the components' parameters of an object's model. Imposed conditions need to be met regardless of the parameters' values (for example, the number of steps in a stair with set stair rise and tread values will depend on the stair's length). Parametric modelling provides mechanisms to translate and embed domain expertise as explicit geometric expressions that can automate generation of building information, especially geometric information, and that can facilitate the generation of a rich building model (G. Lee, Sacks, & Eastman, 2006). 3D object modelling followed the advance in computer technology and grew very popular among designers, although was used mostly for visualisation purposes; documentation, quantity and cost estimation was still related to 2D digital or paper models, such as cross sections and floor plan diagrams. Combination of 3D models and parametric modelling along with semantic enrichment of 3D models has resulted in the development of BIM models. Currently, BIM software developers support a variety of tools for specific objects' editing. Depending on the purpose of each BIM platform, different types of objects or tools are supported. A list of supported objects and tools for some of the most well-known BIM platforms are presented by Eastman et al. (2011). Given the relatively recent introduction of BIM within construction industry as well as the use of 2D or 3D CAD systems for building modelling, the concept of *BIM maturity level* has been introduced. The aim of BIM maturity level is, first, to clarify to the supply-chain the deliverables expected of it, and, second, to clarify to the clients what the supply-chain is able to offer them (BIM Industry Working Group, 2011; Kjartansdóttir, Ingibjörg Birna Mordue et al., 2017). Four levels of BIM maturity are defined (Level 0-Level 3) as presented in Figure 15. Although the exact meaning of BIM maturity levels still remains under debate, the general concept of each level is considered the following (BIM Industry Working

Group, 2011; Kjartansdóttir, Ingibjörg Birna Mordue et al., 2017; NBS, 2014) (BIM Industry Working Group, 2011; Kjartansdóttir et al., 2017; NBS, 2018):

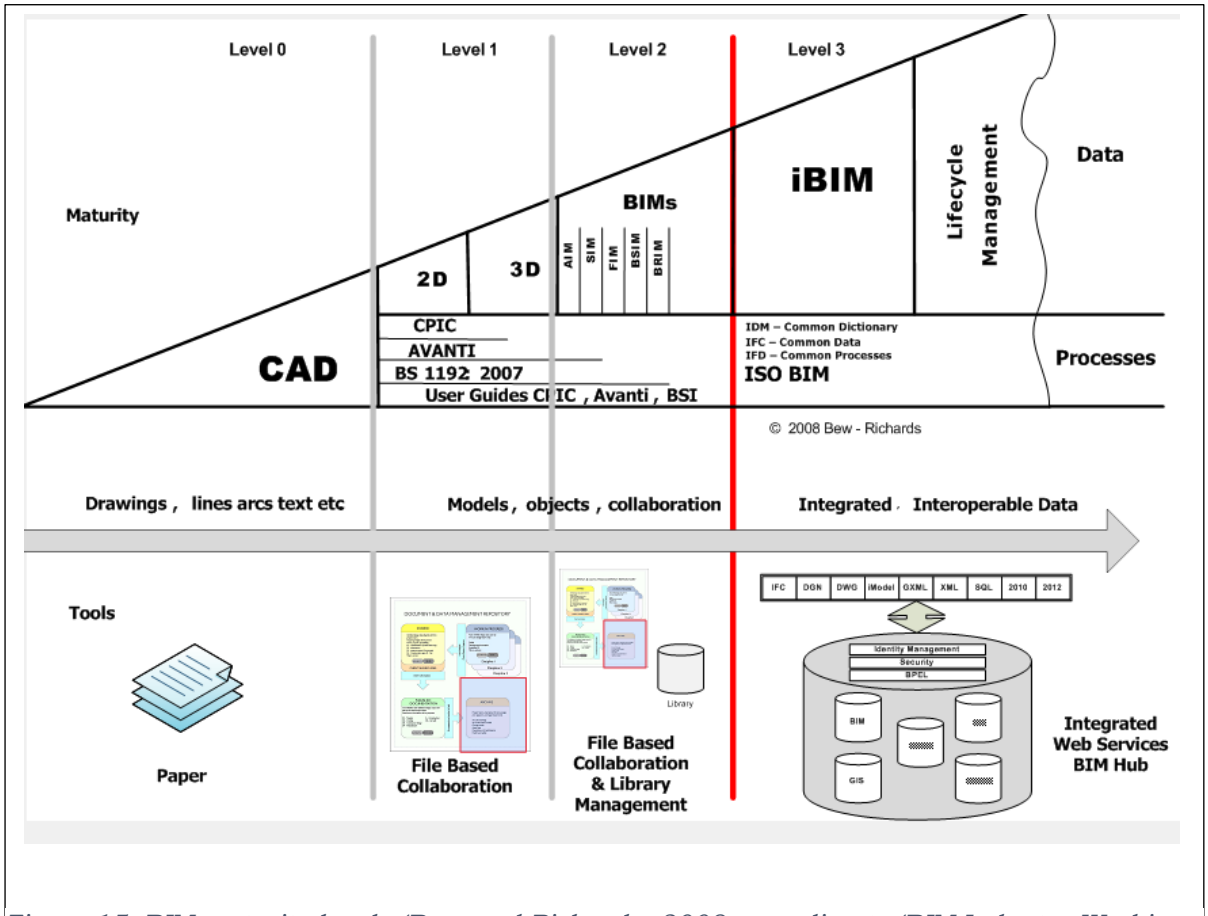


Figure 15. BIM maturity levels (Bew and Richards, 2008 according to (BIM Industry Working Group 2011))

Level 0: This level implies that BIM is not implemented. Unmanaged 2D, paper or digital CAD drawings are used for the collaboration among the project team. 3D models may be available but only for visualisation purposes.

Level 1: This level usually involves 3D CAD models for visualisation purposes, while 2D models are used for drafting of statutory approval documentation and Production Information purposes. A common data environment (CDE) is used for data exchange, which is most often managed by the contractor. Collaboration between different disciplines among the project team does not occur.

Level 2: BIM maturity level 2 is characterised by the collaboration among the project team disciplines, through information exchange. Each group of the project team builds its own BIM model that can be shared with the other groups usually by cloud-based applications. This implies that generated 3D models are exported in common file formats (e.g. Industry Foundation Classes-IFC) within a CDE, so that information from different disciplines can be exploited by different project team groups.

Level 3: BIM maturity level 3, involves full integration of a project's information in an environment that such information is available by involved stakeholders, during all stages of the project's life cycle. Although BIM maturity level 3 has not been fully defined, the vision of its development comprises the development of interdisciplinary nD models that may undergo complex analysis regarding different aspects. In order

to accomplish the goals that are set by BIM maturity level 3, "Open Data" standards need to be developed and adopted so that data exchange is facilitated. Additionally, literature provides a variety of legal issues arising from the development of detailed, interdisciplinary 3D building models (Arensman & Ozbek, 2012; McAdam, 2010; Winfield, 2015). Copyright and ownership of BIM models, responsibility of data maintenance and update[27], liability among the involved parties are, among others, the most common legal issues related to the development of BIM models.

In literature, a fifth level of maturity (level 4) has also been proposed, incorporating 4D characteristics (constructions' development history over time) of the model. In this stage, further enhancing of the model by data collected by sensors is included, while it is expected that building models will be available to operations, employees, users and the public (Poljanšek, 2017; Succar, 2010).

BIM is growing increasingly popular both among professionals and government authorities. National and international BIM standards have been established, such as the National Building Information Modelling Standard-NBIMS (United States) (National Institute of Building Sciences buildingSMARTalliance, 2015), the BS EN ISO 19650-1:2018 (United Kingdom) (National British Specification (NBS), 2018), the HKIBIM BIM Standards (Hong Kong) (Hong Kong Institute of Building Information Modelling, 2018), the Statsbygg BIM Manual (Norway) (Statsbygg, 2011), the AEC (CAN) BIM Protocol (Canada) (CanBIM, 2014), and the ISO/TS 12911/2012. BIM modelling of planned constructions is statutorily required in various countries. Depending on jurisdiction, development of BIM models may be required for major infrastructures, Public Service projects, or to all types of development projects. Currently, the use of BIM technology is mandatory for government projects in the UK (Cabinet Office, UK, 2011), and Hong Kong (The Government of Hong Kong, Development Bureau, 2018), while the Nordic countries have developed public sector BIM standards and requirements (Petrie, 2014). In France, the Digital Transition Plan for the Construction Industry (Plan Transition Numérique dans le Bâtiment) was introduced in 2014, in order to develop the French BIM strategy that will provide for sustainability and reduce costs (Plan Transition Numérique dans le Bâtiment, 2015). In Germany, a staged BIM implementation project has been initiated since 2015. In the first stage (2015-2017), the conditions for the use of BIM at major infrastructure projects were defined, also setting the legal and technical framework, standards and recommendations for using BIM, based on the outcomes of specific pilot projects. The second stage (2017-2020) involves implementation of several pilot BIM projects to develop a set of guidelines, checklists, samples and clarify legal questions related to the use of BIM in infrastructure projects. In the final stage (after 2020), developed BIM specifications will be used for the development of major transport and infrastructure projects (Fuchs, 2017). The contribution of BIM to constructions' planning and management has also been acknowledged by the European Union (EU), which has established a BIM Task Group to encourage the common adoption of BIM in public works, with the common aim of improving value for public money, quality of the public estate and for the sustainable competitiveness of industry (NBS, 2017). Development of BIM Models for public sector building project procurement is required in Singapore, while in other countries it may be related to the area or the value of each development project. For example, in South

[27] This is directly related to the credibility of the model, when edited models are shared between different project groups.

Korea, BIM is compulsory both for public sector projects and projects exceeding S$50 million (Edirisinghe & London, 2015; G. Lee, 2014). Similar requirements, can be traced in countries of the Middle-East, such as the United Arab Emirates, Saudi Arabia and Qatar (Petrie, 2014). An overview of global BIM adoption is presented in Figure 16 (McAuley, Hore, & West, 2017).

Since the introduction of BIM technology, extended research is made on the benefits of BIM exploitation. Given its multi-dimensional character, BIM affects the majority of stakeholders related to a construction project. Bryde, Broquetas, & Volm (2013), explored the project benefits of BIM, examining characteristic BIM-developed projects. They highlight the contribution of BIM to time-savings and cost-control, while note the negative impact of BIM software in several of the examined cases.

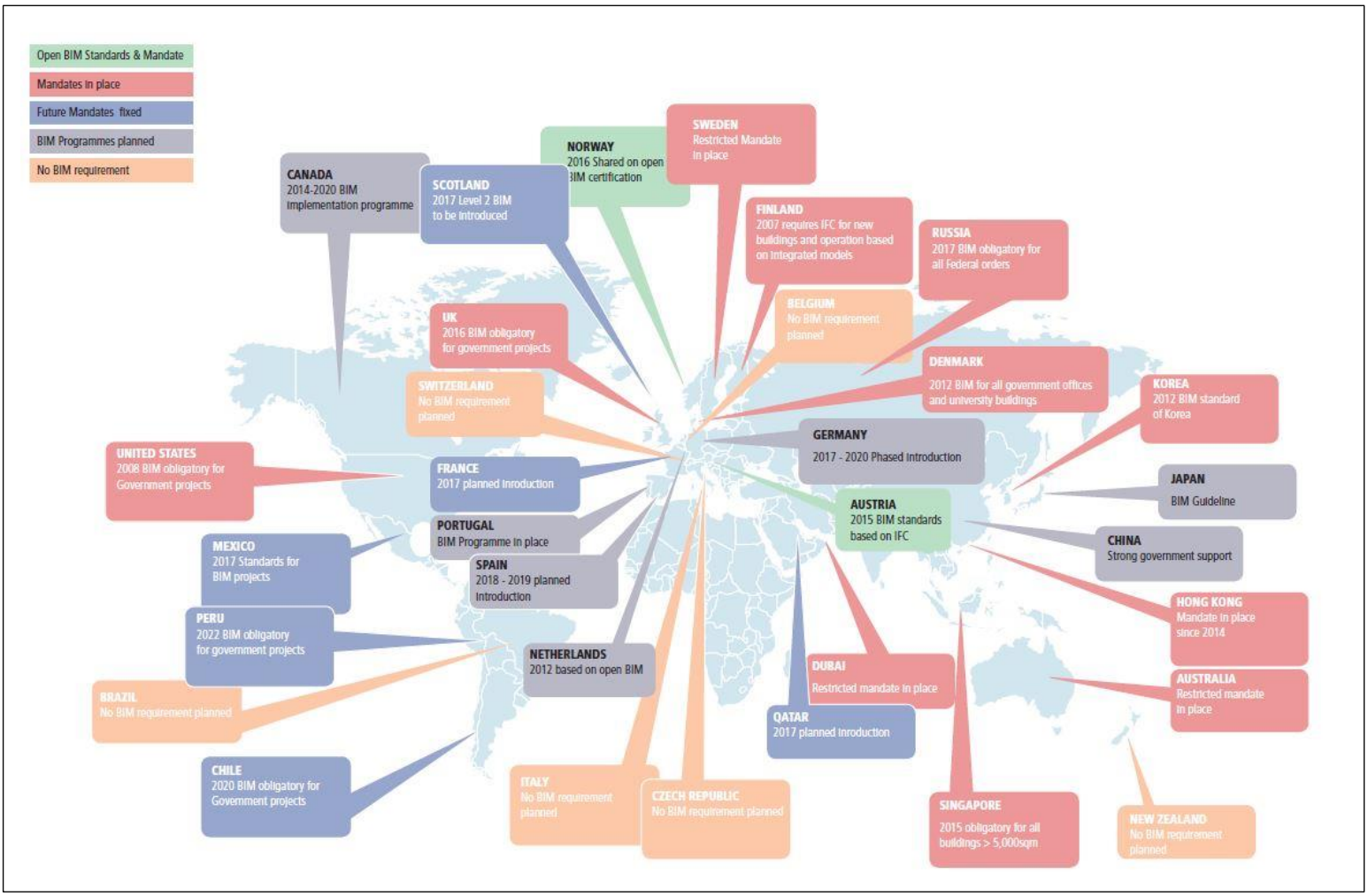


Figure 16. Overview of global BIM adoption (McAuley, Hore, and West 2017).

According to Azhar (2011), BIM provides (i) faster and more effective processes through the sharing and reuse of information, (ii) better design, as simulation and analysis can be applied to BIM models, (iii) controlled whole-life costs and environmental data, (iv) better production quality, (v) automated assembly, as digital product data can be used for manufacturing and assembling of structural systems (vi) better customer service, exploiting the accuracy of BIM visualisation, and (vii) the use of building's specifications, such as requirements, design, construction and operational information in facilities' management. Azhar (2011), summarise the benefits of BIM to visualisation, quantity survey, cost estimation, site logistics,

phasing and 4D scheduling, building management, as well as option, sustainability, constructability and building performance analysis. Those benefits are then assigned to the different stakeholders within a construction project, such as owners, project designers, project constructors and facility managers. A detailed presentation of BIM's benefits along with the problems that can be addressed using BIM can be traced in (Eastman et al., 2011).

Spatial complexity of RRRs imposed on land has reduced the effectiveness of 2D-based cadastral plans, by introducing ambiguities regarding the spatial extent of RRRs. Additionally, 2D representations fail to accommodate vertically overlapping RRRs, in terms of visualisation, querying and spatial analysis. Development of BIM technology fostered research on the exploitation of BIM for 3D Cadastre purposes, which, in fact, relates to the integration of BIM and Geographic Information Systems (GIS). Each of the above systems is based on different departures, with BIM focusing on representing in detail the structural characteristics of vertical facilities (buildings), while GIS emphasises on horizontally distributed features (Ma & Ren, 2017). X Zhang, Arayici, Wu, Abbott, & Aouad (2009), consider BIM to be optimal for modelling new, well defined objects, in relatively micro level, using 3D solids and surfaces; on the contrary, they regard GIS as a means of reconstructing existing objects about which only sparse and incomplete information is available, mainly of outdoor areas, using 2D points, lines and polygons. Exploitation of BIM for 3D Cadastre purposes also relates to the correlation between legal and physical space. Two are the main obstacles in such case. Specifically, the conceptual character of legal space, in contrast with the concrete and conceivable in reality physical space, as well as the inconsistency between legal and physical space, when the former is not fully occupied by a physical entity (E. Dimopoulou, Kitsakis, & Tsiliakou, 2015). The extension of BIM to incorporate legal information has been examined by several researchers (Amirebrahimi, 2012; Atazadeh, Kalantari, Rajabifard, Champion, & Ho, 2016; Atazadeh, Kalantari, Rajabifard, & Ho, 2017; Atazadeh, Kalantari, Rajabifard, Ho, & Champion, 2017; Atazadeh, Kalantari, Rajabifard, Ho, & Ngo, 2017; Mohamed El-Mekawy & Östman, 2012; Mohamed El-Mekawy, Paasch, & Paulsson, 2014; Oldfield, van Oosterom, Beetz, & Krijnen, 2017; Oldfield, Oosterom, Quak, & Veen, 2016; Jantien Stoter et al., 2016, 2017). El-Mekawy & Östman (2012), conclude that BIM's semantic model (Industry Foundation Classes-IFC) can be used for 3D Cadastre purposes, although noting that case-specific modifications or extensions of the IFC model would be required, leading to non-universal, project-based solutions. The same work identifies a number of technical limitations of the IFC standard regarding 3D Cadastre implementation, such as (i) the lack of direct relation between the cadastre-related entities, (ii) the abundancy of non 3D Cadastre-related information due to the lack of IFC projects' abstraction levels (LoD), (iii) the lack of terrain model support by IFC, and (iv) the lack of representation of topologies regarding neighbourhood relationships (Mohamed El-Mekawy & Östman, 2012). However, the value of BIM in handling building information and its capability to relate building components' information with their surrounding environment is acknowledged (Mohamed El-Mekawy et al., 2014). Atazadeh et al. (2016), have developed a prototype BIM model, enriched with ownership data, examining the suitability of BIM in addressing management complexities of RRRs that apply to high rise buildings. According to their research, BIM constitutes a possible solution for management of stratified ownership RRRs on high-rise buildings. Atazadeh, Kalantari, Rajabifard, & Ho (2017b), identified the ambiguities deriving from 2D-

based subdivision plans in defining real property boundaries in functionally and structurally complex multi-storey developments, while also explored the contribution of BIM in presenting unambiguous boundary representations. They conclude that BIM models raise the ambiguities deriving from 2D, text-annotated plans, and allow for better understanding of building ownership boundaries. Exploitation of BIM capabilities in high-rise land administration and especially in modelling and management of 3D real property rights is examined by (Atazadeh, Kalantari, Rajabifard, Ho, & Champion, 2017; Atazadeh, Kalantari, Rajabifard, Ho, & Ngo, 2017). The authors acknowledge that BIM's data model (IFC) does not specify legal information on real property; therefore, they extend BIM spatial and physical elements to support 3D RRR management. Among the benefits of this approach are included the clear representation of physical and legal boundaries, querying capabilities, the semantic enrichment of 3D real property units, and the integration of legal and physical information within the same dataset. Exploitation of existing documentation has been proposed as a cost-effective and time efficient method of creating 3D real property units for 3D Cadastre purposes. Dimitrios Kitsakis & Dimopoulou (2014), examined the variety of databases and repositories where existing real property documentation is maintained, along with their type, quality and suitability for generating 3D real property objects. Oldfield et al. (2016), emphasise on existing BIM models for the development of 3D spatial units. The authors consider IFC's virtual spaces as a way to represent the legal spaces within buildings. However, the need of creating new semantics within the IFC data model to define legal spaces, especially for non-closed or ambulatory boundaries, is highlighted. Stoter et al. (2016, 2017) present the first two cases of registration of legal volumes in The Netherlands. BIM models were used to convert 3D building geometries to legal volumes. 3D pdf files of the legal volumes were exported, to be registered in the Land Registry. It should be noted that 3D registration was added to supplement the "traditional" 2D registration. The uncertainty of the stakeholders to formulate and register 3D legal volumes increased the time required for the 3D registration, also depicting that a 3D-based registration workflow would be more efficient (Oldfield et al., 2017). Based on this, (Oldfield et al., 2017) present a workflow to obtain input BIM data, to be used for 3D Cadastre. Contrary to the research of Atazadeh et al. (2016) and Atazadeh, Kalantari, Rajabifard, Ho, & Ngo, (2017), (Oldfield et al., 2017) do not attempt to extend the IFC schema, to minimise interoperability issues. The authors suggest that non-material legal boundaries are represented using the IFC space and zone objects, whereas they support interrelation between the involved stakeholders and the Land Registry from project's inception, so that the BIM (IFC) models can be customised to the Land Registry's needs as well (Oldfield et al., 2017).

4.6 CityGML

3D city modelling is used for decades to virtually represent urban environment. Development of 3D data acquisition and modelling techniques have significantly reduced data acquisition time and cost, making 3D modelling easier accessible to the public and professionals. Currently, a variety of 3D city modelling techniques is available, such as photogrammetry and laser scanning, extrusion from 2D footprints, synthetic aperture radar, architectural models and drawings, handheld devices, procedural modelling, and volunteered geoinformation (Apostolopoulos, Gkeli,

Petrelli, Potsiou, & Ioannidis, 2018; Biljecki, Stoter, Ledoux, Zlatanova, & Çöltekin, 2015; Gkeli, Potsiou, & Ioannidis, 2019). Based on data input techniques, (S. P. Singh, Jain, & Mandla, 2013), classify 3D modelling methods to Photogrammetric-based methods and Laser Scanner-based methods. Photogrammetric-based methods are further subdivided to *aerial photogrammetry-based* modelling, *satellite photogrammetry-based* modelling and *close range photogrammetry-based modelling*, while Laser Scanner-based ones, include *aerial* and *terrestrial-based* modelling. (S. P. Singh et al., 2013), present characteristic cases of the above mentioned 3D modelling techniques, such as combination of aerial images and cadastral maps, computer vision techniques, combination of photogrammetric with GIS methods, 3D city modelling from single satellite imagery, panorama photogrammetry, videogrammetry, use of Unmanned Aerial Vehicles (UAVs) or Mobile Mapping systems.

Early developed 3D city models were used solely for visualisation purposes. However, it was early acknowledged that 3D city models could serve a variety of purposes (Fig. 17). However, different data formats are not interoperable and inhibit data exchange. Kolbe & Gröger (2005), identify that CAD models can only be used for geometrical purposes and fail to present complex relationships; IFC models emphasise on constructions, so they do not include topographic feature classes, such as terrain or vegetation, while provide limited georeferencing capabilities; finally LandXML data files focus on transportation and land development industry projects, therefore they do not include 3D buildings or other city objects. Therefore, research towards semantic enrichment of 3D city models began, so that interoperable 3D city models were developed, which could support spatial analysis, querying and data mining.

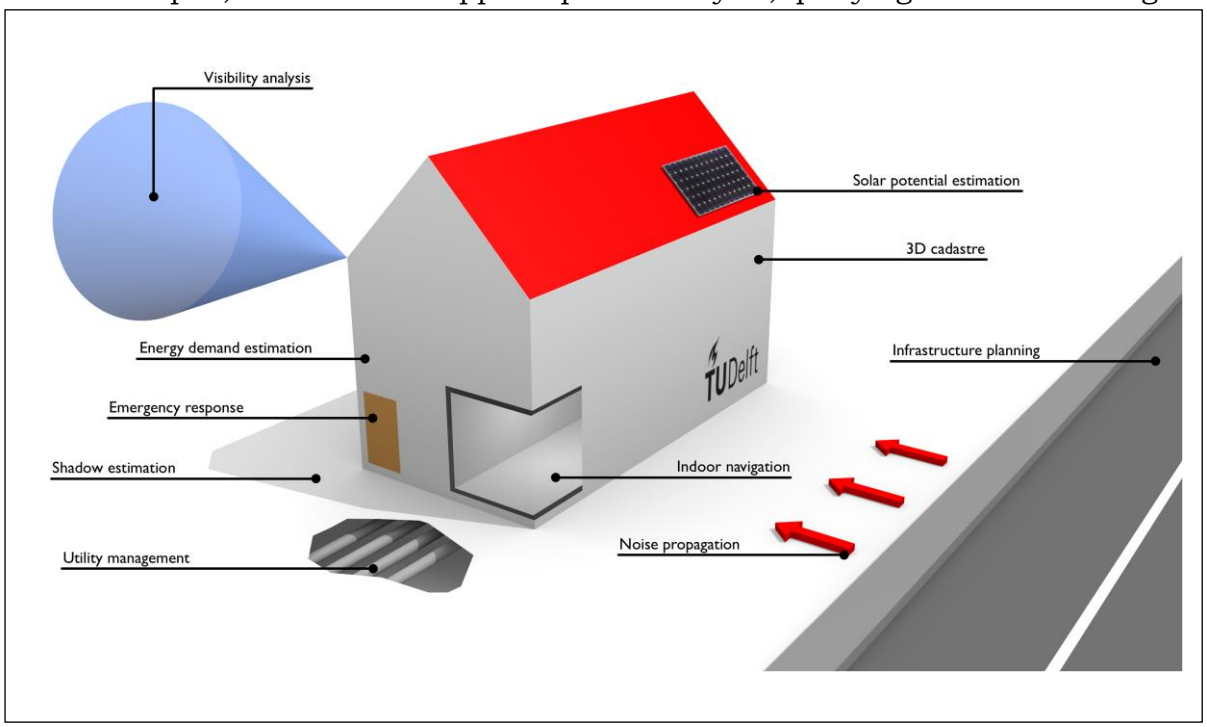


Figure 17. 3D City models' application domains (Filip Biljecki et al. 2015).

Within this concept, CityGML semantic information model has been introduced in 2002. Since 2008, CityGML has been adopted by OGC as a standard for modelling, representing and exchanging of 3D city models' data (Kolbe, Nagel, & Stadler, 2009), while CityGML models have been developed for a variety of cities in Europe, America

and Asia, including Berlin, Paris, Geneva, Vienna, New York, Doha and Yokohama (Gröger, Kolbe, Nagel, & Häfele, 2012; Kolbe, 2012; TU Delft, n.d.) CityGML provides for multi-scale, five-tier data modelling in *Levels of Detail* (*LoD*), starting from LoD0 to LoD4. LoDs define the abstraction level of real world objects, facilitating data collection, visualisation and analysis. This is reflected on the level of 3D objects' generalisation, as well as on their accuracy requirements. Data modelling in LoDs using CityGML allows simultaneous representation of the same object in different LoDs. Briefly, CityGML LoDs can be described as follows (Gröger et al., 2012) and are schematically presented in Figure 18:

- LoD0: This is the coarsest level of detail, comprising of a 2.5D Digital Terrain Model (DTM) over which an aerial image or a map can be draped. Buildings' representation in LoD0 is limited to their footprint and/or roof edge polygons. LoD0 is mostly suitable for regional or landscape purposes.
- LoD1: This level of detail uses prismatic building with flat roof structures. This level of detail covers mostly city or region based scale purposes.
- LoD2: In LOD2, buildings have differentiated roof structures along with thematically differentiated boundary surfaces. This level of detail is mostly suited for city districts and projects.
- LoD3: In LoD3, building models acquire detailed wall and roof structures, including walls and windows. It is used in case where architectural modelling limited to building exteriors is required, or in case of landmarks.
- LoD4: LoD4 is the finest level of detail. Within this level of detail, interior structures within a building model, such as rooms, interior doors, stairs and corridors can be defined. LoD4 models are highly detailed models that can be used in cases of architecture modelling, where buildings' interior is required.

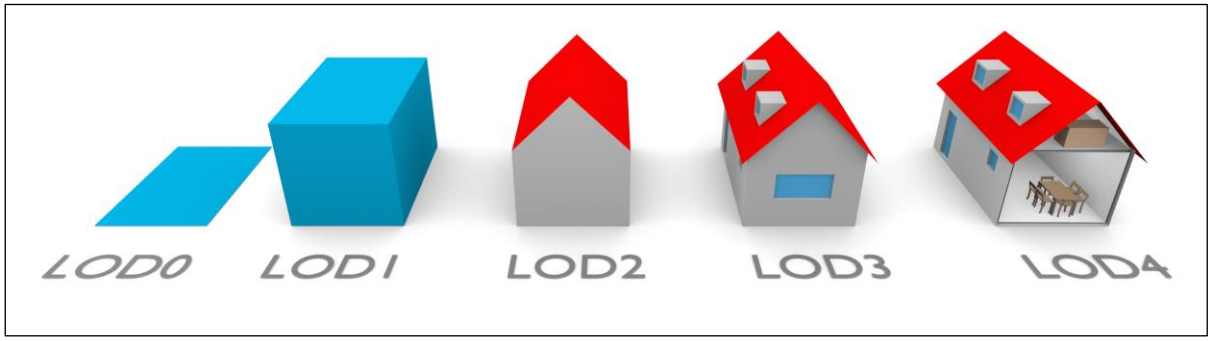


Figure 18. Building represented in LoD0-LoD4 (F. Biljecki 2017).

CityGML comprises of a *core module* and twelve *thematic modules*. The former includes the basic concepts and components of the CityGML data model (Gröger et al., 2012), while thematic modules are used to describe geometry, attributes and semantic information of specific types of 3D city objects. Default thematic modules include (Gröger et al., 2012):

- *Appearance*: textures and materials for other types
- *Bridge*: bridge-related structures, possibly split into parts
- *Building*: the exterior and possibly the interior of buildings with individual surfaces that represent doors, windows, etc.
- *CityFurniture*: benches, traffic lights, signs, etc.

- *CityObjectGroup*: groups of objects of other types
- *Generics*: other types that are not explicitly covered
- *LandUse*: areas that reflect different land uses, such as urban, agricultural, etc.
- *Relief*: the shape of the terrain
- *Transportation*: roads, railways and squares
- *Tunnel*: tunnels, possibly split into parts
- *Vegetation*: areas with vegetation or individual trees
- *WaterBody*: lakes, rivers, canals, etc.

However, apart from the above mentioned thematic modules, CityGML data model can be further extended to include other types of city objects and attributes. This can be achieved by the Application Domain Extensions (ADEs)[28]. ADEs do not only allow the development of new feature types, attributes, geometries and associations, but also enhance existing feature types (Çağdaş, 2012; Gröger et al., 2012). Currently, more than thirty different ADEs have been developed, covering fields from 3D flood information services, to noise modelling or immovable property taxation.

3D Cadastre is considered among CityGML's targeted application areas (Gröger et al., 2012; Kolbe & Gröger, 2005). Semantic enrichment of 3D models has the capacity to provide information on the exact location and extent of legal spaces (defined by RRRs), which correspond to the physical boundaries of a parcel, a building or even a room (E. Dimopoulou et al., 2015). Therefore, various researchers have investigated the exploitation of semantic spatial data models, especially CityGML, for 3D Cadastre purposes. (Dsilva, 2009) proposes an extension of CityGML for cadastral purposes, by developing an ADE. In his work, information regarding ownership rights, floor numbers and coordinates is extracted from scanned documentation, so that the footprints of unique ownership rights can be identified and grouped into individual property units. 2D footprints are then translated to their corresponding height, based on their floor-number, represented in CityGML format and converted to 3D models by raising walls along the 2D property unit boundaries. (Çağdaş, 2012), notes that the ADE of Dsilva (2009) does not specify cadastral parcel, nor adequately considers the legal specifications of property units and their components. Therefore, he suggests a CityGML ADE that integrates CityGML's physical objects with legal objects used for real property taxation, as defined in Turkish legislation. Góźdź, Pachelski, van Oosterom, & Coors (2014), noted the lack of legal information regarding spatial objects within CityGML data model and proposed a model to integrate CityGML and LADM model, presenting an example based on the Polish framework. Within this context a Land Administration ADE has been proposed, indicating the links between (CityGML-based) physical objects and their (LADM-based) legal counterparts. However, the authors note that difficulties emerged while introducing to CityGML model, LADM classes with no CityGML counterparts. On the other hand, (Rönsdorf, Wilson, & Stoter, 2014) examine integration of CityGML and LADM, under the concept of integrating information that derives from different models and refers to the same or overlapping object concepts. In this work, emphasis is not given on developing a country-specific LADM profile that will be used to develop a CityGML ADE, but on directly implementing LADM on an ADE. Ying et al. (2014), aim to the

[28] Another method of extending CityGML data model is the concept of generic city objects and attributes. For more information on this method, please refer to (Gröger et al., 2012).

conversion of CityGML models to 3D property units. In their research, the semantic objects that can be used to generate the geometry of 3D property units[29] are identified. Identified objects are then filtered to remove redundancies (for example a door can be used to define the boundary of a 3D property unit but is not required for the 3D property unit's model) and topological errors deriving from redundancies' removal are corrected, for the extraction of the 3D property unit's model. Condominium units are among the most common types of 3D real property units globally. (Li, Wu, Zhu, Duan, & Luo, 2016) developed a CityGML ADE, with LADM legal concepts for condominium property. Their work aims to describe in detail the ownership structure of condominium ownership, including semantic relations between condominium units' components. Currently, 3D data acquisition and modelling methods allow for the development of high precision 3D city models, but of poor semantic quality. Tekavec, Lisec, & Ferlan (2017), present a process of 3D Cadastre implementation in Slovenia in CityGML LoD1, using cadastral and LIDAR data. The authors also highlight the limitations of such an approach, due to the need of manual 3D object editing and merging of different data quality. Although 3D semantic data may be difficult to acquire, there is abundancy of semantic data based on 2D models. Therefore, instead of developing a thematic ADE, (Pedrinis & Gesquière, 2017) semantically enhance LoD2 CityGML building models by relating them to 2D polygonal cadastral data. This method can be further used to semantically enrich 3D city models also in other cases where polygonal semantic data is available. Given that modelling requirements for 3D Cadastre purposes do not exceed LoD2 [while LoD3 and LoD4 are still relatively difficult and expensive to acquire and develop (Donkers, Ledoux, Zhao, & Stoter, 2016), this method constitutes a time and cost efficient alternative instead of creating 3D semantic models from scratch. Provided that CityGML has been developed as a 3D city model, it is strongly related to buildings and structures, showing limitations on legal space modelling and management. Dimitrios Kitsakis et al. (2019), investigate the exploitation of existing CityGML elements such as ClosureSurface and HollowSpace to model legal spaces with no physical counterparts, e.g. PLRs. However, this proposal is based on conceptual framework and requires to be further tested through prototype implementation to identify its applicability and possible modifications deriving from real-world situations (Dimitrios Kitsakis et al., 2019).

The multiple uses of CityGML data models have stimulated research not only towards different scientific fields, but towards the integration with other data models as well. Extensive research towards integration of CityGML and BIM/IFC standards has been conducted during the years and may provide significant contribution to the technical aspects of developing 3D, multi-purpose cadastral systems within the context of Smart Cities. However, this topic does not fall into the scope of this work, so it will not be further elaborated. Further information on this topic can be traced, indicatively, in van Berlo & de Laat (2011), El-Mekawy, Östman, & Hijazi (2012), Jusuf, Mousseau, Godfroid, & Hui (2017), (Ohori et al., 2017).

[29] Within the context of this research, 3D real property unit is defined as "*a closed and independent spatial domain which is bounded by ownership boundaries or surface*".

5. Analysis of legal issues on real property stratification

In this section the legal issues regarding real property stratification that are traced in literature are analysed. The section starts by analysing the terminology used to describe real property and its spatial extent, as deriving from national legislation. The selection of the countries presented is based on their research regarding 3D Cadastres, while also aiming to include approaches from dominant legal traditions, Civil and Common Law. It needs to be noted that this section does not make an exhaustive research to each of the countries mentioned. Focus is on highlighting the different directions on the examined legal issues, by presenting the features of characteristic national approaches. Table 2 presents the basic characteristics of the countries (states or provinces) referred to in this section.

Table 2. Basic legal and cadastral characteristics of examined countries.

Country	**Jurisdiction**		**Registration System**		**Cadastre purpose**		
	Civil Law based	**Common Law based**	**Titles**	**Deeds**	**Legal**	**Fiscal**	**Multipurpose**
Argentina	✓			✓			✓
Australia[1]		✓	✓				✓
Canada[2,3]	✓	✓	✓	✓			✓
China	✓		✓				✓
France	✓			✓		✓	
Germany	✓		✓		✓		
Greece	✓			✓ [4]	✓		
Israel		✓ [5]	✓				✓
United States[6]		✓		✓	✓		
Malaysia		✓	✓				✓
Netherlands	✓			✓			✓
New Zealand		✓	✓				✓
Norway	✓		✓				✓
Poland	✓			✓		✓	
Singapore		✓	✓				✓
Sweden	✓		✓				✓
Switzerland	✓		✓				✓
United Kingdom		✓	✓		✓	✓	

[1] States of New South Wales, Queensland and Victoria were examined
[2] Provinces of Alberta, British Columbia, Manitoba, New Brunswick and Quebec were examined
[3] Province of Quebec constitutes a mixed jurisdiction, influenced by Civil Law
[4] In transition from deeds to titles system
[5] Mixed jurisdiction influenced by Common Law (Zweigert & Kötz, 1998)
[6] State legislation is based on Common law, except of Louisiana that is a mixed jurisdiction influenced by Civil Law.

5.1 Literature review of the legal issues concerning formation of 3D real property

Land Law constitutes fundamental legislation for the development and prosperity of modern societies. It regulates land use while, through the establishment and registration of real property rights, it allows for land to be used as collateral for credit, taxation or for the creation of securities (de Soto, 2000). Over the last decades, the need of land, especially on urban environment, is growing due to urbanisation, the establishment of large scale under and above ground infrastructures and legal

regulations on securing public benefit. This, results in increased land values and vertical exploitation of land.

This need is partially addressed by real property legislation. Roman principles of vertical accession[30] and ownership's extent "from heaven to hell"[31], allow only for the establishment of limited real rights on land and restrict real property stratification.

According to literature, there is a variety of legal issues that require to be dealt with, in order to allow for the establishment and management of 3D rights on land and, therefore, of 3D cadastral systems. Selected literature focused on jurisdictions where research on the legal amendments for introduction of 3D Cadastre is conducted. Jurisdictions where legislation is considered sufficient to accommodate real property stratification are not included in this section and are examined separately.

Although national legislation stipulations attach three-dimensional characteristics to real property, they also limit the capacity of its management in 3D space, by creating separate, volumetric parcels. Expanding the definition of real property to pertain such capacities constitutes a significant challenge for national legal systems. As land and cadastral laws reflect the national social, historical, cultural and economic characteristics to respond to specific needs, different definitions of 3D objects can be found at international level (Jesper M. Paasch & Paulsson, 2011). It is noted that not only the content of 3D real property definition is under debate, but the term itself as well. Depending on the country and the field of application, different terms are used to denote real property units delimited in 3D space. Jesper M Paasch & Paulsson, (2011), review applied terminology on 3D real property, the context within which such terminology is used, and its content based on the orientation of each definition, e.g. legal or organisational, focus on 3D object's formation or content. Given that apartment/condominium units are the most common examples of 3D real property units worldwide, 3D real property can be easily misinterpreted with this concept, as the content of 3D real property is not accurately defined at international level. The need of defining 3D real property covers a significant portion of literature on the legal aspects of 3D Cadastres, both of national (Caine, 2009; Ekbäck, 2011; Iván & Osskó, 2015; Karabin, 2014; Jenny Paulsson, 2007; Vitikainen & Hiironen, 2012) and international interest (Banut, 2011; Dimitrios Kitsakis, Paasch, Paulsson, Kalantari, et al., 2016; Dimitrios Kitsakis, Paasch, Paulsson, Rica, et al., 2018; J. Paasch & Paulsson, 2014; Jesper M. Paasch et al., 2016; Jenny Paulsson & Paasch, 2011; Ploeger, 2011).

Sandberg (2001), argues that the prevalent legal doctrine on the vertical extent of ownership, which can be summarised in the Latin maxim "*cujus est solum es usque ad coelum et ad inferos*" does not coincide neither with the right of freely exercise of ownership, nor with the freedom of contracts. He considers that 3D parcel registration would require definition of the exact vertical borderlines of each 3D parcel (Sandberg 2001) refer to a specific construction, or to non-material volumes[32].

[30] Superficies solo cedit.
[31] Cujus est solum es usque ad coelum et ad inferos.
[32] This constitutes a distinction between physical and legal objects, also highlighted by Kaufmann & Steudler (1998).

For the introduction of 3D real property units, Norway formed a research committee which indicated the following legal matters to be considered for the formation of 3D real property (Onsrud 2001, 2002, 2003). Definition of 3D real property types.

- The relation between 3D property and surface property.
- The distinction between condominium, registered use rights and 3D property/strata property.
- Relation among the involved parties and definition of the party that should carry the risks.
- Planning and building regulations for the approval of 3D property.

J. E. Stoter (2004), identifies two limitations concerning the cadastral situation of vertically overlapping real property. Firstly, the lack of registration of the space where a right applies and, secondly, that reality cannot be unambiguously defined, based on cadastral registration.

Research on introduction of 3D real property legislation in Sweden highlights the needs of defining real property in 3D and its vertical extent, also presenting concern on its relation to a construction, access, and management of the surface where a 3D property is established (Julstad & Ericsson, 2001). Jenny Paulsson (2007) summarised the purposes of introducing 3D real properties in Sweden to (i) the improvement of real property management to facilitate investments, (ii) overcome difficulties with overlapping building situations, (iii) the formation of property units for buildings, tunnels and underground storage, and (iv) allow for building of new structures on top of already built constructions.

Reviewing the legal amendments on Israeli legislation towards establishment of 3D "spatial" parcels, (Caine, 2009) claims that the new legislation should consider the following:

- Provide clear definition of the spatial parcel and clearly distinct it from traditional 2D real property.
- Regulate fixtures' ownership and indivisibility deriving from Roman principles of vertical accession and ownership extent, so that there is no restrictive impact on spatial parcels.
- Address possible spatial parcellation for speculation purposes through prohibiting creation of empty spatial parcels.
- The ways that spatial parcels can be created and if *numerus clausus* principle should be applied for their creation.
- Establishment of specific regulations for registration of caveats related to spatial transactions.
- Interaction of spatial parcels with other types of immovable property and highlight of their differences, so that they are not used as substitutes.
- Include special provisions for right of access and right of support regarding spatial parcels.

- Interrelation of Property Law and Planning Law within the context of spatial parcels[33].

In 2010, 3D Cadastres working group has worked out a questionnaire, in order to create an international inventory on 3D Cadastres worldwide, also considering the expectations for future development. It examines on a variety of aspects, including general 3D real world situations, infrastructures/utilities, constructions/building units, temporal issues, coordinate issues, RRRs, and plans of survey (FIG working group 3D-Cadastres, 2018). In this questionnaire, differentiations between different countries on the definition of 3D parcel is acknowledged and it is used on the broadest possible sense (FIG working group 3D-Cadastres, 2018). Difference between "physical" and "legal" objects within 3D Cadastre field is highlighted, since the former are not registered as such, but in the form of 3D spaces of the latter (FIG working group 3D-Cadastres, 2018).

(Karki, 2013), supports introduction of a formalised, 3D-based cadastre legislation that would provide for

- the creation of 3D cadastral parcels,
- 3D registration and transfer of rights,
- regulation of transactions between 3D cadastral objects and,
- creation of secondary interests on 3D objects such as 3D leases, easements and covenants.

Position paper on legal aspects of 3D Cadastre in the 2nd International Workshop on 3D Cadastres (Ploeger, 2011), states the importance of discerning between legislation regulating land registration and land tenure. It also highlights the lack of research on the legal aspects of 3D Cadastre, the absence of common rules and terminology, while it also presents the following practical issues to be addressed within 3D Cadastre legislation:

- Which types of 3D cadastral objects (3D properties) can be registered? Are these always related to constructions (buildings, pipelines, tunnels, etc.) as in Norway and Sweden or could it be any part of the 3D space (both airspace or in the subsurface).
- In case of infrastructure objects crossing 2D parcel boundaries, such as long tunnels, and pipelines and cables networks: should these be divided based on the surface parcels (as in Queensland, Australia) or treated as one cadastral object (as in Sweden or the Netherlands)?
- How to deal with the fact that the legal status of such an object, does not have to be the same for all the ground parcels. E.g. one construction situated in three ground parcels, each on the basis of another type of right (e.g. easement, restrictive covenant, lease).
- For the representation (and initial registration) of a 3D cadastral object, is the legal space specified by its own coordinates in a shared reference system (as

[33] Although Property Law and Planning Law are considered not to be related, regulations of the latter affect real property's value, constituting a relation between regulations and property markets (Jaeger, 2006; Kok, Monkkonen, & Quigley, 2014; Pollakowski & Wachter, 1990).

is the practice for 2D in most countries) or is it specified by reference to existing topographic objects/boundaries?

- Should the 3D registration and visualisation reflect the actual dimensions? Or is it sufficient to have a visualisation of property units in buildings based on standard floor-to-floor heights, as in Spain? What is the legal value of these boundaries? Is an investigation of the source documents (title deed, survey plan) needed to get legal binding information?

Choon & Hussin (2012), on their examination of recommendations for legal amendments in order to facilitate Malaysian Cadastral and Land Administration Systems by registering multi-layer properties, highlight the need of clearly defining and protecting rights in 3D properties. Definition of under and above ground, cross boundary utilities as an integral 3D property instead of segregating them based on surface parcels is noted by Choon & Hussin (2012b). Choon & Seng (2014) suggest that National Land Code of Malaysia should be amended so that (i) titles regarding underground or air space can be issued through limited or no rights on surface parcels, (ii) access for above ground 3D parcels is secured and (iii) 3D parcel boundaries are described.

In China, distinction of constructions on surface parcels from use rights to the space above or below surface parcel has been introduced by the amended Real Right Law in 2007, in order to promote land stratification, facilitating national land administration (Guo et al., 2013).

Discussions of the legal group during the 4th 3D Cadastres Workshop in 2014, highlighted the need of investigating the legal difference between 2D and 3D real property, the difference between ownership and building/use rights, the benefits of 3D regarding describing and securing RRRs on land, the contribution of 3D real property in case of informal occupation as well as economic benefits, transparency and cost (Jesper M. Paasch, 2014).

In his proposal of a 3D Cadastre model for Poland (Karabin, 2014) states the importance of defining the range of property rights in 3D space. He proposes the introduction of two new cadastral objects and rules that regulate the creation of 3D cadastral parcels in terms of (a) disposal of the space of cadastral objects and (b) of subdividing volumetric spaces from parcels where built constructions are located.

Since there is no 3D Cadastre system established globally, probably with the exception of Shenzhen in China, 3D units are established through limited real rights on existing 2D legal cadastral framework. However, this type of solutions is partial, since it does not allow for spatial subdivision of real property, mortgaging of 3D volumes, or imposing of Public Law Restrictions (PLRs) volumes of space instead of the whole land parcel (Karabin, 2014; Dimitrios Kitsakis & Dimopoulou, 2016).

Analysis of these issues is attempted by the same group of authors (Jesper M. Paasch et al., 2016), also reaffirming the lack not only of a common terminology, but of a common perception of 3D real property internationally as well. 3D real property units do not only exist in urban areas; rural areas are also of interest, as a variety of 3D cases can be traced in rural land, especially in the form of Public Law Restrictions or for the development of infrastructure projects, environment, or cultural heritage protection (Dimitrios Kitsakis & Dimopoulou, 2018; Dimitrios Kitsakis, Tsiliakou, Labropoulos, & Dimopoulou, 2017; Jesper M. Paasch et al., 2016).

Based on the conclusions of the work of (Jesper M. Paasch et al., 2016), Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., (2016) analyse the definition of real property in six examined countries and present the different cases of registerable or non-registrable 3D objects. They conclude that considering the peculiarities of each country's legislation, implemented solutions regarding 3D real property objects are not significantly different. Emphasis is given to the need of redefining real property on 3D space using unambiguous 3D terminology, the establishment of legal instruments that allow subdivision, consolidation and management of real property in 3D, introduction of 3D Pubic Law Restrictions and transition of existing 2D real property to 3D (Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2016).

Previous work was further enhanced by extending the same research questions to another nine countries globally, resulting in similar conclusions regarding legal requirements for the establishment of 3D cadastral systems (Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018).

Apart from the establishment of 3D real property to accommodate infrastructures and modern constructions, already existing cases of stratified real property need to be regulated within legal and cadastral framework (Dimitrios Kitsakis, Apostolou, et al., 2016). Cases of 3D Special Real Property Objects (SRPO) that were established based on customary rights are examined, considering legal and administrative limitations.

Public Law Restrictions also impose vertical limitations on individuals' rights on land, falling into the legal research on 3D Cadastres field. Limitations on 3D modelling of PLRs emerge as PLRs do not apply neither to physical spaces, nor are parcel-based (Givord, 2012). Dimitrios Kitsakis & Dimopoulou, (2016b) present the variety of 3D related PLRs, the need of 3D definition of PLRs along with their impact on the right of ownership. In their research on 3D PLRs concerning archaeological legislation, underground infrastructures and building regulations, Dimitrios Kitsakis & Dimopoulou, (2017a) conclude that current 2D based legal framework can only partially implement 3D PLRs, as it only provides for application of such restrictions on land parcels as a whole (instead of specific 3D spaces) and introduces ambiguities in the definition of the 3D space that can be exploited by land parcel owners. D Kitsakis & Papageorgaki, (2017) investigate 3D PLRs applying to the protection of water bodies. Existence of explicit, e.g. depth, or implicit, e.g. hydrogeological characteristics, 3D restrictions are traced which are, however, literally described or presented on 2D maps.

Classification of legal issues

Although a variety of legal issues are presented in the above literature review, many of them reflect similar concerns on 3D real property regulations, and therefore they can be grouped together, to assist further analysis.

- *Definition of real property using 3D terminology* is among the most common references in the above literature review. It comprises not only the definition of, contemporary, land parcels, but of 3D cadastral objects as well. Real property definition also involves terminology. Well defined 3D real property objects can be easier understood both by the public and professionals in order

to be used within everyday practice, and by researchers who aim to examine and adjust them to different legal contexts.

- *Terminology used to describe real property and definition of the spatial extent* of real property, both in terms of land parcels and of 3D objects is also among the suggested research issues. This would allow for efficient real property stratification as interested parties can be aware of the exact height and depth that land can be exploited, is encumbered or under restrictions by Public Law.
- *Relation with surface property.* This relates to the interrelation of 3D property with surface parcels so that neither of these inhibits proper operation of the other, e.g. 3D parcels' rights for access or support.
- *Distinction from other rights.* In this case, other types of rights used to establish stratified properties are considered. The differences between the each option need to be clear, as each type of right serves a particular purpose, thus it is not used as a substitute for the other.
- *Relation of 3D properties with a construction or possibility of empty spaces*. The possibility of establishing 3D real property for the construction of above or below the earth's surface constructions, or if 3D real property concept can be extended also to the establishment of "empty" volumes of space. In the former case, cross-boundary objects, especially infrastructures, need to be considered (e.g. are they to be regarded as an entire object or separated based on surface parcels?), while in the latter, denying of "empty" volumes, although prevents speculation purposes, restricts the possibility of imposing Public Law Restrictions (PLRs) on 3D space.

5.2 Definition of real property

Land, real estate, real estate property and immovable are terms that are very commonly used to denote a part of the earth where specific property rights apply in benefit of specific beneficiaries.

According to the (FIG, 1995), "*land may be defined as any portion of the earth to which rights of ownership, stewardship, or use may be exercised. Thus the land may include, for example, the surface area of the earth, buildings and permanently fixed improvements, surface and subsurface resources including water, and in some instances even well-defined units of air space (e.g. for power easements). Often the land and the buildings on the land are referred to as real estate and the various rights associated with land are called real property*".

This distinction is very important for Land Administration systems since it reflects the spatial and legal aspects of land that are registered to national land registries and cadastres. In several jurisdictions, land, real estate and immovable property are defined separately on different laws (e.g. New South Wales, Singapore), in relation to the right of ownership, its extent on vertical direction, and the objects pertained within the ownership right.

5.2.1 Civil Law jurisdictions

According to the Swiss Civil Code (art. 655), immovable property includes parcels on land and buildings thereon, distinct and permanent rights recorded in the land register, mines and co-ownership shares in immovable property. According to art. 943, the same data is also required to be recorded in the land register.

The French Civil Code does not explicitly define real property. However, articles 518-526 define a variety of immovable objects. Specifically, Art. 518 defines land and buildings as immovables, while water pipes bringing water to an immovable are considered immovables as well, forming part of the tenement on which they are attached (art. 523). Rights such as usufruct of immovable things, servitudes or land services and actions for the purpose of recovering an immovable, also constitute immovables by the object to which they apply (art. 526).

In the German Civil Code, article 94 defines as essential parts of a plot of land "*the things firmly attached to the land, in particular buildings…*".

Dutch Civil Code defines as immovable the land, the not yet mined minerals, the plants connected with the land, and the buildings and constructions permanently attached to the land, either directly or through a connection with other buildings or constructions. (Art. 3:3).

Russian Civil Code (art. 130-1) stipulates immovables (or the immovable property, realty) as "*the land plots, the land plots with mineral deposits and everything else, which is closely connected with the land, i.e., such objects as cannot be shifted without causing an enormous damage to their purpose, including the buildings and all kind of structures, objects of incompleted construction… The law may also refer to the immovables certain other property*".

Article 334 of the Spanish Civil Code, defines in detail the content of immovable property including, inter alia, land, buildings, constructions of all kinds joined to the ground, mines, quarries and rights in rem pertaining to immovable property.

Section 2 (art. 462-470) of Louisiana Civil Code defines immovable things such as buildings, tracts of land, constructions permanently attached to the ground, component parts and incorporeal immovables, e.g. rights and actions that apply to immovable things (art. 470). Distinction is made in article 464 on buildings that belong to a person other than the owner of the ground, thus constituting separate immovables.

Civil Code of Quebec defines immovables as "… *land and any constructions of permanent nature and forming an integral part thereof, non-extracted minerals …*" (art. 900). Real rights in immovables are also stipulated as immovables (art. 904).

Article 119 of the Czech Civil Code defines real estate property as lands and buildings connected with the ground by a firm foundation.

Greek Civil Code defines immovables as land and its constituent parts (art. 948), including, among others, things firmly attached to the ground, especially buildings (art. 954).

The Swedish Land Code defines real property as land (Chapter 1, Section 1) that is further divided in property units. The content of a real property unit is further defined in Section 2. It includes, among others, "*… buildings, utilities, fences and other*

facilities constructed within the property unit for permanent use... A property unit also includes a building or other facility constructed outside the property unit, if it is intended for permanent use in the exercise of an easement in favour of the property unit and does not belong to the property unit where it is situated".

Earth's surface along with buildings permanently attached to the land are defined as real estate by Polish Civil Code (art. 46). However, according to the same article also parts of buildings that, under specific provisions, constitute separate ownership from the land can be regarded as real estate. According to the cadastral law, cadastral parcel is a continuous area located on a specific cadastral district, is legally homogenous and it is separated from its surroundings with boundary lines (Bydłosz, 2012).

In China, land is either state-owned (urban land) or collectively owned (rural land) China (Urban state-owned land) (Property Law, art. 47, 48, 58). State-owned urban land includes the land "*… within the limits of cities … industrial and mining areas*" (Art. 2, Interim Regulations of the People's Republic of China concerning the Assignment and Transfer of the Right to the Use of the State-owned Land in the Urban Area, 1990). According to art. 58 of Property Law, collectively owned rural land includes, among others, land, buildings and facilities.

5.2.2 Common Law jurisdictions

In Common Law, the Roman principles regarding the vertical extent of real property also apply (Goldschmidt, 1964; Rothbard, 1982; Haim Sandberg, 2001; Surveyors Registration Board of Victoria, 1994b). However, statutory establishment of 3D real property units in several Common Law jurisdictions (e.g. Australia and Canada), proves that Common Law provides more flexibility for real property stratification (D. Kitsakis & Dimopoulou, 2014; Jenny Paulsson, 2007; Haim Sandberg, 2001).

Law of Property Act of the United Kingdom stipulate that land " *includes land of any tenure, and mines and minerals, whether or not held apart from the surface, buildings or parts of buildings (whether the division is horizontal, vertical or made in any other way) and other corporeal hereditaments; also a manor, an advowson, and a rent and other incorporeal hereditaments, and an easement, right, privilege, or benefit in, over, or derived from land; and "mines and minerals" include any strata or seam of minerals or substances in or under any land, and powers of working and getting the same; and "manor" includes a lordship, and reputed manor or lordship; and "hereditament" means any real property which on an intestacy occurring before the commencement of this Act might have devolved upon an heir*".

In New Zealand, according to Land Transfer Act (2017), land includes estates and interests, buildings and other permanent structures, land covered with water, plants, trees, and timber on or under land. Cadastral Survey Act provides for a different definition stipulating that land includes *"(a) subsoil, airspace, and water and marine areas; and (b) interests in or over land*".

In New South Wales, land is separately defined in each statute (New South Wales Land Registry Services (NSW LRS), n.d.). In case that there is no separate definition and there is nothing evident in rebuttal, Common Law definition applies. According to the Real Property Act, by land it is referred to "*Land, messuages, tenements, and hereditaments corporeal and incorporeal of every kind and description or any estate or interest therein, together with all paths, passages, ways, watercourses, liberties,*

privileges, easements, plantations, gardens, mines, minerals, quarries, and all trees and timber thereon or thereunder lying or being unless any such are specially excepted". A similar definition is also followed by the state of Victoria (Real Property Act). As regarding to Crown land, Victoria's Land Act (art. 339), limits the depth of land alienation "*to such depth below the surface as the Governor in Council may by any order direct*". According to the Surveyor Board of Victoria (1994), land ownership of alienated Crown land, extends to fifty feet below the land surface; below that depth, ownership is retained by the Crown (Surveyors Registration Board of Victoria, 1994a). Queensland's Acquisition of Land Act stipulates that land "*means land, or any estate or interest in land, that is held in fee simple…*", while under the Acts Interpretation Act "*land includes messuages, tenements and hereditaments, corporeal or incorporeal, of any tenure or description, and whatever may be the interest in the land*".

In Canada, Alberta Land Titles Act define as land "*land, messuages, tenements and hereditaments, corporeal and incorporeal, of every nature and description, and every estate or interest therein, whether the estate or interest is legal or equitable, together with paths, passages, ways, watercourses, liberties, privileges and easements appertaining thereto and trees and timber thereon, and mines, minerals and quarries thereon or thereunder lying or being, unless any of them are specially excepted*". The same definition is also used in the Real Property Act of Manitoba in Canada.

In the United States, real property, or in some cases real estate, is commonly used "*coextensive with lands, tenements and hereditaments*" (e.g. California Civil Code, Art. 14(b); New York Real Property Actions and Proceedings, Art.1 Sec. 111-2; South Carolina Code of Laws, Section 18-1-20; North Carolina General Statutes, Chapter 12). Title 10 on Property Rights and Transactions of Nevada explicitly includes within real property "*all possessory right to the soil for mining and other purposes*". United States' courts are reluctant to sever surface parcel from above ground air space (Schwartz, 2015). Separation depends on state legislation and its implementation on each state's counties, and it is, in most cases, related to condominium legislation. For example, Florida Condominium Act stipulates that land "*may mean all or any portion of the airspace or subterranean space between two legally identifiable elevations and may exclude the surface of a parcel of real property*" (sec. 103).

According to the Land Code of Malaysia land includes the surface (including air space) of the earth and all substances forming that surface; the earth below the surface and all substances at the surface; all vegetation and other natural products; all things attached to the earth or permanently fastened to anything attached to the earth; and land covered by water (Zulkifli, Alias, & Choon, 2017). Section 44 of Malaysian National Land Code stipulates that any person to whom land has been alienated or holds reserved land under lease, or has been granted temporary occupation license of any land "*is entitled to the exclusive use and enjoyment of so much of the column of airspace above the surface of the land, and so much of the land below that surface, as is reasonably necessary to the lawful use and enjoyment of the land…*". As regarding to underground land, State authority may "*specify the depth up to which the underground land directly and immediately, below the alienated land*

may be used, and different depths may be specified in respect of different parts of such underground land"[34] [National Land Code, art. 92B (1)].

In Singapore, definition of land differs, depending on each statute. Several of the definitions used are the following:

- "*land of any tenure, any building or part thereof, so much of the air-space above the surface as may be reasonably used or enjoyed by any proprietor, and so much of the subterranean space below the surface as is reasonably necessary for the use and enjoyment of the land, whether or not held apart from the surface, and any estate or interest therein*" (Sale of Commercial Properties Act),

- "*any airspace, subterranean space, foreshore, and benefits to arise out of land and things attached to the earth or permanently fastened to anything attached to the earth*" (Land Acquisition Act),

- "*(a) the surface of any defined parcel of the earth, so much of the subterranean space below and so much of the column of airspace above the surface whether or not held apart from the surface as is reasonably necessary for the proprietor's use and enjoyment, and includes any estate or interest therein and all vegetation growing thereon and structures affixed thereto; or*

  (b) any parcel of airspace or any subterranean space whether or not held apart from the surface of the earth and described with certainty by reference to a plan approved by the Chief Surveyor and filed with the Authority, and includes any estate or interest therein and all vegetation growing thereon and structures affixed thereto,

  and where the context so permits, the proprietorship of land includes natural rights to air, light, water and support and the right of access to any highway on which the land abuts" (Land Titles Act).

State Lands Act of Singapore, stipulates that alienation or disposal of state lands may involve *"(a) a parcel of the surface of the earth extending in depth and height as is reasonably necessary for the use and enjoyment thereof; (b) a parcel of airspace or subterranean space regardless if it is separately held from the land surface and (c) to such depth below the earth's surface as the President may by order direct (Sec. 3A).*" Subterranean space that is reasonably necessary for the use and enjoyment of land is defined in Sec. 3B (1), being "*(a) such depth of subterranean space as is specified in the State title for that land; or (b) if no such depth is specified, subterranean space to -30.000 metres from the Singapore Height Datum.*", without derogating from

"*(a)any reservation, by or under this Act or other written law, in favour of the State — (i) to all mines and minerals, mineral oil, natural gas, stone, clay, sand, gravel, and other natural deposits; or (ii) to enter upon any land and to search for and take any minerals, mineral oil, natural gas, stone, clay, sand, gravel, and other natural deposits which may be found in or below the land;*

(b) any condition implied (by or under this Act or other written law) in any State title for any land with respect to opening of or working any mines or quarries, or

[34] In case that a minimum depth has been defined for a specific class, description or location of land, minimum depth cannot be less than the defined minimum depth [National Land Code, art. 92B (1)].

digging for minerals, mineral oil, natural gas, stone, laterite, clay, sand, gravel, and other natural deposits; or

(c) any rule of law or written law relating to ownership of any column of space above any defined parcel of the surface of the earth.".

According to sec. 3B (3) of the State Lands Act any reference to subterranean space reasonably necessary for use and enjoyment of surface earth to any other law shall refer to the definition described above [sec. 3B (1)].

5.2.3 Content of real property ownership

Ownership is considered to be the strongest right that can be acquired over land. According to the French Civil Code (art. 544), "*ownership is the right to enjoy and dispose things in the most absolute manner*". Reference to the rights of enjoyment and disposal are stipulated in the Civil Codes of Spain, Quebec and Louisiana although not in "absolute manner". Only the Civil Code of Quebec stipulates that enjoyment and disposal of a thing can be exercised "*fully and freely*". Regardless the case, all of the aforementioned Civil Codes also restrict the powers of the right of ownership within legal limitations using stipulations such as "*provided they [the right to enjoy and dispose things] are not used in a way prohibited by statutes or regulations*" (French Civil Code, art. 544), "*without greater limitations than those set forth in the laws*" (Spanish Civil Code, art. 348), "*subject to the limits and conditions for doing so determined by law*" (Civil Code of Quebec, art. 947) or "*within the limits and under the conditions established by law*" (Civil Code of Louisiana, art. 477). According to Akkermans (Akkermans, 2008) the right of ownership in France is considered to be absolute[35] (in the sense that it constitutes the most extensive real property right of the French Civil Code), exclusive (the owner may exclude others from his right to use, enjoy or dispose of an object) and perpetual (it last for as long as the object on which ownership has been established exists).

In the German Civil Code, ownership allows its holder "*to deal with the thing at his discretion and exclude others from every influence*" (art. 903). Within the same concept, the Greek Civil Code allows the owner to dispose a thing at will and exclude any action thereon by another (Art. 1000), while Swiss Civil Code stipulates that the owner of an object is free to dispose of it as he or she sees fit (art. 641, par. 1) and may also reclaim it from anyone withholding it and protect it against unwarranted interference (art. 641, par. 2). Although the right of ownership provides its holder all the powers that can be exercised over a "thing" (Akkermans, 2008; Georgiades, 2016), the same articles also include restrictions to the powers of an owner. German Civil Code (art. 903) restricts the right of an owner[36] "*to the extent that a statute or third-party rights do not conflict with this*", while the Swiss Civil Code requires that owners' rights need to be exercised "*within the limits of the law*". Finally, according

[35] Rights are characterised as "absolute" also in other jurisdictions, however in contrast with French stipulation, this term is not used to denote that the right of ownership provides unlimited power over the thing (Storme, 2002).

[36] Reference on property is made also by the German Constitution, not only in terms of protection, but to its content and limits as well (art. 14, par. 1). Reference on the obligations deriving from property as well as its role in serving the public good is also made (art. 14, par. 2).

to the Greek Civil Code (art. 1000), the law or the rights of other parties must not be infringed.

According to the Dutch Civil Code ownership is the most extensive right that an owner can have on a thing (art. 5:1, par. 1; Akkermans, 2008). Stipulation regarding the powers of an owner is similar to those of the codes influenced by German Civil Code, allowing the owner to use the thing to the exclusion of everyone else (art. 5:1, par. 2). However, the right of ownership needs to be exercised with respect to the rights and entitlements of others to the thing, as well as on the restrictions based on the rules of written and unwritten law (art. 5;1, par. 2).

In Common Law jurisdictions, property law rules are based on judicial precedent, while the concept of ownership is not statutorily defined (Praduroux, 2017). According to the estate system that applies in Common Law jurisdictions, only the monarch or the state has the full ownership over land, while individuals acquire "parts" of land-ownership for a specific duration (Martin, 2003). Honoré (Hodgson, 2013) describes eleven interests and rights of an owner against an asset.

- *Right to possess*, in the sense of exclusive physical control of a thing.
- *Right to use.* The right of personal use and enjoyment by the owner.
- *Right manage.* The right to decide how and by whom a thing shall be owned.
- *Right to the income.* The right to enjoy any fruits, rents and profits deriving from the use of a thing.
- *Right to the capital.* This right provides an owner the power to alienate, consume, waste or destroy a thing he owns. Such power is not unlimited; further restrictions may apply to one or more of those powers, based on legislation.
- *Right to security.* The owner has the right to retain ownership of a thing for as long as he pleases, providing that he remains solvent. This right does not exclude the possibility of land expropriation, or of protection from a greater danger.
- *Incident of transmissibility.* According to this incident an interest is transmitted to the holder's successors *ad infinitum*.
- *Incident of absence of term.* According to this incident, ownership does not cease to exist at a future date or upon the occurrence of a future event. In the latter case, occurrence of the event needs to be certain even if it is indeterminate.
- *Duty to prevent harm.* The owner of a thing can manage and use the thing owned, subject to the condition that such use does not bring harm to others.
- *Liability to execution.* This incident implies that an object can be taken away from his owner for debt, either by execution of judgment debt, or on insolvency.
- *Residuary character.* In case that limited rights have been imposed on a thing, such rights revert, after their extinction, to the holder of the ownership right.

Modern legal understanding of property ownership uses the *bundle of rights (*or *bundle of sticks)* metaphor to distinguish the different types of powers on real estate that can be passed on other persons (Pierre, 1997). Schlager & Ostrom (1992), distinguish five bundles of rights including access, withdrawal, management, exclusion and alienation. Bundles are associated with property-rights' holders, including owners, proprietors, claimants and authorised users (Schlager & Ostrom, 1992). The bundle of rights concept is considered to capture well the way that ownership interests can be divided over time, among different people and common-interest communities, also highlighting the connection of different parties (Baron, 2014). On the other hand, this model is getting criticised for treating property as a mere collection of individual rights, without taking into account the holistic character of real property (Ellickson, 2011; Smith, 2011). Other researchers, focus their criticism on the emphasis of ownership on the exclusion of non-owners, rather than on the exclusive character of the owner to set the agenda over the owned thing (Katz, 2008).

Although legislation does not allow for different types of ownership to be imposed on real property, the right of ownership can be shared by different individuals under co-ownership. Co-ownership does not imply fragmentation of the ownership right; co-owners share the right under equal or non-equal, indivisible shares of the whole property. Such regulations can be traced in German Civil Code (art. 743, 744), Greek Civil Code (art. 1113), Swiss Civil Code (art. 646), Swedish Land Code (Chap. 4, sec. 8), Spanish Civil Code (art. 392, 393).

In Common Law jurisdictions the concepts of *joint tenancy* and *tenancy in common* can be considered to be analogous to the co-ownership right of Civil Law. Joint tenancy allows two or more tenants to hold undivided interest over a real property. In order for a joint tenancy to be applied, four "unities" need to be in force for each of the joint tenants: (i) unity of time (joint tenants' interest needs to be held at the same time), (ii) unity of title (joint tenants acquire their interest by the same title), (iii) unity of interest (joint owners acquire the same, identical interest in real property) and (iv) unity of possession (each joint owner holds an indivisible interest in the whole real property) (Akkermans, 2008; Alberta Land Titles, 2002; Registrar of Titles and Registrar of Water Allocations, 2009 (New South Wales Land Registry Services (NSW LRS), n.d.)). The difference among the two concepts is the right of survivorship. When one of the joint tenant is deceased, his interest is entitled to the surviving joint tenants. This does not apply to the tenancy in common concept. In case that one of the joint tenants within a joint tenancy decides to severe his joint tenant interest, then he becomes a tenant in common among with the rest interest holders. Furthermore, no equal share of interest is required among the tenants in common (Alberta Land Titles, 2002; Registrar of Titles and Registrar of Water Allocations, 2009; New South Wales Land Registry Services (NSW LRS), n.d; British Columbia Property Law Act, sec. 13).

5.3 Land parcels and 3D cadastral objects

Legal establishment of 3D cadastral objects has been introduced in national legislation in order to complement traditional, 2D cadastral parcels. Henssen (1995), considers a generic definition of land parcel as a continuous area of land where unique and homogenous interests are recognised. In some cases, other terms are

used instead of parcel, such as *lot* (Queensland, Victoria, Singapore, Malaysia) or *base land/parcel* (New Zealand), although all denote individual, clearly defined land units. However, such individual units are based on each cadastral system's purpose, (FIG, 1995) e.g. fiscal, legal or multi-purpose cadastre, as well as on national legal and organisational context (FIG working group 3D-Cadastres, 2018). 3D real property does not constitute a substitute of 2D real property, but aims to complement and extend the capabilities of traditional cadastral systems, in order to cope with the complexities that derive from complex, vertically overlapping RRRs (Jesper M. Paasch et al., 2016). According to 3D Cadastres Working Group a 3D parcel is defined as "*the spatial unit against which (one or more) unique and homogeneous*[37] *rights (e.g. ownership right, lease or other land use right), responsibilities or restrictions are associated to the whole entity, as included in a Land Administration system*" (FIG working group 3D-Cadastres, 2018). Subsections 5.3.1 and 5.3.2 present terms and definitions used to describe cadastral parcels and 3D real property units, while in subsection 5.3.3 different concepts are compared.

5.3.1 Land parcels

Land parcel constitutes the basic spatial unit of cadastral systems (FIG, 1995)[38]. A land parcels is a closed single area, delimited by boundaries, where homogenous rights apply and it is held in one ownership (Economic Commission for Europe, 2004). In most cases, land parcels extend vertically from the centre of the earth to infinity, based on the Roman maxim "*cujus est solum es usque ad coelom et ad inferos*". Physical boundaries of land parcels create a legal space where real property rights and PLRs apply. Within this space, physical constructions are developed. It is clear that legal interests' relation to their spatial component requires their spatial extent to be unambiguously defined, registered and presented on cadastral systems. Combination of the growing number of interests in land, both private and public, and the vertical stratification of such interests is challenging contemporary land

[37] Homogenous means that the same combination of rights equally apply within the whole 3D spatial unit. Unique means that this is the largest spatial unit for which this is true. Making the unit any larger would result in the combination of rights not being homogenous. Making the unit smaller would result in at least 2 neighbour 3D parcels with the same combinations of rights (FIG working group 3D-Cadastres, 2018).

[38] According to (Economic Commission for Europe, 2004), the extent of land that is one unit of ownership constitutes the Basic Property Unit (BPU) that may include one or more parcels. However, in practice in many European countries BPU consist of only one parcel.

parcel concept, as multiple RRRs by multiple stakeholders apply to different parts or volumes of a land parcel, or even cannot be restricted within a single parcel (Fig. 19).

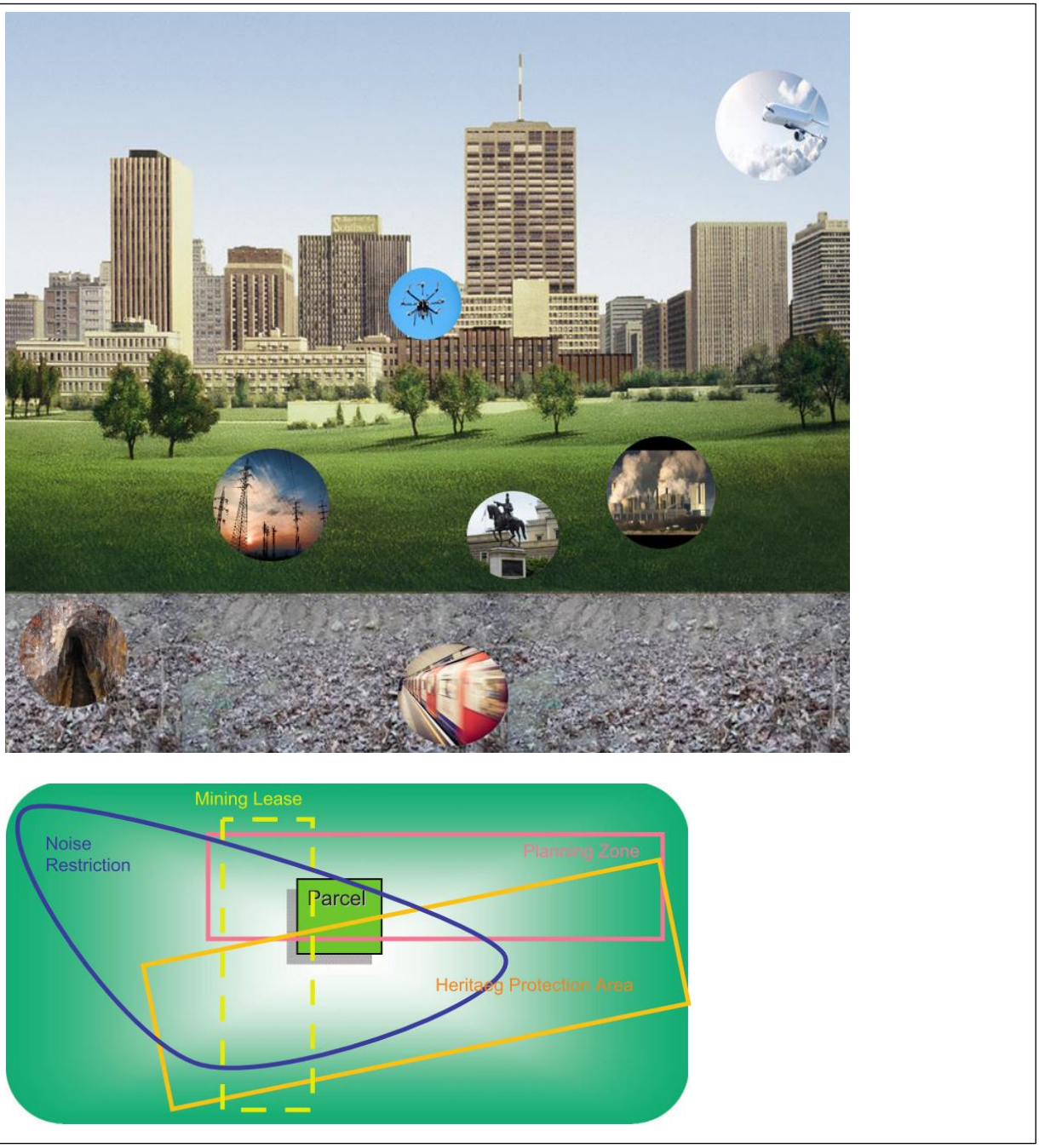


Figure 19. (Top): Multisurface RRRs (Dimitrios Kitsakis and Dimopoulou 2018). (Bottom): Non-parcel based interests (R. M. A. Bennett, Wallace, and Williamson 2006).

Therefore, it seems that a land parcel is not limited due to its 2D character, but due to the lack of a regulatory framework to delimitate it in 3D space, as highlighted by Jesper M. Paasch & Paulsson (2011).

This subsection reviews the terms used to define land parcels, their content and spatial extent above and below the land surface[39]. This procedure aims to identify the characteristics of land parcels, the possibilities and the limitations that the land parcel concept provides for stratification of real property. Concepts such as condominium, apartment or horizontal property ownership are not within the scope of this section, so they are not examined.

The Swedish Land Code defines property units to be the fundamental component of real property. Property units constitute land delimited either horizontally or both horizontally and vertically (Chap. 1, Sec. 1)[40]. Although Swedish law does not explicitly define the vertical extent of property units, it is generally accepted that the land surface owner is entitled to make use of the space above and below the land surface (Julstad & Ericsson, 2001).

A different approach is followed by the Cadastre Act of Norway, where parcel is *"… land demarcated by parcel boundaries on the earth's surface and with the restrictions deriving from the possible creation of 3D parcels…"*. The same section also defines the vertical extent of a parcel that *"… extends as far down into the ground and as far up into the air as private land rights reach according to general rules*" (Sec. 5, a).

Polish Cadastral Law defines cadastral parcel as "*the continuous piece of lands, located within the limits of one cadastral district, uniform from the legal perspective and distinguished from the surrounding areas by means of boundary lines*" (Karabin, 2014). As far as the extent of land ownership, art. 143 of the Polish Civil Code stipulates that property extends to the space above and below the surface, within the limits set by the socio-economic zoning (Parzych, Śliwiński, & Bydlosz, 2013).

Dutch Civil Code does not provide for a clear definition of a land parcel (van Vliet, 2006). However, Cadaster Act of the Netherlands describes a plot as "*a part of the territory of the Netherlands, the bounds of which the Agency has established with the help of survey data on the basis of particulars relating to legal status, purpose and use, and which is identified by its cadastral code*". Components of land ownership are described in art. 5.20 (par.1) of the Dutch Civil Code, including, as far as the law does not provide otherwise, (a) the topsoil; (b) the layers of earth beneath the topsoil; (c) the groundwater that comes to the surface naturally or through an installation; (d) the water above the soil unless it has an open connection to water covering another's land; (e) buildings and constructions permanently attached to the soil, either directly or through a connection with another building or construction, unless they are a component of someone else's immovable thing; (f) plants (vegetation) and trees connected to the soi*l*. The same article (par. 2), makes special provision regarding ownership of networks, which belong to the person who has lawfully installed them or to his legal successors. Reference on the vertical extent of the right to use the space above and below a surface parcel is defined in art. 5.21. According to par. 1, a land parcel owner has the right to use the space above and under land's surface. This does not exclude others of making use this space as long as they make use of it so high above or so deep under the surface that the owner has no interest

[39] In case that real property units' definition does not explicitly refer to their vertical extent, this may derive from regulations on ownership of immovables.

[40] The same definition is also used in the Real Property Formation Act (Chap. 1, Sec. 1a)

in opposing against it (par. 2). On the same article, par. 3 excludes from the above mentioned stipulations the right to fly in airspace.

In Germany, parcels are not defined in federal legislation, but by each federal state's legislation. According to German Civil Code (Art. 905), ownership extends to the space above the surface and to the subsoil under the surface. However, the owner may not prohibit influences that are exercised at such a height or depth that he has no interest in excluding them.

Technical Requirements for Cadastral Survey of Greece, define as land parcel a continuous area of land that is indivisibly owned by one or more beneficiaries (Sec. 1.12), based on the definition of immovable in the Greek Civil Code (Art. 948). The extent of real property ownership is defined in Art. 1001 of the Greek Civil Code "*above the surface and below the ground*", since no other law applies. However, according to the same article, the owner cannot forbid an action taking place high or low enough to be of interest to him (Papaefthymiou et al., 2004).

French Civil Code (Art. 552) stipulates that ground ownership involves "*ownership of what is above or below it*". The same article provides for restrictions based on the Title of Servitudes or Land Services regarding above ground plantings and constructions, while below ground constructions and excavations "*are subject to limitations resulting from statutes and regulations relating to mines and from police statutes and regulations*". The parcel is the unit of cadastral (land) ownership. It is defined as all adjoining lands that belong to the same owner, located in the same "lieu-dit" (locality) (https://www.cadastre.gouv.fr).

According to the Spanish Civil Code (Art. 350) "*The owner of a plot of land is the owner of the surface and of what is underneath it*". However, the next part of the article restricts performing of building works, plantations and excavations which may be convenient*, "save for any easements, and subject to the provisions of the laws relating to mining and waters and police regulations.*" Parcel is defined as a portion of land that is delimited by a closed line and owned by one or several individuals (Conejo Fernandez, 2003).

Swiss Federal Regulation on Land Registers defines a parcel of land as any land having sufficiently defined limits. In Swiss Civil Code, Art. 667 on the substance of land ownership defines that "*Land ownership extends upwards into the air and downwards into the ground to the extent determined by the owner's legitimate interest in exercising his or her ownership rights.*", including all buildings, plants and springs, within the limits prescribed by law.

In Argentina, Art. 4 of Cadastral National Law defines parcel as "… *a representation of a continuous real estate territory identified by a polygonal boundary with one or more legal titles of possession… "* (Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). Argentinean Civil Code (Art. 1945) stipulates that "*dominio*" (equivalent term for ownership in Argentinean Civil Code) extends to the subsoil and air space, to the extent that this is possible and there is no different provision made by special legislation.

Rights that are connected with a land parcel's ownership can also be considered as parts of the parcel, e.g. German Civil Code, Art. 96; French Civil Code, Art. 526; Spanish Civil Code, art. 334 (10). According to the Swiss Civil Code, separate or permanent rights (leasehold, water source rights, etc.) are regarded as plots of land

for the land register (Swiss Civil Code, Art. 943). Similarly applies also in Greece, where personal immovable property also pertains usufruct or predial servitude on a land parcel (Greek Civil Code, art. 949).

In Common Law jurisdictions there is no explicit stipulation defining the vertical extent of ownership, as Common Law does not provide for a statutory definition of the concept of ownership, even in general terms (Praduroux, 2017). Prevalence of the Roman maxims is recognised, although the actual upper limit of landowners' rights is affected by legislation on air-space navigation and on judicial precedence. As far as ownership below land surface is concerned, regulations regarding mineral ownership apply. Regulations that provide for creation of underground volumes have been introduced in Australian states, Singapore and Malaysia, as presented in section 5.2.3. Characteristic land parcel definitions within Common Law jurisdictions follow.

British Columbia Land Title Act defines parcel as "*a lot, block or other area in which land is held or into which land is subdivided*" (Part 1, sec. 1).

Boundaries Confirmation Act of New Brunswick define parcel as *"(a) an area of land or an air space parcel defined by a plan of survey or a subdivision plan filed under the Registry Act or the Land Titles Act, as the case may be, that can be separately conveyed as defined, or (b) an area of land described in a single description in a document registered or filed under the Registry Act or the Land Titles Act, as the case may be, that can be separately conveyed as described.*"

In Alberta, Municipal Government Act[41] defines that parcel means *"(i) where there has been a subdivision, any lot or block shown on a plan of subdivision that has been registered in a land titles office; (ii) where a building affixed to the land that would without special mention be transferred by a transfer of land has been erected on 2 or more lots or blocks shown on a plan of subdivision that has been registered in a land titles office, all those lots or blocks; (iii) a quarter section of land according to the system of surveys under the Surveys Act or any other area of land described on a certificate of title;*" (Part 18, Sec. 1).

In Queensland the term parcel is used meaning *"(a) land that is a lot; or (b) a part of a lot that is a declared parcel*" (Land Valuation Act 2010). In the Registrar of Titles directions for the preparation of plans, that stipulate the standards and specifications of plans to be submitted to Queensland's Titles Registry, parcel is used meaning "*a lot, part lot, easement, lease, profit a prendre, covenant, common property, carbon abatement interest or exclusive use area*". A lot is defined as "*a separate, distinct parcel of land created on the registration of a plan of subdivision…*" (Land Act). Land Titles Act define lot as "*a separate, distinct parcel of land created on (a) the registration of a plan of subdivision; or (b) the recording of particulars of an instrument[42];*". The difference among these two units is that a lot constitutes the

[41] As referred to by the Law of Property Act [part 3, sec.14(h)]

[42] According to the same Act, instrument means

(a)a deed of grant or certificate of title; and

(b)a will, grant of representation, or exemplification of a will, that may be used to deal with a lot; and

(c)a deed that relates to or may be used to deal with a lot; and

(d)a power of attorney that may be used to deal with a lot; and

(e)a request, application or other document that deals with a lot and may be registered under this Act; and

(f)a map or plan of survey that may be lodged; and

surface (or base) parcel, while parcel denotes a unit comprised within a lot under form of apartments, common properties or other volumes (Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). A similar concept, as far as terminology is concerned, also applies in Malaysia, where lot constitutes the basic administrative unit and is defined as "*any surveyed piece of land to which a lot number has been assigned…*" (National Land Code). Lots can be further subdivided to parcels[43], while for underground space a specific spatial unit, stratum, has been introduced in the National Land Code of Malaysia. According to art. 92B of National Land Code, State Authority specify the depth below which underground land may be used. The same article, makes provision for definition of different depth levels regarding different parts of underground land. Lot units also exist in Singapore. Lots constitute separate pieces of land, to which individuals are entitled with real property rights (Khoo, 2011). Land Titles (Strata) Act, defines lot as "*a stratum[44] which is shown as a lot on a strata title plan, and includes a lot specified as an accessory lot[45] on any such plan*". In combination with land definition, land lots, subterranean lots and airspace lots can be created[46].

In Victoria, a lot means "*a part (consisting of one or more pieces) of any land (except a road, a reserve or common property) shown on a plan which can be disposed of separately and includes a lot or accessory lot on a registered plan of strata subdivision and a lot or accessory lot on a registered cluster plan*" (Subdivision Act, Part 1). The term parcel is also used and it is defined in Land Tax Act, meaning "*any land that is— (a) contiguous or separated only by a road, railway or other similar area across or around which movement is reasonably possible; and (b) owned by the same person;*". Parcels can be subdivided into lots through registration of a plan of strata subdivision. Land Act of Victoria, provides for limitation on depth alienation of Crown lands, based on order directed by Governor in Council [art. 339 (1)]. However, subsection 6 explicitly states that such restriction does not limit alienation of Crown land to any height above the surface. In New South Wales, a parcel is an area of land defined by measurement (New South Wales Land Registry Services (NSW LRS), n.d.). According to Strata Schemes Development Act, parcel means the land comprising the lots and common property (when referring to a strata scheme[47]), or the land comprised in a plan lodged as a strata plan. Lots also exist, defined as "*one or more*

(g)another document that may be deposited; and

(h)an electronic conveyancing document.

[43] With the meaning of individual units comprised within a building that is subdivided (Strata Titles Act)

[44] Stratum is defined as "*any part of land consisting of a space of any shape below, on or above the surface of the land, or partly below and partly above the surface of the land, the dimensions of which are delineated*" [Land Titles (Strata) Act]

[45] An accessory lot is defines as "a lot intended for separate proprietorship and use with any other specified lot or lots for any purpose" [Land Titles (Strata) Act]

[46] Further types of lots, not falling into the scope of this thesis can be created, under Land Titles (Strata) Act.

[47] Under the Strata Schemes Development Act strata scheme means:

(a) the way a parcel is subdivided under this Act into lots or lots and common property, and

(b) the way unit entitlements are allocated under this Act among the lots, and

(c) the rights and obligations, between themselves, of owners of lots, other persons having proprietary interests in or occupying the lots and the owners corporation, as conferred or imposed under this Act or the Strata Schemes Management Act 2015.

cubic spaces shown as a lot on a floor plan relating to the scheme…[48]" (Strata Schemes Development Act).

Rules for Cadastral Survey of New Zealand, define a parcel as "*an area or space that is a single contiguous portion of land separately identified in a Cadastral Survey Dataset or in the integrated cadastre*".

In Israel, a parcel can be defined as a piece of land, part of a Registration Block, registered in the land Registration Books and defined by its shape, boundaries' lengths and area (Shoshani, Benhamu, Goshen, Denekamp, & Bar, 2005). According to art. 11 of the Land Law, "*ownership in a land parcel extends to all underlying depth, subject to the laws concerning water sources, oil, mines, quarries et alia, and to the empty space above it, without detracting from rights of flight, subject to any relevant provision of the law.*" (Caine, 2009).

5.3.2 3D real property units

Stratification of real property has introduced the need of separation between land surface and objects or volumes above or below it. The difference between 3D cadastral objects and cadastral objects deriving from limited real rights such as easements, rights of superficies, condominium and apartment rights needs to be distinct. 3D real property operates complementarily to existing property rights in order to extend real property management capabilities in cases where limited real rights fail to represent complex real world situations (Caine, 2009). This subsection, presents the types of 3D real property units that were introduced, or are proposed to be introduced in different countries.

The Swedish Land Code, defines two types of 3D property objects (Chap. 1, Sec. 1a).

- Three-dimensional property unit: a property unit which in its entirety is delimited both horizontally and vertically
- Three-dimensional property space: a space included in a property unit other than a three-dimensional property unit and delimited both horizontally and vertically.

Cadastre Act of Norway (Chap. 2, Sec. 5), stipulates that "*a 3D parcel, a building or structure, or a delimited physical volume for which planning and building permission has been granted, that has been subdivided as a separate property*" can be created as a separate cadastral object. According to the same section, 3D parcels may also comprise of permanent facilities on unowned seabed or in unowned surface parcels. However, section 11, imposes restrictions regarding 3D parcel formation. The building or structure that the 3D parcel comprises of, needs to extend into or under a different cadastral parcel, while the remaining parcel land (above or below the 3D parcel), needs to be capable of exploitation for an independent purpose. The same section explicitly forbids the use of 3D parcels in purposes which can be served by the establishment of condominium schemes.

In China, since land is State or collectively owned and a dual system of recording the (State-owned) land parcel and individual land use rights on it, the latter can be considered as 3D property objects, related to a physical construction (Yu et al., 2012). Besides, according to the Property Law of People's Republic of China, separate

[48] This definition applies when related to a strata scheme

construction rights can be created on, above or below the ground (under condition of not infringing prior usufruct rights on land) (art. 136), thus explicitly referring to stratification of construction rights on land.

Karabin (2014), proposed the introduction of two new cadastral objects for the establishment of Polish 3D Cadastre, instead of the existing cadastral parcel. The 2D cadastral parcel is defined as "*located within the limits of one cadastral district, the continuous piece of land, uniform from the perspective of the legal status, distinguished from the surrounding areas in the (x-y) plane by means of boundary lines and characterised by the determined vertical range in the "z" direction*", while the 3D cadastral parcel is considered as "*a continuous and compact piece of land, uniform from the perspective of the legal status, distinguished from the space of one or several 2D cadastral parcels from a given district - having a specified spatial range*".

On the other hand, Bydlosz (2013b), supports the "transformation" of existing, 2D-described objects to 3D objects. According to this approach cadastral parcel definition should be defined as a right prism that can be placed underground or aboveground (or both), restricted vertically by the provisions of Geological and Mining Law and Aviation Law.

In Singapore, Land Titles (Strata) Act, uses the term stratum referring to "*any part of land consisting of a space of any shape below, on or above the surface of the land, or partly below and partly above the surface of the land, the dimensions of which are delineated*". The same stipulation is also used in the Sale of Commercial properties Act.

According to the National Land Code of Malaysia, the concept of stratum is used, meaning "*a cubic layer of underground land*" (Art. 92A). Regarding above surface ground air space, Strata Titles Act has introduced the concept of "parcel" which, in relation to a subdivided building, means an individual unit within a subdivided building, and "storey" meaning "*any horizontal division of a building whether or not on the same level throughout and whether above or below the surface of the ground*" (Art.4).

In Canada, New Brunswick has established air space parcels defined as "*volumetric parcel of air space, whether or not occupied in whole or in part by a building or other structure*" (Air Space Act, Art. 1). In British Columbia, air space parcels are defined as "*volumetric parcel, whether or not occupied in whole or in part by a building or other structure, shown as such in an air space plan*" (Land Titles Act, art. 138). The same definition is also used in the Real Property Act of Manitoba (art. 133). Alberta Land Titles Act (art. 86) has established strata space, "*volumetric space, whether it is (a) located below or above or below and above the surface of the land, or (b) occupied in whole or in part by any structure, and that is shown as strata space on a strata space plan.*"

In Queensland a base parcel can be subdivided into different types of parcels through the registration of a registration plan. Created parcels can be unlimited in height and depth (*standard parcels*), fully limited by bounding surfaces (*volumetric parcels*) or defined by reference to floors, walls and ceilings (*building parcels*) (Department of Natural Resources and Mines, 2013). The remainder of a standard base parcel after subdivision of building or volumetric parcels constitutes the *remainder parcel*, while lots that are restricted by height or depth, either by reference to a defined distance

or by defined planes, constitute *restricted lots* (Department of Natural Resources and Mines, 2013). It needs to be noted that, according to the Land Act of Queensland, lots refer to a separate distinct part of land that is created on the registration of a plan of subdivision (Part 1, Sec. 3).

In New South Wales, stratum lots are used to restrict a parcel of land in height or depth (New South Wales Land Registry Services (NSW LRS), n.d.); Conveyancing Act, sec. 196C). Lots can be further subdivided into strata lots which may include "*lots wholly or partially inside building, external lots (that maybe wholly or partially covered) and open space lots*" (New South Wales Land Registry Services (NSW LRS), n.d.). New South Wales legislation uses the term "cubic space[49]", as a general term to define 3D air space (Jenny Paulsson, 2007). Cubic space is used both in defining "lot" [*one or more cubic spaces shown as a lot on a floor plan relating to the scheme, but does not include any common infrastructure, unless the common infrastructure is described on the plan, in the way prescribed by the regulations, as a part of the lot.* (NSW-Strata Schemes Development Act 2015, Sec. 4). In Victoria, stratum[50] means "*a part of land consisting of a space of any shape below, on, or above the surface of the land, or partly below and partly above the surface of the land, all the dimensions of which are limited*" (Transfer of Land Act 1958).

New Zealand's Unit Titles Act, use the concept of units to describe "*a part of the land consisting of a space of any shape situated below, on, or above the surface of the land, or partly in one such situation and partly in another or others, all the dimensions of which are limited, and that is designed for separate ownership*" (Sec. 4).

In the United States, air-rights constitute a kind of 3D real property units. Alternatively, the term "air-space" is used. Unused development rights can be transferred from one lot to another under Transfer of Development Rights (TDR) concept, while air rights are being conveyed in the United States already since 1908 (Eisenstadt & Utton, 1976; Goldschmidt, 1964).

In Israel, based on the results of a 2 year R&D project, the concept of spatial sub-parcel (Fig. 20) was chosen as the primitive 3D cadastral unit (Shoshani, Benhamu,

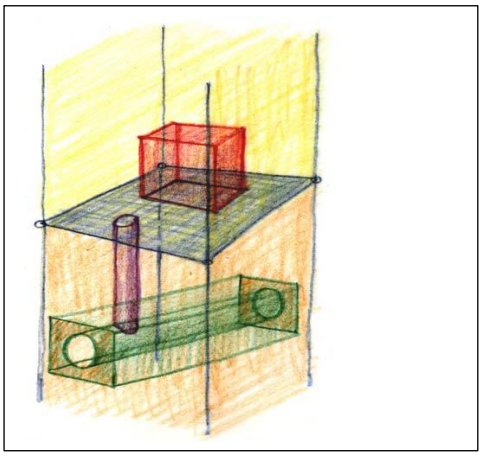


Figure 20. Spatial sub-parcel concept of Israel.

[49] Repealed Strata Schemes (Freehold) Development Act stipulated that cubic space "*includes a reference to space contained in any three-dimensional geometric figure which is not a cube*" [sec. 5 (3)].
[50] According to (Sherry, 2017), the term stratum is not commonly used in Victoria.

Goshen, Denekamp, & Bar, 2004). According to the 3D sub-parcel concept, surface parcel is subdivided vertically to, at least, one 3D volume bound within the 2D parcel's volume and the remaining 3D space (Felus et al., 2014).

5.4 Relation between 3D real property and surface property

With 3D parcellation of real property, new relations between the different property units are introduced, which need to be regulated, especially regarding residual ownership of the surface parcel and the above or below lying separate 3D volumes. This sections examines the relation between 3D real property units and traditional surface property in terms of requirements or restrictions imposed on each type of real property, such as access or support. Examined cases are limited on jurisdictions where 3D real property legislation is in force, not including legislation on apartment ownership. National approaches are grouped on the categories presented below.

5.4.1 Generic restrictions

This section includes jurisdictions where no explicit reference on the relation between 3D real property units and traditional land parcels is made in legislation. In such case, generic restrictions on unobstructed exploitation of the remaining from 3D real property units' subdivision parcel or land parcel related regulations may apply.

The Law Committee on revising Cadastre Act of Norway, considered that surface property should constitute the basic property object, comprising the residual volume after extracting a 3D parcel from the surface parcel (Onsrud, 2002b). However, concern that this volume extraction would affect, and gradually remove, the principle of ownership's vertical accession was raised, proposing that properties lying on "*no man's land (terra nullius)*", i.e. below general rules' reach of private land rights, would not require subdivision from surface property (Onsrud, 2003)[51]. Sec. 11 of Cadastre Act of Norway requires that 3D parcels created from cadastral parcels require, among others, not to obstruct the independent exploitation of the remaining cadastral parcel. This stipulation combined with the "*restrictions deriving from the possible creation of 3D parcels*", as provided in parcel definition, regulates the interrelation between traditional land parcels and 3D real property units in Norwegian legislation, so that both types of real property units may efficiently operate in tandem.

Swedish legislation does not explicitly regulate the interrelation between surface parcels with 3D real property units. However, provisions regarding establishment of easements can be applied in favour of 3D real property units as both Land Code (Ch. 1, sec. 1a) and Real Property Formation Act (Ch. 1, sec. 1a) stipulate that their provisions concerning land may apply also to other space included in a real property unit or jointly owned between several real property units. Regulation of property formation as defined in Chapter 3 of the Real Property Formation Act outlines suitability conditions of each type of created parcel. Such conditions can be used to describe the interrelation between different types of real property units. According to Sec. 1, property formation should be carried out in such a way that ensures enduring

[51] According to (Haim Sandberg, 2001), the doctrine of vertical accession of ownership should not inhibit real property stratification, as it restricts owners' rights to freely exercise ownership and their freedom of contracts. It also inhibits efficient land exploitation in cases that legislation provides for restrictions or land expropriation on a land parcel as a whole, which could instead apply to a separate land volume.

suitability of the real properties that are formed regarding their location, extent and other conditions. In case of 3D real property units (three-dimensional property or three-dimensional property space), it is required that "*it is clear that this measure is more appropriate than other measures for achieving the purpose intended*". Specifically, requirements regarding formation of 3D real property units are stipulated in Sec. 1 a, including that (i) the property unit is intended to contain a building or other facility or part of the same, (ii) the property unit is assured of the rights necessary in order for its appropriate use to be possible, (iii) it is clear that the measure is justified, having regard to the structure and use of the facility, and is calculated to lead to more appropriate management of the facility or to secure the financing or erection of the facility, and (iv) the property unit, if it is intended for housing purposes, is calculated to comprise at least five dwelling units. In case that real property formation involves a structure not yet erected, requirements on securing the financing or the erection of the facility, as well as on the time of completion of the facility which involves the formation of the 3D real property unit apply. In case that relation between different real property units requires to be regulated through establishment of easements, Chapter 14 of Swedish Land Code applies. According to sec. 1, easements need to promote appropriate land use and refer to a purpose of enduring importance to the dominant real property unit. However, easements may not be combined with a duty of the owner of the servient property unit to perform anything but the maintenance of a road, building or other facility to which the easement refers.

In Canada, British Columbia Land Titles Act stipulates that air space parcels constitute land and lie in grant (art. 139), while the relation between air space parcels and surface land is clearly defined in art. 140 which clarifies that grant of an air space parcel does not imply grant of any kind of easement or any covenant restricting land use, or a covenant to convey part of the grantor's land (par.1). The same article, par. 2 stipulates that, unless expressly granted, the rest of the space that remains after granting an air space parcel remains in the grantor. Similarly applies in New Brunswick, where Air Space Act (art. 2) stipulates that air space parcels constitute land and shall be dealt as land. This is further clarified in art. 6 stipulating that air space parcels "*shall devolve and may be conveyed or otherwise dealt with in the same manner and form as other land*" [art. 6 (1)]. The fact that formation of an air space parcel does not involve the creation of any easement or restrictive covenant on use or land conveyance is provided in art. 6(2), using a similar stipulation with British Columbia's legislation[52]. Ownership status of the remaining space after conveyancing of an air space parcel is defined in art. 6(3) of the same act which stipulates that "*Unless expressly conveyed, the title to the air space above the upper limits and below the lower limits of an air space parcel remains in the transferor*". Real Property Act of Manitoba also considers air space parcel to constitute land and they can be "*transferred, leased, mortgaged, charged or otherwise dealt with in the same manner as other land registered under this Act*" [art. 133(4)]. Although there is no specific reference on the relation of air-space parcels with surface property, since air-space parcels are dealt in the same manner as land, easements can be applied. In case of further subdivision of air-space parcels Condominium Act applies [Real Property Act, art. 133(4)] which explicitly refers to creation of easements such as installation of

[52] British Columbia Land Titles Act refers to a grantor granting an air space parcel, whereas New Brunswick legislation uses the term transferor.

services or support and shelter [Condominium Act, art (41)]. A different case applies in the province of Alberta, where Land Titles Act does not include regulations on the relation between 3D real property units and land parcels. Although easements or agreements on access, establishment of utilities or structural support are required among the involved parties (Alberta Land Surveyors Association, 2011), no such provision is made to the strata volumes part of Land Titles Act.

5.4.2 Implied easements

In this section, jurisdictions where implied easements or necessary rights are provided in legislation, regarding 3D real property units are presented. Provision that such easements carry all ancillary rights in order to be effective is made, as well as that easements are consistent with reasonable use and enjoyment of 3D real property units, while not interfering to the reasonable use and enjoyment of the remaining real properties.

Land Act of Victoria regulates lease and alienation of Crown lands in strata (sec.134A, 339A). Both sections make explicit reference that provision for "*any necessary rights of support of the stratum or other land or of any building or structure erected or to be erected on those lands*" [subsection (2)(b)(iii)], as well as for "*any necessary rights for the passage or provision of services (including drainage, sewerage, or the supply of water, gas, electricity or telephone) to or through the stratum, where those rights are necessary for the reasonable enjoyment of the stratum or other land*" [subsection (2)(b)(iv)] is required for the lease or alienation to be granted. Section 339A on alienation of Crown land also requires that alienation should not be granted in case that the grantee, and his successors, do not obtain reasonable access and use of land (subsection 3a), and that the grant interferes with the exercise of rights of the registered proprietor lessee or license of other land (subsection 3c). Subdivision Act provides that they are implied all easements and rights necessary to provide, inter alia, support, shelter or protection, passage of services or rights of way, if such easements or rights are necessary and consistent with the "*reasonable use and enjoyment of the lots and common property*". Easements are implied over *"(i) all the land on a plan of subdivision of a building; and (ii) that part of a subdivision which subdivides a building; and (iii) any land affected by an owners corporation; and (iv) any land on a plan if the plan specifies that this subsection applies to the land; and for the benefit of each lot and common property*" (Sec.12, subsection 2). In Queensland, rights of access and support of lots are contained in a building management statement which is an instrument that, inter alia, contains provisions that benefit and burden the lots to which it applies (Land Title Act, sec. 54A, 54C). According to sec. 54B of the same Act, a building management statement must comprise of two (or more) volumetric format lots, or one (or more) volumetric format lots and one (or more) standard format lots. In case of a building management statement, rights of access or support may operate even if not established through a formal registered easement (Land Titles Act, sec. 54C, subsection 3; Land Act, sec. 294D, subsection 4). New South Wales legislation also provides for implied easements regarding subjacent and lateral support, on registration of a building management statement regarding a building and its site (Conveyancing Act, sec. 196K). Such easements are implied as appurtenant to each of the lots that include a part of the building that are capable of enjoying support, affecting those parts of the building that are capable of affording support (Conveyancing Act, sec. 196K).

Reference to implied easements for support is also made on Strata Schemes Development Act regarding lots and common property that a part strata parcel[53] consists of.

State Lands Act of Singapore provides for implied easements belonging to each parcel of land for the subjacent support by any other parcel of land, capable of affording such support, affecting each parcel of land that is capable of being supported (sec. 3C, subsection 1). Implied easements also entitle the grantee to install, maintain or repair structures supporting the dominant tenement, as well as to access the servient tenement for the installation, maintenance or repairing of any such structures, on condition that the rights of the holder of the servient tenement for enjoyment of use and occupation of his land are not impaired, and damage from any activities carried out in the exercise of implied easements are minimised (sec. 3C, subsection 3).

In New Zealand, Unit Titles Act defines as "*incidental rights"* appurtenant rights to common property and to each unit of a unit development including, among others, support and passage of services (sec. 73, subsection 1). Incidental rights carry all ancillary rights and responsibilities necessary to make them effective as if they were easements (Sec. 73, subsection 3).

5.4.3 Explicit provisions

This section focuses on Malaysian statutes regulating the relation between 3D real property units and traditional land parcels. Malaysian legislation provides for detailed, explicit regulations, although referring only to underground 3D real property units.

In Malaysia, alienated underground land is subject to conditions of protection and support of adjoining underground land, as well as of access from all parts of underground land to the surface, as specified by State Authority (National Land Code, sec. 92B-92G). The distinction between alienated underground land (up to the depth specified by State Authority) and the remaining underground land, is made on sec. 92B (subsection 4), 92D (subsection 7) and 92E (subsection 3). Provision is also made that remaining underground land (below alienated, or leased underground land) shall be capable of being used up to the depth that State Authority has specified (National Land Code sec. 92D, subsection 5; sec. 92F, subsection 4; 92G, subsection 4).

5.5 Distinction between 3D objects and other real property rights

In jurisdictions where no specific provision is made regarding 3D real property units, limited real property rights are employed to achieve stratification of real property. This approach provides rights on land owned by another person, with respect to the principles of functional, physical and legal unity of property, as described by Parisi (2002). Despite the fact that such legal instruments have proved efficient for centuries [the right of emphyteusis dates back to the fourth century BC (Rome, 2008)], their capacity to provide and secure rights on scarce natural resources and on increasingly denser, modern urban environment seems to be limited. Real

[53] Parcel that is created by subdivision into lots or lots and common property of "land including part only of a building and consisting of one current plan lot or 2 or more current plan lots (whether contiguous or not)" [Strata Schemes Development Act, sec. 9(1)(b)].

property rights comply with the "*numerus clausus*" principle (i.e. they are restricted in number and each one has specified content), and may differ depending on each jurisdiction. However, despite that real property rights operate differently from 3D real property objects, the use of the former in cases of real property stratification introduces difficulties in understanding operation of the latter. This section presents the differences between the most common limited real property rights and 3D real property objects, along with their advantages and disadvantages as regarding to real property stratification. Comparison between the use of limited real rights and 3D real property units, follows in section 6.

5.5.1 Servitudes

Since servitudes allow for specifically defined rights of a land parcel owner to another owner's land, they have been extensively used for real property stratification purposes, mainly for the establishment, repairing and maintenance of utility networks and infrastructures, lying above or below the earth's surface. Servitudes for support of structures or for access may also be established in favour of 3D real property objects (in jurisdictions where 3D objects have statutorily established), condominium or apartment units.

The main issues that can be traced regarding exploitation of servitudes for real property stratification can be summarised in the following:

- Servitudes (easements) are not defined or delimited in 3D. Case-specific regulations, specifically in case of utilities, may provide for exploitation of the underground, or of the aerial space above the land's surface encumbered by a servitude (Tsoumas, 2015). However, it remains a surface parcel related right that requires to be tailored to each specific case, while it cannot be unambiguously presented on cadastral maps, or interrelated with other vertically overlapping RRRs.

- Servitudes (easements) constitute limited real property rights, therefore they cannot be further encumbered by other limited real rights. This means that if real property stratification is achieved through establishment of a servitude (easement), the stratified real property can neither be encumbered by another servitude (easement), nor used as collateral (Georgiadis, 2012; Van Staden, 2015; Yiannopoulos, 1968). In most jurisdictions, legislation does not prohibit the establishment of multiple servitudes, of the same or of different type, on a land parcel. However, new servitudes apply to the remaining part of the encumbered ownership right, thus being lesser compared to those established earlier (Triantos, 2000). Restricted easements that are allowed in several Common Law jurisdictions facilitate land management by restricting the right of ownership on a specific 3D space. However, it is noted that restricted easements concept operates in jurisdictions where 3D real property units are established. Consequently, this concept cannot be considered as an individual means of real property stratification.

- The specific types and the content of servitudes (easements) based on the *numerus clausus* principle, restricts their suitability for 3D definition and management of PLRs. Servitudes of passage and public easements are the most commonly used servitudes (easements) related to real property stratification and 3D Cadastre. Although legislation provides for a variety of PLRs (see Sec. 5.5), there is no provision for them to be applied in the form of

servitudes (easements). Legislation already provides for tolerance of emissions, smoke or vibration from neighbouring land parcels (under specific conditions), although does not regard such nuances as servitudes (easements). Agreements between neighbouring landowners are also stipulated by legislation not as servitudes (easements), but under the form of personal limited real rights. In Common Law jurisdictions, conservation easements (or conservation covenants) can be used to impose environmental PLRs. Cutting & Cahoon (2005), suggest that radiation, heat, light, odour, radiation and any other substance carried from a polluter to a land parcel by air, water or soil should be regarded as trespass to the land parcel. According to this approach, such trespass constitutes an "easement to pollute" of involuntary nature, encumbering the receptor's land. Conservation easements (or conservation covenants) may also be combined with restricted easements, so that environmental PLRs can be described in 3D context.

5.5.2 Usufruct

Comparing the characteristics of the right of usufruct to the requirements of 3D real property units, it seems that it cannot serve the purposes of real property stratification. The main deficiencies of usufruct for real property stratification purposes can be summarised in the following:

- Establishment of a usufruct may provide to a third party, the use and gathering of the profits of a real property. However, usufruct extends to the encumbered land parcel as a whole and cannot be used to create separate volumes where individual rights apply.

- According to usufruct legislation, the usufructuary is obliged to preserve the substance of the real property. This means that the economic purpose of the real property should not be modified and no substantial changes should be made to the real property by the usufructuary. Since one of the primary aims of real property stratification is the definition of spatial volumes for the vertical allocation of different RRRs on land, it is evident that the restrictions that apply to concept of usufruct do not comply with the aims of real property stratification.

- Similarly to the rest of limited real rights, usufruct is not subject to other limited real rights, most notably mortgage, while the right applies during the lifetime of tis holder. Therefore it is not an attractive concept for real property investments.

5.5.3 Right of superficies

The structure and content of the right of superficies is clearly closer to the concept of real property stratification. This can be easily proved by the fact that the right of superficies is used for several years as a means of separating surface parcel ownership from ownership of constructions above or below land surfaces. Expansion of the right of superficies to be used on the registration of real property volumes is presented by J. Stoter et al. (2016, 2017). The advantages of using the rights of superficies include the rights' duration and the fact that they can be subject to other limited real property rights (although under specific limitations). Given that rights of superficies can be established for maximum duration of 99 years, while in some jurisdictions they may be in perpetual, they constitute an attractive option for long-term, real property investment projects.

On the other hand, two main disadvantages of their use for real property stratification may be traced. First, rights of superficies can be used in simple cases of real property stratification, since they merely create two distinct real property entities, i.e. the surface parcel and the space above and/or below it. Although multiple rights of superficies can be established on a land parcel, this does not allow for separation of individual real property units lying on different height levels. Secondly, rights of superficies are related to, either existing or not yet constructed, buildings or structures. Therefore, the right of superficies cannot be used to create separate legal spaces that are not directly related to physical volumes.

5.5.4 Emphyteusis

Emphyteusis is a right that is also common for real property stratification purposes while its characteristics resemble not only those of the right of superficies and of the personal servitude of usufruct, but of lease contracts as well (Akkermans, 2008). However, emphyteusis is not so widely used, compared to the rest of limited real property rights, and several jurisdictions have abolished this type of right. The advantages and the disadvantages of using the right of emphyteusis in real property stratification can be summarised in the following:

- Emphyteusis separates the ownership of a land parcel from its use and exploitation. Although this constitutes a simple way of real property stratification, it is doubtful that such a right could accommodate multiple, complex cases of vertically overlapping land uses.

- Similarly to the right of superficies, emphyteusis is a right of potentially long duration (depending on jurisdiction, its least maximum duration can be 99 years, or it may be established in perpetuity), while it is not related to the life-time of the right holder. Land held under the right of emphyteusis is also subject to other limited real rights and it can be used as collateral. Therefore, it constitutes an attractive option for long-term, real property investment projects. On the other hand, the right of emphyteusis provides to its holder ownership of the buildings and constructions that are erected on the encumbered parcel, only for the duration of the emphyteusis. Afterwards, according to the *superficies solo cedit* principle, constructions' ownership reverts to the land parcel owner, with no compensation on the holder of the emphyteusis.

- Depending on jurisdiction, emphyteusis may be subject to clauses of non-alteration or of specific use of the immovable. Evidently, the former case limits the efficiency of the right of emphyteusis for real property stratification purposes, while the latter restricts real property stratification on specific types of exploitation of the immovable.

- Emphyteusis is related to buildings or constructions on the encumbered land parcel. Hence, it cannot be used to create legal spaces that are not related to physical structures, e.g. PLRs.

5.5.5 Composite ownership

Composite ownership types have been developed to exploit space vertically, for residential and commercial purposes (C. van der Merwe, 2016). The structure of composite ownership rights allows for vertical partition of real property, within the *superficies colo cedit* principle, through the shared ownership of the surface parcel

and of the common building parts. Additionally, composite ownership types constitute individual property units that can be further encumbered by limited real property rights. These aspects of composite ownership types constitute the main argument against real property stratification within a 3D Cadastre concept. Although implementation of composite ownership concepts is indeed operating efficiently for more than 50 years, there are several disadvantages that inhibit its use for real property stratification purposes.

- The use of composite ownership types is limited to specific types of real property use, such as accommodation or commercial purposes. In several jurisdictions, other types of uses may be provided such as parking, caravan sites, mooring spaces for yachts and boats, or even graveyard sites. However, stipulated land use types refer only to the above-mentioned land use types and cannot be used in case of under, or above ground infrastructures.

- Composite ownership comprises of an indivisible share on common property ownership. Although this secures compliance to the *superficies solo cedit* principle, it may complicate cases of real property stratification where no common property exists, or in projects where ownership of the surface parcel is not intended (i.e. underground subway line passing below residential buildings).

- Composite ownership is mainly used to create different ownership volumes within buildings. Therefore, composite ownership is created over a well-defined physical structure, using diagrams that present the exact boundaries of each property unit. This cannot be applied in several cases of real property stratification, when RRRs are imposed on legal spaces, or are not related to a physical construction (e.g. PLRs). In several jurisdictions, bare land condominiums may be stipulated in legislation. However, the only difference between bare land and conventional condominium units is that the former refer to a parcel of land that has not been developed.

5.5.6 Indirect ownership

Indirect ownership units have been developed to serve accommodation purposes and do not constitute real property rights, but personal rights of the shareholder against the company. Relation of indirect ownership rights' holders to real property is achieved through acquisition of shares within the collective association, corresponding only to rights of exclusive use within the development and, in most cases, cannot be used as collateral. In case of the establishment of non-material, legal spaces, such as PLRs, these are out of the scope of indirect ownership rights. Therefore, indirect ownership is not suitable for real property stratification purposes.

5.5.7 Special Real Property Rights and Objects

Special real property rights and *objects* constitute particular rights and objects that apply only to specific types of real property use. Additionally, they derive from a specialised national background, reflecting, among others, each country's legal, cultural and historic particularities. Therefore it is difficult to be adjusted and applied to foreign legal and administrative contexts. Above mentioned special rights mostly regulate the relations between the involved parties to minimise conflicts and facilitate parcel's exploitation. However, they cannot be used neither in cases of multilevel stratification purposes, nor to create "layers" of rights applying to different legal or physical spaces.

The concept of *land objects,* if adopted and enriched with 3D characteristics, can prove very useful in the field of real property stratification and 3D Cadastre. Legal and physical land objects can be used both in case of legal and physical space, as well as in cross boundary infrastructures. Introduction of such a concept would, however, require reconfiguration of land and cadastral legislation from a parcel-based system to a land object-based system.

5.6 Public Law Restrictions

Most of modern legal systems around the world regard the right of ownership as a social function pertaining rights, restrictions and responsibilities to its holder (Crawford, 2011; Spyridakis, 2001a). Therefore, the extent and the content of the right of ownership is significantly affected by regulations and restrictions deriving from Public Law (Public Law Restrictions-PLRs). Public Law comprises the rules that regulate the relations between citizens and the state[54], compelling the former to conform to the regulations of the latter, in the course of exercising supreme authority of the state, or of another Public Law legal person (Agallopoulou, 2005). PLRs aim to promote the expansion of national economy allowing a degree of state interventionism, to serve the purposes of social policy and to protect public benefit and national security (Georgiadis, 2012). PLRs usually restrict the powers that a land owner may exercise over his land and provide additional power to administrative bodies. However, restriction of the powers deriving from the right of ownership does not establish private rights in favour of other individuals that hold real property rights on the neighbouring land parcels, or in favour of the encumbered by PLRs parcel itself (Georgiadis, 2012). PLRs are also related to the content of the right of ownership as they can be regarded as external restrictions on the (unlimited) total, immediate and absolute power deriving from real property ownership, or as restrictions inherent to the nature of ownership, or as restrictions that apply when exercising the powers that derive from the right of ownership (Georgiadis, 2012). Based on their purpose, PLRs can be classified to the following categories (Georgiadis, 2012; Spyridakis, 2001b):

- Restrictions deriving from public and national security purposes;
- Restrictions aiming to secure public health;
- Restrictions serving purposes of urban planning, building regulations and aesthetic appearance of cities;
- Restrictions allowing passage to cross-boundary infrastructures and utilities;
- Restrictions for the protection of landscape, archaeological sites and monuments;
- Restrictions serving social economy and social policy;
- Environmental protection restrictions.

Increase of the number of PLRs, is followed by increase of their impact on real property management. In Switzerland more than 150 laws, ordinances and regulations are considered to regulate contemporary life (Givord, 2012), while

[54] The notion of Public Law also pertains the rules which regulate a state's organisation and operation (Agallopoulou, 2005).

Twaroch (1998, according to (Gerhard Navratil, 2012)) has identified more than 40 laws that directly influence the use of land in Austria. In the state of Victoria in Australia (R. M. A. Bennett, Wallace, & Williamson, 2006) have identified 66 Acts (out of a whole of 620 Acts) that affect ownership rights, equal to be registered. Although PLRs are spatially defined, they are not validated, registered and publicised as thoroughly as real property rights stipulated by Private Law (Cadastre and Land registry Knowledge Exchange Network, 2015).

Publication of the visionary work "Cadastre 2014" (J Kaufmann & Steudler, 2001), highlighted the need of enriching cadastral records with PLRs. Research community was not unfamiliar to PLRs imposed on land, e.g. (Dale & McLaughlin, 1999; L Ting & Williamson, 1999; Lisa Ting & Williamson, 2001; United Nations, 1996), but such restrictions were examined as a (not distinct) part of the broader concept of RRRs imposed on land. On the occasion of its workshop in 2015, Cadastre and Land Registry Knowledge Exchange Network (CLRKEN) has conducted a survey among its country members on the documentation of PLRs, identifying and classifying the most common categories of PLRs (Cadastre and Land registry Knowledge Exchange Network, 2015):

- Environment and nature protection;
- water protection;
- spatial and land-use planning zones;
- cultural heritage;
- public infrastructure corridors and zones;
- traffic lines and zones
- forest management and protection;
- contamination sites, pollution;
- public easements, servitudes;
- coastal protection zones;
- national border restrictions;
- sea and water public domain;
- biological diversity;
- security zones;
- noise;
- concessions;
- cultivation restrictions;
- mining related rights and restrictions.

Figure 21 summarises the most common PLRs, based on the responses of 22 of the country members of CLRKEN on its survey on PLRs (Cadastre and Land registry Knowledge Exchange Network, 2015).

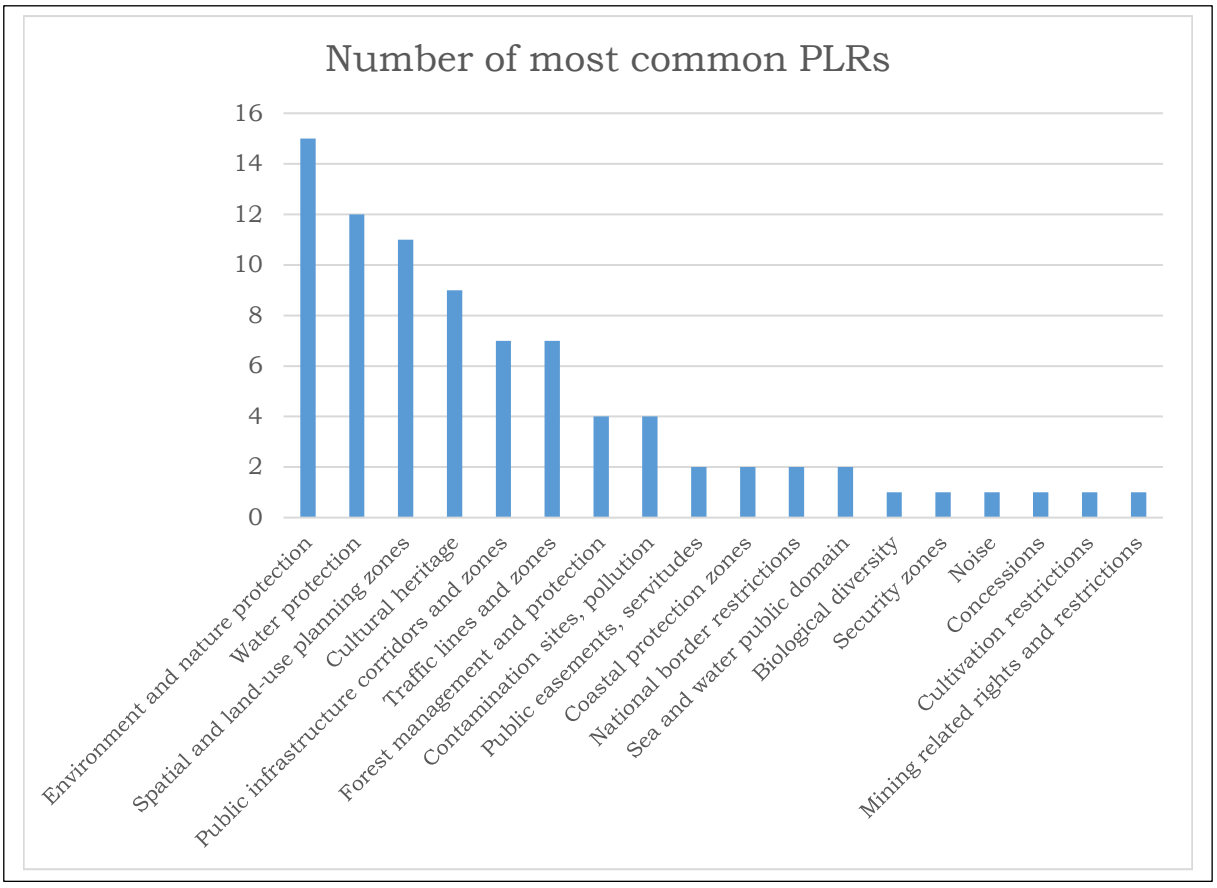


Figure 21. Most common PLRs according to the survey of CLRKEN (adjusted (Cadastre and Land registry Knowledge Exchange Network 2015).

The number of documented PLRs in each country significantly differs, ranging from 2 (Albania) to 266 (Latvia) (Figure 22) (Cadastre and Land registry Knowledge Exchange Network, 2015). Depending on the development of each National Spatial Data Infrastructure, the capability of overlaying PLR zones to cadastral parcel maps may be provided, while each jurisdiction may allow for open access to national PLR spatial data, or restricted access merely among interested parties. It is noted that in several jurisdictions, registration of PLRs to their corresponding registry does not affect their validity, e.g. Law of Property Act of Estonia (Kuus, 2011; Nielsen, 2015).

Differences between legislation, Spatial Data Infrastructure and land administration systems do not allow for a uniform system of PLRs' recording. For example, in federal countries different laws apply in each state therefore, different content may be recorded in state databases, despite the uniformity that federal legal requirements provide.

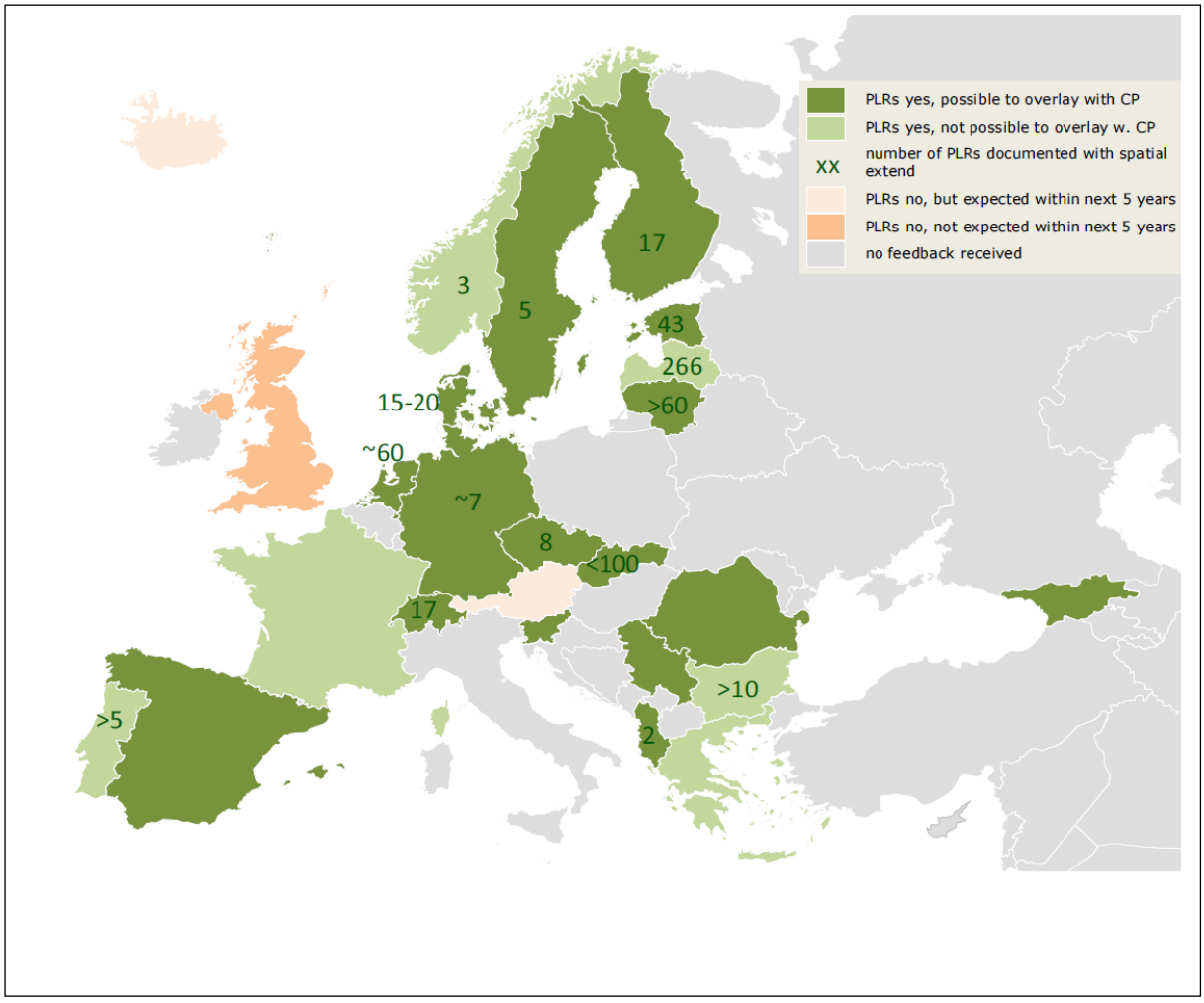


Figure 22. Documentation of PLRs and possibility of overlay with cadastral landownership parcels (CLRKEN, 2015).

Currently, several countries systematically record PLRs on land. Recording and management of PLRs worldwide varies depending on each jurisdiction. In the Spanish Cadastre, PLRs are mainly recorded as parcel attributes and are also used for land parcel valuation. Typical examples of PLRs in Spain are heritage and cultivation restrictions (Velasco, 2015). Other jurisdictions have established themed cadastres which focus on recording specific types of objects. In Greece, the Archaeological Cadastre has been established, incorporating all descriptive and geospatial data related to cultural heritage areas, both on state and privately-owned land. This includes the location of archaeological sites and monuments on horizontal plane, boundaries of protection zones, along with descriptive information on the legal or administrative acts that impose restrictions on land. Similar information can be traced on the Cultural Heritage application of the Estonian Land Board Geoportal. Both registries operate as individual repositories and are not related to other national spatial data registries; overlay of cultural heritage data is available in case of the Estonian Cultural Heritage application, while Hellenic Cadastre orthophotos were

used as basemaps of the Greek Archaeological Cadastre. On the other hand, Norwegian Environment Agency (Miljo-Direktoratet) and the Danish Natural Environment Portal (DMP), integrated cultural heritage and landscape to environmental maps including, among others, information on nature and environmental monitoring, agriculture, soil and air pollution, water quality and noise (Norwegian Environment Agency, 2019), (Denmark's Environmental Portal, 2019). Similar integrated or individual portals can be traced in Serbia, Finland, the Netherlands and the United States. Mapping of cultural heritage, environmental or other characteristics, does not necessarily imply that such information constitutes a map of spatial PLRs. Although such maps can be used to inform interested parties of the situation that applies to a specific region, e.g. existence of an archaeological site or soil pollution within an area, if no reference is made on the specific metric values that apply (deriving from legal statutes) and to their spatial extent, their contribution to provide easy access and legal certainty to the involved parties remains limited. Despite the use of themed cadastres to register specific types of PLRs, this approach cannot efficiently accommodate PLR registration, as it mostly emphasises on the objects involved (e.g. archaeological antiquities, utility networks) rather than on the RRRs imposed on land (Dimitrios Kitsakis & Dimopoulou, 2016). For example, archaeological cadastres present the location of ancient antiquities in 2D and provide the legal documents that impose specific restrictions on the location of the antiquities and on neighbouring land. Similarly, utility cadastres depict the 2D location of utility lines, along with each line's depth, but do not define the zones where restrictions apply due to the utility line's installation (e.g. building restrictions along a utility line's course for its protection and maintenance).

Existing databases and registries, along with the features that are recorded as well as their data type and format, are presented in Table 3.

Table 3. Existing databases and registries and data features recorded (based on (Dimitrios Kitsakis and Dimopoulou 2014)).

Registry	**Data type (Graphical/ descriptive)**	**Data Type Format (Analogue/Digital)**	**Spatial data**
Archaeological Cadastres	- Descriptive data (legal documents) - Graphical data (archaeological sites/ monuments)	digital	x, y coordinates of archaeological sites' polygons, monuments
Building Dwelling Register - BDR	Depending on country/State	digital	- x, y parcels' centroid coordinates - number of floors
Cadastre (may comprise more databases), Land Registry	- Descriptive data (legal/ administrative db) - Graphical data (cadastral index map)	- digital (however scanned drawings may be available) - analogue (paper drawings)	- x, y coordinates, footprint of multi-surface property, - depending on country/State, heights may be recorded
Environmental Registries[1]	- Descriptive data (legal documents) - Graphical data	digital	x, y coordinates of polygons, points
Utility Maps	Graphical data	digital	- x, y coordinates

			- Heights are not always recorded, may be incomplete or available for specific utilities or parts of utilities
Municipal Building Departments	Graphical data	depending on municipality	- Dimensions on construction drawings, - x,y coordinates (if cadastral sheet required) - elevation data in cross sections
Mineral Cadastre	- Graphical data - Descriptive data	digital	- Definition of mines in 2D using geographic coordinates - descriptive depth reference

[1] May include, individual or unified, registries recording soil contamination, groundwater protection, conservation and protected areas.

Identification of the PLRs that are imposed on a land parcel within the multitude of individual PLR databases and registries constitutes a laborious task for interested parties, in terms of time and cost (Küntzel & Kaufmann, 2012) both for the identification of all types of PLRs imposed on land and for PLR data acquisition. Further issues such as mapping of literal legal descriptions of each restriction, or data accuracy and compatibility among different datasets may arise.

In order to avoid such limitations and systematically record all PLRs applying to land, Swiss Federal Act on GeoInformation (2007), established the Cadastre of Public-Law Restrictions on landownership (art. 16)[55]. Cantonal PLR Cadastres are established to each Swiss canton and are managed jointly by federal government and the cantons. Swiss Confederation is responsible for the strategic orientation and overall supervision of PLR Cadastres, while cantons are responsible for their maintenance (Federal Act on GeoInformation, 2007, art. 34). Swiss PLR Cadastres record seventeen (17) PLRs, classified in eight (8) sectors (Table 4) (Federal Office of Topography swisstopo, 2015).

Table 4. Classification of PLRs registered to Swiss PLR Cadastres (based on Federal Office of Topography swisstopo, 2015).

Sector	Restrictions
Contaminated sites	Cadastre of contaminated sites Cadastre of contaminated military sites Cadastre of contaminated sites at civil airfields Cadastre of public transport contaminated sites
Railways	Project planning zones for railways Building lines for railways
Airports	Project planning zones for airports Building lines for airports Security zone plan
Groundwater protection	Groundwater protection zones Groundwater protection area

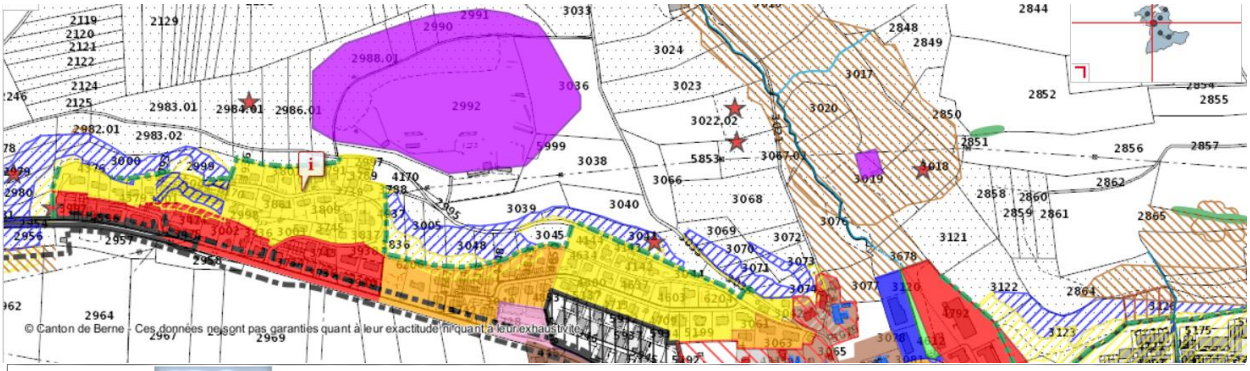
[55] Provision for the documentation of Public-Law restrictions with geometrical characteristics has also been introduced in article 57 of the Law on official surveying of the Principality of Liechtenstein (Jürg Kaufmann, 2015), while Land Cadastre Act of Estonia (art. 12) stipulates that objects giving rise to restrictions shall be registered on the restrictions map (RIS) (Kuus, 2011)

Noise	Noise sensitivity levels (in land-use zones)
Motorways	Project planning zones for motorways Building lines for motorways
Spatial Planning	Land-use planning (cantonal/municipal)
Forests	Forest perimeters (in building zones) Forest distance lines

Swiss PLR Cadastre data are available in dynamic (via cantonal geoportals) or static (as official PDF documents) form (Federal Office of Topography swisstopo, 2015) and consist of (Barbieri, 2015):

- The legal provisions that impose restrictions on land and the effects of such restrictions.
- A map depicting the region where PLRs apply.
- The general regulations on which rulings are based.
- Additional information.

An example of the PLR Cadastre of the canton of Bern is presented in Figure 23.



RÉSULTAT THÈME | OBJETS LIÉS

Résultats connexes pour Dispositions juridiques

Titre	Type	Lien (en allemand)	Lien (en français)
▲ Plans d'affectation communaux/Wohnzone_1-geschossig/Gemeinde Wohlen bei Bern (5)			
Baureglement_(BR)_vom_11._März_2011	Dispositions juridiques	https://oerebfiles.apps.be.ch/36001/1203/Baureglement_Wohlen_bei	https://oerebfiles.apps.be.ch/36001/1203/Baureglem
Loi fédérale sur l'aménagement du territoire	Bases légales	https://www.admin.ch/ch/d/sr/c700.html	https://www.admin.ch/ch/f/sr/c700.html
Loi sur les constructions	Bases légales	https://www.belex.sites.be.ch/frontend/texts_of_law/392	https://www.belex.sites.be.ch/frontend/texts_of_law/
Ordonnance sur les constructions	Bases légales	https://www.belex.sites.be.ch/frontend/texts_of_law/391	https://www.belex.sites.be.ch/frontend/texts_of_law/
Ordonnance sur les notions et les méthodes de mesure dan...	Bases légales	https://www.belex.sites.be.ch/frontend/texts_of_law/390	https://www.belex.sites.be.ch/frontend/texts_of_law/

Figure 23. Top: PLR Cadastre map of the canton of Bern showing the areas where PLRs in different colours. Bottom: Link to statutes imposing PLRs (Canton de Berne, 2019).

Despite the fact that several PLRs are currently registered and mapped, this does not involve 3D registration and mapping, even though legislation may explicitly define PLRs in terms of height, depth or volume (Dimitrios Kitsakis et al., 2019). 3D PLRs are not always explicitly defined in 3D. There are several PLRs applying to 3D space that are described using either non-geometrical characteristics (e.g. soil permeability impact on groundwater pollution), or that are qualitatively defined (e.g. landscape protection) (Dimitrios Kitsakis & Dimopoulou, 2017a; Dimitrios Kitsakis et al., 2019).

Exploitation of 3D models has been proposed by several researchers for infrastructures' modelling, e.g. (Döner et al., 2010; Vandysheva et al., 2011), , protection of cultural heritage and traditional settlements (D. Kitsakis et al., 2017), geoheritage management (Cayla & Martin, 2018), as well as in environmental applications and in Environmental Impact Assessment studies (Danese, Casas, & Murgante, 2008; Ducci & Sellerino, 2013; Hełdak, Szczepański, & Patrzałek, 2012; Sheng, 2011; Jantien Stoter, de Kluijver, & Kurakula, 2008). Use of 3D models is considered to foster public participation and flexibility in planning options (Lai, Kwong, & Mak, 2010). However, technical limitations such as level of detail, cost, system architecture requirements, as well as data accuracy, scale consistency and completeness impact on the reliability and accountability of the resulting 3D models (del Campo, 2012; Lai et al., 2010), thus complicating 3D physical environment modelling. Limitations of 3D physical environment modelling, affected less 3D modelling of PLRs since the latter merely requires the development of simple geometric primitives where restrictions apply, based on 2D coordinates along with their corresponding height, depth or volumetric characteristics (Dimitrios Kitsakis & Dimopoulou, 2018).

Within this context, Dimitrios Kitsakis & Dimopoulou (2016b, 2018) identified the following categories of 3D related PLRs (Table 5), which are described in the forthcoming sections.

Table 5. Categories of PLRs with 3D components along with their definition in legal documentation (based on (Dimitrios Kitsakis & Dimopoulou, (2016b, 2018).

PLR category	*Sub-categories*	*Explicit*	*Non-geometrical*	*Type**
Mines	i. State-owned, landowner minerals	✓	✓	Ql
	ii. Oil, gas	✓		Qt
	iii. Terrestrial or located underwater	✓		Qt
Cultural Heritage (terrestrial or underwater)	i. Archaeological sites	✓	✓	B
	ii. Monuments	✓	✓	B
	iii. Intangible Cultural heritage	✓	✓	B
Environment	i. Physical environment (geology, soils, land, hydrology, surface and ground water resources, air and noise, landscape and visual amenity)	✓	✓	B
	ii. Biological environment (aquatic and terrestrial habitats, flora and fauna, biodiversity and protected areas)	✓	✓	Qt
	iii. Socioeconomic environment (land use, demography, employment, education, infrastructure, public services and public health)	✓	✓	B
Civil Aviation	i. Non-military manned air vehicles	✓		Qt
	ii. Unmanned air vehicles (UAVs)	✓		Qt
Urban Planning and Construction Regulations	i. Urban planning	✓		Qt
	ii. Construction regulations	✓		Qt

Utilities (subsurface or aerial)	i. Public utility networks, other major infrastructures (pipelines, subway lines, tunnels)	✓		Qt

* Ql: Qualitative 3D characteristics, Qt: Quantitative 3D characteristics, B: Both qualitative and quantitative 3D characteristics.

5.6.1 Environmental Impact Assessment as a means of reflecting Public Law Restrictions

The first instance of international interest on environmental protection dates to 1972 in Stockholm, with the adaptation of the Declaration of the United Nations Conference on the Human Environment (or Stockholm Declaration). Since then, environmental protection has attained both national and international interest, through introducing constitutional stipulations on environmental protection [e.g. in the constitutions of Greece (1975), Spain (1977) and Portugal (1978)] and by international conventions, agreements and treaties, such as the Rio Declaration on Environment and Development (1992), the Kyoto Protocol (1997), ending up to the Paris Agreement (2016). Physical environment constitutes a complex system of interrelated components including soil, surface, groundwater, fauna, flora and landscape. Such components are neither always quantifiable, nor are their relations clear and definable (Dimitrios Kitsakis & Dimopoulou, 2018). Therefore, environmental protection legislation creates a case-specific, dense, complex fabric of regulations. Environmental protection constitutes one of the main fields of state interventionism, imposing various types of restrictions and responsibilities on land (Siouti, 2011).

Environmental legislation requirements for construction projects with significant environmental impact, are reflected in Environmental Impact Assessment (EIA) requirements, which incorporate all provisions on environment protection, also including specific legislation stipulations (e.g. mining, or archaeological laws). EIA is an instrument used to evaluate possible impacts of a development to the environment. In case that examination of the impacts of a project or development in the socio-economic characteristics of an area is required as well, an Environmental and Social Impact Assessment (ESIA) is compiled. Canter (1996), defines EIA as the systematic identification and evaluation of potential impacts (effects) of proposed projects, plans, programs or legislative actions, relative to the physical-chemical, biological, cultural and socio-economic components of the total environment. Lawrence (2003), provides a more detailed definition of EIA, although not substantially different from Canter's (1996), defining EIA as the "*systematic process of determining and managing (identifying, describing, measuring, predicting, integrating, communicating, involving and controlling) the potential (or real) impacts (direct and indirect, individual and cumulative, likelihood of occurrence) of proposed (or existing) human actions (projects, plans, programs, legislation, activities) and their alternatives on the environment (physical, chemical, biological, ecological, human health, cultural, social, economic, built and their interrelations)*". EIA is an iterative process aiming to identify potential negative environmental impacts, which derive from a project's construction and to minimise their effect, in order to achieve sustainable development. EIA was first introduced by the United States National Environment Policy Act (NEPA) in 1969 (Caldwell, 1988). During the following decades, EIA requirements were introduced in the environmental laws of several countries including Canada (1973), Australia (1974), China (1979), Japan (1984) and

Malaysia (1987), while the introduction of Directive 85/337/EEC and its later amendments has contributed to the expansion of EIA within European Union (EU) members (Glasson, Therivel, & Chadwick, 1999). Standards of EIA are based on environmental performance and quality requirements and are defined by national and international legal instruments. Several environmental and social aspects are expressed in qualitative terms, therefore appropriate significance criteria were developed.

Environmental Components	Project Activities								
	Plant Construction	Farming of Kenaf	Use of Pesticide Fertilizer	Transport of Raw Materials	Water Intake	Solid Waste	Effluent Discharge	Emissions	Employ-ment
Surface Water Quality			x			x	x		x
Surface Water Hydrology					x				
Air Quality				x				x	
Fisheries			x				x		
Terrestrial Wildlife Habitat	x								
Terrestrial Wildlife	x								
Land Use Pattern		x							
Highways/Railways				x					
Water Supply			x				x		
Agriculture		x							
Housing									x
Health						x	x	x	
Socioeconomic									x

Figure 24. Examples of checklist matrices and networks (https://eco-intelligent.com)

Evaluation criteria	Alternative quarry locations				
	Fraser's Quarry	Marsden Site	Penrose Quarry	Timms Hill	Garner's Quarry
Practical factors					
Accessibility	■	●	♦	♦	♦
Capacity	■	♦	♦	♦	■
Services	♦	■	♦	♦	♦
Ownership	■	■	■	●	■
Security	♦	■	♦	■	■
Current availability	♦	♦	♦	■	■
Economic factors					
Need for transfer station	Yes	Yes	No	No	No
Existing infrastructure	♦	■	●	♦	♦
Road condition	❖	●	●	■	■
Cover material	■	■	■	■	■
Operating cost	▫	■	▫	▫	▫
Environmental					
Adequate separation	♦	♦	●	■	♦
Hydrology	■	■	■	♦	■
Topography	♦	♦	■	♦	■
Visibility	♦	♦	■	♦	♦
Conservation value	♦	■	♦	♦	♦
Traffic route	♦	■	♦	■	♦

♦ Site satisfies criterion; ● Unfavourable; ■ Partial satisfaction; ▫ Information unavailable; ❖ Not relevant.
Source: Module on Selected Topics in Environmental Management. UNESCO Series of Learning Materials in Engineering Sciences, UNESCO, 1993.

Figure 25. Example of matrix (www.nzdl.org).

Currently, EIAs are strongly related to GIS systems to perform interpretation and analysis of collected data, as well as to present relevant information on maps and charts. They also present the significance of residual impacts after mitigation measures using checklists, matrices, networks, overlays and geographic information systems (GIS), expert systems and professional judgement (Canter, 1996; UNEP, 2002) (examples are presented in Figures. 24-26). Significance is strongly dependent on each specific project. Therefore, no uniform significance criteria can be defined; significance criteria are based on the characteristics of each type of impact and on the values of the environmental issues affected (European Commission, 2017).

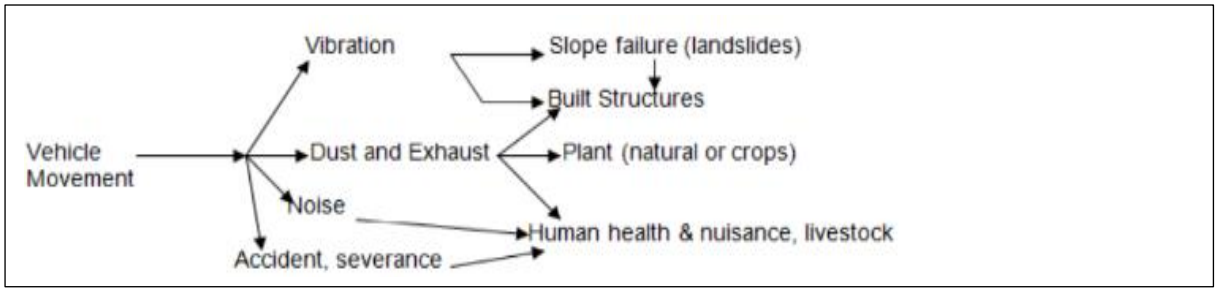


Figure 26. Example of network diagram (https://eco-intelligent.com).

Use of 3D modelling in EIAs is limited to the creation of photomontages in case of landscape analysis, combined with GIS methods. Potential contribution of 3D modelling techniques in impact assessment is presented in several research works (Danese et al., 2008; Hełdak et al., 2012; Ngo, Tsand, & Wong, 2014). However, concerns regarding technical requirements and data suitability are also raised (del Campo, 2012; Lai et al., 2010).

Internationally, EIA legislation that has mostly affected national laws includes those of the United States of America (NEPA, 1969), New Zealand (RMA, 1991), Canada (CEAA, 1993) and European Union (Directive 85/337/EC and its later amendments) (Sadler & McCabe, 2002).

In the United States, the Environmental Impact Statement (EIS)[56] is a legal document aiming to assist decision making process regarding the approval of proposed federal actions and to inform the public and other government agencies of the environmental impacts of a proposed facility (Carson, 1992). EIS is required to present (i) the environmental impact of a proposed action, (ii) non-avoidable adverse environmental effects, proposed alternatives, (iii) relations between local short-term uses of human environment and the maintenance and enhancement of long-term productivity, as well as (iv) potential irreversible and irretrievable commitment of resources required by the proposed action (NEPA, 1969, Sec. 102 [42 USC § 4332]). Apart from Federal legislation, more than 30 states among the United States have introduced NEPA equivalent laws at state level, while others require compilation of environmental impact reports both on public and private activities, e.g. state of California (Canter, 1996).

Resource Management Act (RMA) of New Zealand, aimed to integrate the variety of statutes, regulations and orders to a single legal regime (Sadler & McCabe, 2002),

[56] The resultant report of the Environmental Impact Assessment process is, in many countries, also defined as Environmental Impact Assessment (or Environmental Assessment), while in the United States, the term Environmental Impact Statement (EIS) is used (Canter, 1996).

promoting sustainable management of natural and physical resources (RMA, 1991, sec. 5). Within the context of this Act, environmental requirements are stipulated in national environmental standards, in the form of technical standards, methods, or requirements, which apply to several fields, such as air quality, sources of drinking water, telecommunication facilities, electricity transmission activities, assessment and management of contaminants in soil and plantation forestry (New Zealand Ministry for the Environment, 2018). Environmental standards of ecological flows and water levels, marine aquaculture, as well as outdoor storage of tyres are currently under development (New Zealand Ministry for the Environment, 2018).

Canadian Environmental Assessment Act (CEAA) aims to protect the components of the environment from adverse environmental effects caused by a designed project, in cooperation and communication with aboriginal people, through cooperation and coordination between federal and provincial governments (CEAA, 2012, art. 4). Environmental effects can be related to an act or thing, a physical activity, a designated project or existing project and include changes to environmental components, fish, fish habitats and aquatic species, migratory birds, as well as impacts on health and socio-economic conditions, physical and cultural heritage, current use of lands and resources for traditional purposes, and any structure, site or thing that is of historical, archaeological, paleontological or architectural significance for aboriginal people (CEAA, 2012, art. 5).

In the European Union, EIA is employed to identify, describe and assess in an appropriate manner, in the light of each individual case, the direct and indirect significant effects of a project on (i) human beings, fauna and flora population and human health, (ii) biodiversity, with particular attention to protected species and habitats; land, soil, water, air and climate and landscape, (iii) material assets, cultural heritage and the landscape, and, (iv) the interaction between the previously referred factors (European Commission, 2014).

Legal definition of the environment does not merely include natural characteristics of human surroundings, such as soil, air and water. Environmental legislation in most of the developed countries, incorporates within the concept of environment physical resources, ecosystems, landscapes, as well as social, economic and cultural conditions, monuments and historic areas. Given that E(S)IA incorporates all types of PLRs applying to a specific project, E(S)IA requirements are used to identify 3D characteristics deriving from PLRs.

5.6.2 Environment

This section presents the 3D characteristics of environmental protection PLRs. The section is further subdivided in subsections, focusing on environmental components that extend on 3D space, either explicitly or implicitly.

5.6.2.1 Physical environment

Physical environment comprises of geology, soils, land, hydrology, surface and ground water resources, air and noise, landscape and visual amenity. Each of these components are interrelated and pertain 3D characteristics, while environmental protection legislation stipulates restrictions or regulations that can be explicitly defined in 3D (such as restrictions in height, depth or volume), restrictions or regulations that may apply to 3D space but are defined by non-geometrical 3D characteristics (such as soil characteristics in case of groundwater protection), and implied 3D restrictions or regulations, which are based on non-quantifiable

characteristics (e.g. aesthetics), such as landscape view (Dimitrios Kitsakis et al., 2019). This section presents the 3D characteristics of physical environment components, along with already applying or potential 3D restrictions.

Geology

Geology examines the physical structure and substance of the Earth and the processes which impact on their formation. Although examined individually, geological characteristics are strongly related to soil, ground and surface water characteristics, while mineral resource recovery also pertains direct geological impacts (Marriott, 1997). Cendero et al. (2000), focus on the contribution of geomorphology to EIA process. They conclude that the role of geomorphology is limited, due to the fact that landform is regarded as a permanent setup on static equilibrium, rather than as a result of complex processes in a dynamic equilibrium (Cendero et al., 2000). Characteristics of geological formations, such as their stability for construction, their permeability and porosity, the existence of groundwater aquifers, seismicity and faults, sinkholes, springs, natural gas, oil wells, mineral resources or volcanic activity, may inhibit several land use types, or potential land use types may result in adverse geological impacts (Marriott, 1997). For example, additional measures or relocation may be required for constructions on high permeability soils, to prevent leaching of pollutants into groundwater; an example of geological impacts deriving from land use is the change of subsurface strata due to mining activities. Examination of geological characteristics of an area usually pertain exploitation of geological drift maps. However, such maps classify rocks based on age rather than type, thus limiting their usability within the EIA process (Hodson, 1995). Geologic impacts comprise of geologic hazards, land-use compatibility and impacts on mineral resources and resource development, while impacts associated with geologic conditions include the removal and disposal of unsuitable material, the leaching of pollutants into groundwater systems, the interception of the watertable during excavation and its consequent dewatering, as well as the exposure of acid-producing geologic formations to rainwater (Marriott, 1997). Canter (1996), distinguishes in literature several examples of potential detrimental effects on geological environment by developments and vice versa. Out of this classification, those applying to 3D space are the following:

- Land subsidence resulting from overpumping of groundwater, oil, gas or resources.
- Changes in water-surface hydraulics and erosional patterns, resulting from the removal of construction material.
- Landslides caused by overdevelopment on soil types of inappropriate slope stability.
- Construction and operation of facilities of high polluting potential (such as nuclear power plants, chemical production plants, waste disposal or storage facilities) in areas characterised by seismic instability.
- Soil compaction, resulting in soil erosion and affecting drainage patterns.
- Impact on soil chemistry by acid rain. Combined with soil permeability features, it may also pertain infiltration and groundwater pollution.
- Soil or groundwater pollution due to underground pipelines' leakage.
- Potential loss of underground pipelines' physical integrity due to acidic or corroding soils.

The Institute of Geologists of Ireland (2002) have compiled a detailed list of potential geology-related impacts on the issues examined within EIA (human beings, fauna and flora, soil, water, air, climate, landscape, material assets, cultural heritage, and their interactions) within existing environment (before any project development takes place), potential significant impacts deriving from a project's development, as well as corresponding, potential mitigation measures. Several geology-related issues are traced in almost all of the EIA required topics (Table 26). 3D geology issues regarding existing environment (baseline conditions) pertain depth, geometrical, physical (e.g. soil permeability and strength) and chemical (e.g. groundwater vulnerability, soil chemical composition and pH) characteristics.

Table 6. Geology-related issues of EIA topics with 3D characteristics based on Institute of Geologists of Ireland, (2002).

Topic	**Issues**	**Geology issues**	**3D Characteristics**
Human beings	Health and safety	Trace element levels	•Contaminated soil/groundwater •Ground stability
	Land use	Land use and geology	
Soil	Mineral soils	• Soil descriptions • Geomorphology • Surface water	•Soil texture and structure •Extent and thickness •Discontinuities/ preferential flow paths •Geochemistry
	Surficial and bedrock deposits	• Geological setting • Geophysical investigations	•Depth to bedrock •Rock types •Surficial deposits
	Peat/fens	• Peatland • Geometry • Bedrock and subsoil types • Hydrology/hydrogeology • Peat stratigraphy	•Boundaries and thickness •Bedrock and subsoil types •Hydrology and hydrogeology
	Estuarine sediments	Description of sediments	•Type of sediment •Geometry of sediments, including boundaries and thickness •Engineering characteristics
	Engineering characteristics	• Soil/subsoil/bedrock description and classification • Rock Mass Classification • Strength • Permeability • Compressibility • Chemical composition, pH • Exacavatability.	•Rock Mass Classification •Strength •Permeability •Compressibility •Chemical composition, pH
	Vibration	• Site description • Vibration survey • Blasting parameters	•Location and distance from impacted residences, structures and animals •Response to blasting activities at all directions
	Aquifers	Type of aquifer	•Extent, thickness, slope •Recharge, soil/subsoil infiltration conditions •Water table level and type •Water table fluctuations •Groundwater flow direction and gradient •Permeability, transmissivity, storage

			•Groundwater quality
Water	Ground/surface Physical Chemical	• Surface watercourses • Groundwater conditions • Groundwater quality • Groundwater vulnerability • Karst features	•Directions of flow, quantity of flow (extremes of flow/drought) •Beneath groundwater conditions •Groundwater quality •Groundwater vulnerability •Quantities from abstraction points •Karst features location
Landscape	Character	• Landscape type • Influence of geology • Character of landscape	•Elevation, relief, slopes
Cultural heritage	Natural Heritage	• Natural Heritage Areas (NHA)[1]/ Special Areas of Conservation (SAC)[2] • New sites	

[1]: Area considered important for habitats, or which holds species of plants and animals whose habitat needs protection (National Parks & Wildlife Service, 2019).
[2]: Special Area of Conservation means a site of Community importance designated by the Member States through a statutory, administrative and/or contractual act where the necessary conservation measures are applied for the maintenance or restoration, at a favourable conservation status, of the natural habitats and/or the populations of the species for which the site is (European Commission, 1992).

Table 6 above (column "3D characteristics"), incorporates a variety of features, not directly defined in 3D, of non-geometrical or qualitative nature. Despite the fact that they may not be defined in terms of height, depth or volume, such characteristics impact on 3D space, due to their interrelation with the rest of environmental parameters examined in the EIA (Dimitrios Kitsakis et al., 2019).

Levels of trace elements, refer to the level of contaminants to soil or groundwater. Therefore, they constitute 3D characteristics, traced in soil or groundwater volumes, while combined with soil permeability, they define volumes susceptible to soil and groundwater pollution, or polluted volumes. Similarly, in case of karst areas or other geological fractures, a volumetric network of contaminated, or vulnerable to contamination, areas can be defined that need to be protected according to soil and groundwater protection requirements. As regarding to land use, depending on the type of intended projects, impacts on the chemical or physical characteristics of soil may be implied. Characteristic example of such case, is mineral resource recovery that implies direct geological impacts (Marriott, 1997; Peter Morris & Therivel, 2005).

Protection and mitigation measures

In this section, an indicative list of common measures to minimise the impact of constructions to geology and vice versa are presented. It is not within the scope of this section to elaborate on such measures; emphasis is given to their 3D characteristics, explicit, non-geometrical, or implied. It is noted that there can be no uniform or comprehensive list of mitigation measures, due to the unique combination of location and development specifications (European Federation of Geologists (EFG), 2003). Common mitigation measures regarding geological impacts are the following (M El-Mekawy & Östman, 2010; European Federation of Geologists (EFG), 2003):

- Increase of wall thickness or use of specific backfill or bedding material to underground trenches, to reduce fault movements' impacts (Fig. 27, left).
- Lowering of groundwater tables or replacement of liquefiable soils.

- Bypassing of liquefiable soils (Fig. 27, right).
- Reducing the slope inclination with additional soil deposits or lowering groundwater levels, or replacing/reinforcing sensitive soil layers.
- Removal or in-situ remediation of contaminated soils.

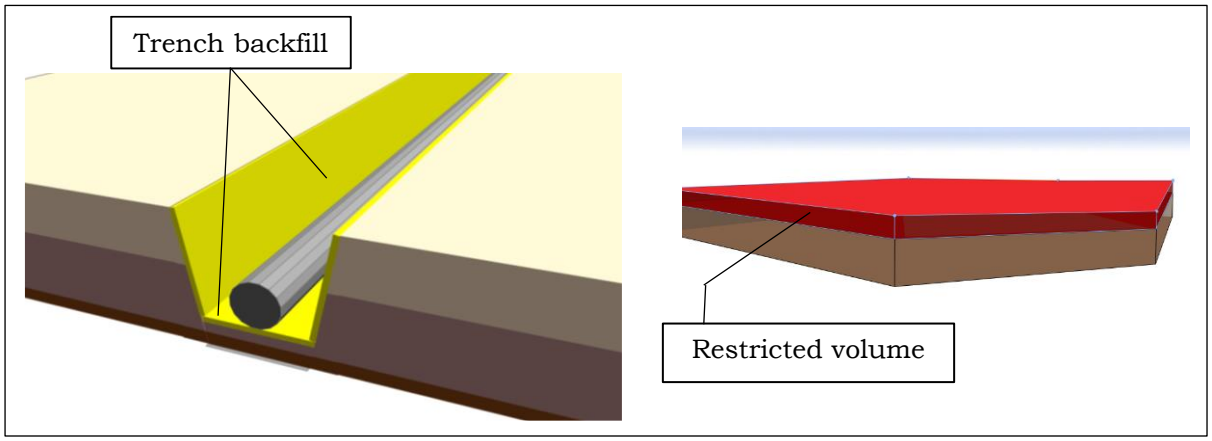


Figure 27. Left: backfill and bedding of underground trenches. Right: Soil volumes that need to be bypassed (Dimitrios Kitsakis and Dimopoulou 2018).

Soil

Significance of soil in human life is indisputable since it constitutes, together with water, the fundamental requirement for satisfying ecological and economic needs (Fritzsche, Jahrmarkt, & Li, 2018). German Federal Soil Protection Act (BBodSchG, 1998), distinguishes three main soil functions: the natural soil function (that constitutes both the basis for life and living habitat, and a medium for decomposition, balance and restoration due to its filtering, buffering and substance-converting operations), the function of soil as an archive of natural and cultural history, and the function of soil as a background for human activities (Vogel, Bannick, & Böken, 2004). Soil characteristics can be regarded as three-dimensional, even when not directly defined in 3D terms, as they impact on construction operations and constructions' stability (Marriott, 1997). Legislation on soil protection per se is not common in national legislation. Specific legislation on soil protection can be traced in a limited number of countries, such as Germany and the Netherlands (Raffelsiefen, M. Strassburger, 2017), while regulations regarding soil protection are scattered in land laws, administration laws, environmental protection laws, natural resource laws and related subordinate legislation (Fritzsche et al., 2018; Vogel et al., 2004). Potential environmental impacts of a project's development on soil, include soil contamination by leakages or spillages, soil compaction during construction phase (resulting to impact on soil drainage and, consequently, on groundwater recharge and flood levels) and soil instability (Institute of Geologists of Ireland, 2002). Although soil is considered as part of physical-chemical environment, it is strongly related to other environmental components (Canter, 1996). For example, vegetation is associated to soil characteristics, thus affecting the habitat types that can be traced in a region. Similarly, soil characteristics dictate the quantity of contaminants that infiltrate to groundwater, thus affecting groundwater contamination (groundwater below low permeability soils or below soils of high sorption potential are less vulnerable to contamination; however, this increases the risk of surface water contamination through surface run-off).

As applying to all environmental protection related legislation, regulations on soil protection are based on the principles of prevention and precaution[57] (Fritzsche et al., 2018; Raffelsiefen, M. Strassburger, 2017; Vogel et al., 2004). Within this context, soil conservation laws, where such laws are statutorily established, or EIAs require the compilation of soil survey reports, presenting the soil conditions that apply to an examined region. According to the Soil Science Division Staff of the United States Department of Agriculture (Soil Science Division Staff, 2017), a soil survey "*describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organised database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems*" (p. 1). Soil description characteristics with 3D connotation within a soil survey can be summarised in the following (Soil Science Division Staff, 2017)[58]:

- Depth to the lower boundary of a soil horizon or layer[59].

- Thickness[60] of horizon or layer.

- Vertical subdivision of horizons (in case that different characteristics occur at different depth within a sequence of horizons of the same classification). Different horizons or layers are characterised by different physical characteristics, therefore, interrelate differently with potential underground developments and land use.

- Lithologic discontinuities[61]. The changes in particle distribution or mineralogy traced in lithologic discontinuities, affect soil characteristics, thus changing the impact of a development on soil and vice versa (for example, lithologic discontinuities may reduce soil stability required for a specific type of development, creating a soil stability volumetric restriction).

- Topography[62]. The 3D nature of horizon boundaries topography, defines the accurate size, location and dimension of soil horizons, allowing for exact

[57] Several environmental principles can be traced on international environmental law, applicable to various environmental issues (Rayfuse, 2016). Other well accepted principles are these of sustainable development, intergenerational equity, intra-generational equity, prevention of harm, common but differentiated responsibility, precaution, polluter pays, the right to a healthy environment and access to information and public participation in environmental decision-making (good governance) (Kravchenko, Chowdhury, & Bhuiyan, 2012).

[58] This thesis does not aim to present an extensive, detailed analysis of soil characteristics and their interrelations. Presented information is limited on the purposes of 3D Cadastre-related environmental Public Law Restrictions. Indicatively, for detailed information on soil survey requirements, please refer to (Reinhold, Blume, Asio, Spaargaren, & Schad, 2006) or (Soil Science Division Staff, 2017).

[59] A soil horizon is a layer, approximately parallel to the surface of the soil, that is distinguishable from adjacent layers by a distinctive set of properties produced by the soil-forming processes (i.e., pedogenesis). The term "layer" is used instead of "horizon" if the properties are inherited from the parent material, such as sedimentary strata (Soil Science Division Staff, 2017).

[60] Thickness is defined as the vertical distance between their upper and lower boundaries of the horizon or layer (Soil Science Division Staff, 2017)

[61] Lithologic discontinuities are considered the significant changes in particle distribution or mineralogy of a soil (Ahr, Nordt, & Schaetzl, 2017).

[62] Topography refers to irregularities of the surface dividing the horizons (Soil Science Division Staff, 2017).

presentation of soil characteristics between consecutive strata. Examples of topography variations are presented in Figure 28.

- Near surface subzones[63]. Despite their limited depth, near surface subzones constitute the "dynamic" component of soil and constitute volumes of different physical and mechanical properties.

- Root restricting depth[64]. Root restricting depth constitutes a physical limit of root penetration on soil and impacts both agricultural production, by limiting the ability of plant roots to penetrate to depths of soil that sustain plants during common short-term droughts (Raper, Schwab, & Dabney, 2000), and structural activities, by creating volumes that underground constructions are not affected by plant roots.

- Soil texture[65]. Texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through soil (Food and Agriculture Organization of the United Nations (FAO), n.d.). Therefore, it affects soil stability, erosion and fertility.

- Existence of rock, pararock fragments or artefacts on soil[66]. Existence of fragments, affects the physical and mechanical characteristics of soil, thus creating zones of different physical and mechanical characteristics that affect the stability of ground or underground constructions. Similarly, artefacts impact on soil properties, depending on their quantity (the volume of a unit occupied by artefacts), cohesion (ability of an artefact to remain intact after significant disturbance), penetrability (the relative ease with which roots can penetrate the artefact and potentially extract any stored moisture, nutrients, or toxic elements), persistence (the relative ability of solid artefacts to withstand weathering and decay over time), roundness (the sharpness of edges and corners of natural objects), safety (the degree of risk to humans from contact with soils that contain artefacts), shape and size (Soil Science Division Staff, 2017).

- Soil structure[67]. Soil structure affects soil mechanics, fertility, agronomic productivity, porosity and erodibility (Bronick & Lal, 2004). Soil structure characteristics pertain shape, size, grade (distinctness of units), compound structure and extra-structural cracks (macroscopic vertical planar voids that are much smaller in width than in length and depth) (Soil Science Division

[63] Zones of the uppermost 1 to 18 centimetres of soil, whose morphology is affected by antecedent weather and soil use (Soil Science Division Staff, 2017).

[64] Restricting root depth is the depth at which soil physical and/or chemical characteristics strongly inhibit root penetration (Soil Science Division Staff, 2017).

[65] Soil texture refers to the proportion of the various particle-size classes (or soil separates, or fractions) in a given soil volume and is described as soil textural class (Reinhold et al., 2006).

[66] Rock fragments are unattached pieces of geologic or pedogenic material 2 mm in diameter or larger that have a strongly cemented or more cemented rupture-resistance class. Pararock fragments are unattached pieces of geologic or pedogenic material 2 mm in diameter or larger that are extremely weakly cemented through moderately cemented (Soil Science Division Staff, 2017). Artifacts are discrete water-stable objects or materials created, modified, or transported from their source by humans, usually for a practical purpose in habitation, manufacturing, excavation, agriculture, or construction activities (Soil Science Division Staff, 2017).

[67] Soil structure refers to size, shape, and arrangement of solids and voids, and the forces that affect these characteristics (Lal, 1991)

Staff, 2017). Therefore, soil structure volumes are related to regulations regarding protection from erosion and flooding.

- Soil consistence[68]. Soil consistence includes resistance of soil material to rupture, resistance to penetration, plasticity, toughness, and stickiness of puddled soil material, and the manner in which the soil material behaves when subject to compression (Soil Science Division Staff, 2017). Consistence properties of soil are reflected in soil excavation difficulty (Soil Science Division Staff, 2017). Each of the above mentioned characteristics constitute volumes of different permeability, root penetration, porosity and water movement (Fitzpatrick, McKenzie, & Maschmedt, 2001).

- Roots. Roots refer to the quantity, the size and the location of roots in each layer (Soil Science Division Staff, 2017). The significance of recording root characteristics on soils lies to their contribution in controlling soil erosion. Therefore, depending on root characteristics, volumes of different soil vulnerability are defined, that can be used in combination with soil erosion regulations, both during infrastructures' design and protection measures.

- Pore space[69]. Pore space affects and is affected by critical aspects of almost everything that occurs in the soil: the movement of water, air, and other fluids; the transport and the reaction of chemicals; and the residence of roots and other biota (Nimmo, 2013). Pore space constitutes a fluid conduit within soil, thus affecting soil and groundwater retention, and contamination. Depths of different pore space value, define volumes of different influence of groundwater or soil contamination, stability or reaction to contaminants in case of infrastructure design, or can be used to define measures to prevent soil and groundwater contamination, erosion, runoff or liquefaction.

- Chemical properties. Chemical properties of soil refer to the interaction of a soil with a chemical solution, depicting the chemical composition of soil (Schoeneberger, Wysocki, & Benham, 2012). Soil chemical properties include reaction (soil pH level), presence of carbonates of divalent cations (effervescence), presence of manganese oxides, salinity and sodicity and the amount of sulphates and sulphides on soil (Soil Science Division Staff, 2017). Given that above mentioned chemical characteristics differ at various depths and impact on soil and groundwater contamination, they constitute volumes of different chemical characteristics, which can be used to assess impacts on soil in case of infrastructure developments, or to the designation of protection measures against soil or groundwater contamination.

- Soil water[70] . Soil water includes inundation (the state of soil areas covered by liquid, free water) (Soil Science Division Staff, 2017), drainage [natural process by which water moves across, though, and out of the soil as a result of the force of gravity (Fausey, 2005)], water movement (the rate of flow into and within the soil and the related amount of water that runs off and does not enter the soil) (Soil Science Division Staff, 2017) and infiltration (the process

[68] Consistence is the degree and kind of cohesion and adhesion that soil exhibits and/or the resistance of soil to deformation or rupture under an applied stress (Schoeneberger et al., 2012).

[69] Pore space is considered the portion of the soil's volume that is not occupied by, or isolated by solid material (Nimmo, 2013).

[70] Soil water refers to the state of water regimes-schemes for the description of the state of the soil water at a particular time and for the change in soil water state over time (Soil Science Division Staff, 2017).

of downward water entry into the soil) (Soil Science Division Staff, 2017). Soil water characteristics depend on each soil stratum's type, therefore they extend on different volumes, based on the depth level of each soil or subsoil. Given that different soil characteristics apply to each soil type, and that soil description characteristics are interrelated (while also affected by external parameters such as land use or precipitation), they can be used to define safety volumes, or volumes where restrictions apply, to secure public health, safety, and assess the impact of potential constructions' development.

Protection and mitigation

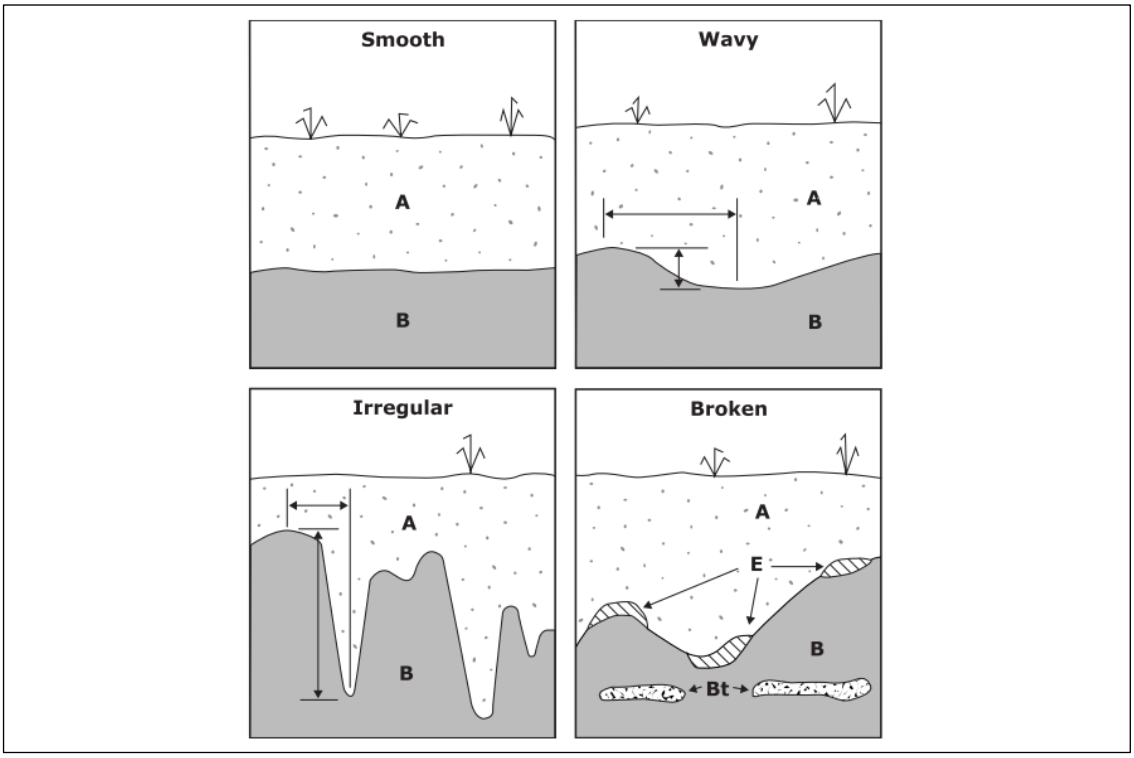


Figure 28. Types of topography between horizons (Schoeneberger, Wysocki, and Benham 2012).

This section presents the most common soil protection and mitigation measures. This section does not intend to elaborate on technical issues and characteristics of prescribed measures; its aim is to identify those pertaining 3D characteristics, which can be incorporated within a 3D PLR context. Existing laws on soil conservation and protection do not stipulate explicit soil protection or mitigation measures, but set the framework within which such measures operate. The values of critical parameters of potential soil risks are specified in subordinate legislation or standards (e.g. Environmental Code (Sweden) (Chap. 5, sec. 2); Soil Protection Act (The Netherlands); Soil environment conservation Act (Republic of Korea) (art. 5(3)); Resource Management Act (New Zealand), sec. 43), while protection and mitigation measures are specified in detail in E(S)IA reports, based on each project's specifications, as well as on regional soil characteristics. The most common soil protection and mitigation measures can be summarised in the following (Danish Enviromental Protection Agency, 2002; Fritzsche et al., 2018; Hodson, Stapleton, & Emberton, 2001):

- Removal of the contamination for off-site disposal. According to this technique, contaminated soil requires to be removed and transferred to a landfill site.

- Excavation and on-site disposal. In this case, contaminated soil is retained to a custom-designed facility, while waste management may be required. Depending on site conditions, use of impermeable liners may be used, to retain the extracted, contaminated soil (ITRC (Interstate Technology & Regulatory Council), 2010).
- On-site stabilisation. These techniques remove the ability of a pollutant to move off-site.
- In situ bio-remediation. This method is applied to soils contaminated by organic pollutants, using natural micro-organisms to break such pollutants down.
- Soil washing. Soil washing uses liquids, sometimes combined with chemical additives, to remove contaminants and minimise material for disposal, especially in case of metal-contaminated soils.

Regardless of the mitigation method used, depth characteristics are required to define existing or extractable contaminated soil volumes on a site, or remaining contaminated volumes after remediation, while soil's physical characteristics affect the propagation of contaminants to the rest of subsoil strata and/or groundwater.

Surface and groundwater
Water constitutes one of the most significant resources for life and human existence (Zuppi, 2008). Water resources are classified in surface and groundwater resources, which are, however, interconnected (United States Environmental Protection Agency (US EPA), 2008) (Fig. 29), within a context of climate, landform, geology and biotic factors (Sophocleous, 2002).

Given that surface water bodies are characterised by specific depth, and groundwater bodies are traced and extend on specific depth below ground level, while streams and aquifers exchange water horizontally and vertically (Sophocleous, 2002), it is clear that both surface and groundwater bodies constitute three-dimensional volumes on which PLRs apply for protection or remediation from contamination. Three-dimensional character of groundwater within legal documentation is also identified in the stipulations of the European Water Directive (WFD) (2000/60/EC) on aquifers and groundwater bodies[71]. According to the Directive, a groundwater body constitutes a coherent sub-unit of a river basin, which can be identified either (a) separately within different strata overlying each other in the vertical plane, or (b) as a single body of groundwater spanning the different strata (European Commission, 2004). This introduces a legal space classification of groundwater bodies that does not need to be based on homogenous natural characteristics or concentration of

[71] According to Art. 2.11 of the WFD, an aquifer is defined as "*a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater*", while art. 2.12 defines groundwater body as "*a distinct volume of groundwater within an aquifer or aquifers*".

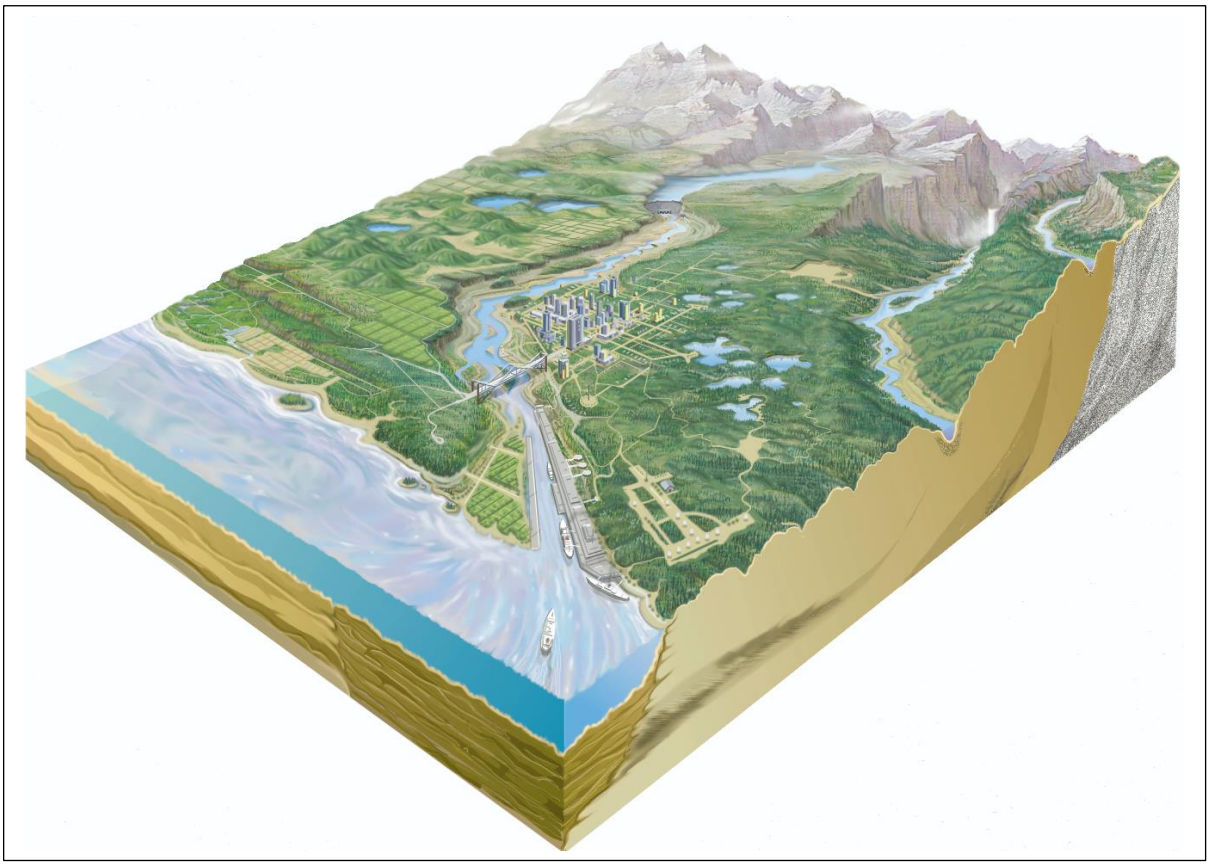


Figure 29. Human activities and structures that affect the interaction of ground water and surface water in various types of landscapes (Winter et al. 1998).

pollutants, but follows the objectives set by the Directive (e.g. the appropriate description of the quantitative and chemical status of groundwater) (European Commission, 2004). Three-dimensional characteristics are also required for the initial and further characterisation of groundwater bodies such as (WFD, Annex II, 2):

- the location and boundaries of groundwater bodies,

- groundwater bodies' abstraction and artificial recharge,

- the general character of the overlying strata in the catchment area from which the groundwater body receives its recharge,

- geological characteristics of the groundwater body including the extent and type of geological units,

- hydrogeological characteristics of the groundwater body including hydraulic conductivity, porosity and confinement,

- characteristics of the superficial deposits and soils in the catchment from which the groundwater body receives its recharge, including the thickness, porosity, hydraulic conductivity, and absorptive properties of the deposits and soils,

- stratification characteristics of the groundwater within the groundwater body,

- an inventory of associated surface systems, including terrestrial ecosystems and bodies of surface water, with which the groundwater body is dynamically linked,

- estimates of the directions and rates of exchange of water between the groundwater body and associated surface systems,

- sufficient data to calculate the long term annual average rate of overall recharge,

- characterisation of the chemical composition of the groundwater, including specification of the contributions from human activity.

The main potential impacts on surface water derive from the development of constructions and may include (Marriott, 1997; P. Morris, Biggs, & Brookes, 2005; National Roads Authority, 2008):

- flood risk and disturbance of drainage patterns due to the alteration of watercourse morphology,
- changes on flood characteristics, such as magnitude, duration and frequency,
- impacts on surface water due to sediment plumes,
- changed surface water runoff and velocities,
- depletion or salinization of freshwater,
- soil erosion or subsidence
- freshwater pollution due to solid or liquid waste, hydrocarbons, fuels, nutrients, or other chemicals,
- changes in dilution capacity and,
- impact on riparian drainage.

The most significant impacts on groundwater bodies mainly refer to the pollution of groundwater and may derive from natural sources or human activities (United States Environmental Protection Agency (US EPA), 2008). The former include pollution from natural or naturally occurring substances traced in rock or soil, which can be dissolved in water[72], while the latter are related to effluent deriving from septic systems, improper disposal of hazardous waste, landfills, spilling from underground tanks, leakage of surface impoundments, sewers or pipelines, contamination due to the use of pesticides and fertilisers, mining activities and poorly, improperly constructed or abandoned wells (United States Environmental Protection Agency (US EPA), 2008). Most common impacts can be summarised in (P. Morris et al., 2005):

- Changes in water table levels.
- Infiltration changes.
- Chemical or organic pollution.
- Movement of the contaminated groundwater.

Protection and mitigation measures

This section presents the most common water protection and mitigation measures. There is no intention to elaborate on technical issues and characteristics of

[72] The filtering effect of groundwater moving through porous rock need also to be taken into account (P. Morris et al., 2005)

prescribed measures; this section's aim is to identify measures pertaining 3D characteristics, which can be incorporated within a 3D RRR context. According to literature, common water mitigation measures are the following (Danish Enviromental Protection Agency, 2002; P. Morris et al., 2005):

- In case of watercourse crossings, specifications for minimising sediment dispersion and impacts on river ecology are required. Depending on the means of minimising sediment dispersion, volumes of containment of sediment disposal can be created allowing the management of sediments.
- Management of groundwater pumping and surface run-off. This relates to measures of mitigating disturbance of irrigation systems, while it is also associated with physical characteristics such as soil type, elevation and topography, which prevent or delay runoff from continuing downstream (US Geological Survey (USGS), 2018).
- Measures to intercept run-off from a development's working corridor. Employed measures, e.g. sandbags or settlement tanks, define the volumetric capacity of water run-off that can be intersected from the working corridor.
- Employment of cut-off ditches to prevent water from entering to excavations. Cut-off ditches may prevent specific water capacities based on their depth and soil characteristics, thus creating 3D volumetric protection zones around the area of excavations.
- Use of bunded areas to store materials with polluting potential. Hazardous substances require to be stored within impermeable bunded areas to prevent groundwater pollution by accidental spills. Ground surface in areas of vulnerable groundwater resources needs to be upgraded to impermeable for use at temporary facilities, so that accidental groundwater pollution is prevented. Above mentioned measures are either directly defined in 3D, e.g. by reference to storage volume, or in relation to ground characteristics, e.g. permeability level.
- Specification of the water volume which can be extracted from a water source, especially in aquifers near the sea, to avoid sea water intrusion.
- Construction of flood defences, taking into account their storage capacity and potential impact on neighbouring areas. This relates to the height and the slope of embankments, as well as to topographical characteristics of the area.
- Pumping of contaminated groundwater or in-situ remediation treatments of contaminated groundwater. In such case, volumes of extracted or treated groundwater can be defined and interrelated with potential contamination of nearby soil, ground or surface water, due to the movement of contaminated groundwater.
- Cut-off of groundwater contamination through impermeable vertical barriers, or through reactive, permeable barriers to reduce groundwater contaminant load during groundwater passage. Similarly to the above, volumes of "restricted" contaminated groundwater, or infiltrated

groundwater can be defined, to be further used for protection measures, environmental assessment, designation and planning of underground infrastructure projects.

Air quality

Changes on air quality may affect human, plant and animal life, as well as materials and structures (Canter, 1996; Elsom, 2005). Air quality impacts are commonly related to emissions of major developments. However, the impact on air quality by dust nuisance during the earth-moving and materials' handling operations in the process of construction stage, as well as by the increase of vehicle emissions related to a development, need also to be considered (Elsom, 2005). Air is polluted, and its quality deteriorates, by the presence of one or more contaminants, in such quantities and in such duration that may be, or tend to be, injurious to human, plant or animal life, to property (materials), or may unreasonably interfere with the comfortable enjoyment of life and property, or the conduct of business (Canter, 1996). This description of air pollution incorporates pollution deriving both from human activities and from natural causes (e.g. volcanic gas)[73]. Sivaramanan (2014), compiles air pollution sources to the following categories: sources of energy generation; transport; industry; households; agricultural practices; land mining, earth moving activity and quarrying; burning of wastes and incinerators; natural sources. Air quality is defined by the concentration of each contaminant, compared to standard values, and are expressed in volumetric terms, as mass of substance per unit volume of air ($\mu g/m^3$), or as volume of substance on volume of air (parts per million-ppm, parts per billion-ppb). In several jurisdictions, such as the United States and the United Kingdom, the impairment of visibility from pollution plumes is considered, as well, an impairment deriving from manmade air pollution (US Clean Air Act, 1970; UK Environmental Protection Act, 1990).

Air pollution is by nature three-dimensional, and its dispersion is affected by meteorological factors such as wind direction and speed, as well as atmospheric turbulence (Tiwary & Colls, 2010). Height also affects the dispersion of air pollution, especially mixing and inversion height[74] (Canter, 1996). Research and development of 3D air pollution models (Barratt et al., 2018; Boubrima, Bechkit, Rivano, & Soulhac, 2016; Liu, Zhu, Wang, & Liu, 2010; Wästberg, J., Billger, & Haeger-Eugensson, M. Sjöberg, 2013) (Fig. 30), shows that definition of air pollution vulnerable volumes can be supported and mapped.

[73] Former definitions of air pollution did not take into account pollution deriving from natural causes, but were limited to pollution deriving from anthropogenic activities (Tiwary & Colls, 2010).

[74] *Mixing height* is the height above the earth's surface, on which pollutants mix with air. The *inversion height*, is the height above the earth's surface on which air temperature increases along with altitude increase (instead of the natural temperature decrease during altitude's increase) (Canter, 1996).

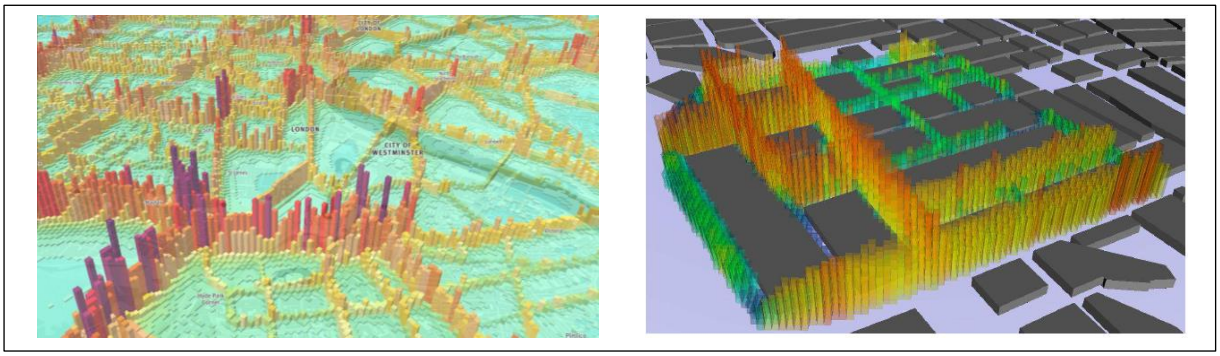


Figure 30. (Left) London atmospheric emissions inventory in 3D (London maps, 2018). (Right) Air pollution visualised by boxes of different heights (Sheng 2011).

Air pollution protection and mitigation measures

In this section, common air pollution protection and mitigation measures involving 3D aspects are presented. It is not within the aims of this section to provide exhaustive or elaborate technical specifications on such measures; presentation is limited to 3D-based measures. Measures are required when specific standards, related to pollutants' concentration to the atmosphere, are exceeded, or there is risk to be exceeded due to an activity or development. Such standards are in most cases defined in subordinate legislation. The following measures can be traced in literature (Elsom, 2005; Tiwary & Colls, 2010):

- Improving the dispersion of an emission, by increasing of stack height, reheating of the flue gases at higher temperature, and emitting them at greater velocity.
- Road trenching and embankments, to reduce pollution emitted from vehicles.
- Mitigation of air pollution by using vegetation.
- Location of infrastructures or developments away from sensitive receptors.

Noise

Similarly applying to air quality, noise propagation also extends to 3D space, as it is propagated in all directions and it is affected by the condition of its carrier (solid, liquid or air) (Givord, 2012). Besides, the fact that noise sources are traced in 3D space, also pleads for the 3D nature of noise (Lu, Becker, & Löwner, 2017). Despite that noise is closely related to vibration, examination of vibration impacts is only required in case of specific types of infrastructure projects (e.g. railways or projects that require substantial demolition or piling) (Therivel & Breslin, 2005). Noise is defined as unwanted sound (P. Morris & Therivel, 1995; Therivel & Breslin, 2005), and it is related to a range of effects on human health (World Health Organization (WHO), 2018). Literature research depicts that anthropogenic noise pollution also affects animal life (Fletcher & Busnel, 1978; Knight & Swaddle, 2011; Ortega, 2012).

Sound level derives from the frequency and the amplitude of air pressure, detectable by the human ear (Therivel & Breslin, 2005). Other parameters need also to be taken into account depending on the type of different noise sources (e.g. noise deriving from transportation, industry or residential areas), while multiple noise sources have cumulative effect. Sound level regulations aim to control overall noise levels in a

region, set maximum noise limits on emitted noise, or to separate noise sensitive areas from sources of noise (Therivel & Breslin, 2005).

EU Directive 2002/49 already provides for compilation of noise maps and strategic noise maps (Art. 4) while Annex I (which defines noise indicators) stipulates specific heights for noise indication measurements. 3D data such as building heights, noise barriers and topography are taken into account for noise calculation; however, in most cases 2D noise maps are compiled, that do not allow insight to the 3D aspects of noise (Jantien Stoter et al., 2008). To this aim, research towards generation of 3D noise maps is conducted, including 3D noise maps of Stockholm (Sheng, 2011), Paris (Butler, 2004), Delft (Jantien Stoter et al., 2008) and Hong Kong (Law, Lee, & Tai, 2004). CityGML Noise Application Domain Extension (ADE) has been developed to allow for 3D noise mapping along with exploitation of topological and semantic features provided by CityGML, e.g. application for noise mapping in North Rheine-Westphalia (Czerwinski, Sandmann, Stöcker-Meier, & Plümer, 2007). Interest is also shown in the 3D mapping of specific types of noise sources, such as traffic noise (Lu et al., 2017) or outdoor music events (ten Kate, 2017).

Protection and mitigation measures

In this section, common noise pollution protection and mitigation measures involving 3D aspects are presented. It is not within the aims of this section to provide exhaustive or elaborate technical specifications on such measures; presentation is limited to 3D-based measures.

Mitigation is required so that noise levels do not exceed the noise levels recommended by noise standards. Mitigation measures may also be implemented to decrease noise impacts, even in case that noise standards are met, in order to reduce annoyance and complaints (Therivel & Breslin, 2005). Mitigation measures aim to reduce the noise level in its source, by minimising potential noise sources, or to create volumes within which noise propagation is absorbed before reaching noise-sensitive areas. Common 3D-based noise mitigation and protection measures are the following (Therivel & Breslin, 2005); (Environmental Protection Department, 2018); (U.S Department of Transportation, 2018); (World Health Organization, 1999); (Science Communication Unit, 2017):

- Minimisation of traffic noise by traffic regulations that allow, quieter, smooth-flow traffic.
- Definition of buffer zones of undeveloped land around a high-noise development.
- Protection of buildings sensitive to noise pollution from noise sources by intermediate noisier components (for example, retail buildings in front of residential buildings).
- Acoustic fencing using topographical features of the area, tree plantings, or artificial materials.
- Building layout (protection of noise sensitive rooms by less noise sensitive rooms by locating the former closer to noise pollution sources).

- Vertical allocation of building uses depending on their sensitivity to noise pollution (e.g. allocation of noise sensitive uses in higher levels of a building, and less noise sensitive uses on road level).

As regarding to the impact of noise pollution to animal life, the following mitigation measures are prescribed (Carvalho, Santos, Mira, & Lourenço, 2017; Jacobson, 2005; Silva Lucas, de Carvalho, & Grilo, 2017):

- Construction of crossing structures, such as pipe or box culverts, tunnels and wildlife underpasses and overpasses.
- Construction of noise barriers.
- Changes in road elevation, use of materials that reduce noise.

Above mentioned measures, create volumes where specific noise characteristics apply, and can be used during planning and design stages of developments in order to assess the impact of potential development projects, to monitor existing noise conditions, or to impose further noise mitigation restrictions.

Landscape and visual amenity

Landscape impacts activities on built and natural environment in multiple ways: it contributes to people's enjoyment of the environment, attracts investments, sets the regional identity of a region, promotes biodiversity and affects the intensity of the impact by natural phaenomena (Therivel, 2005). Different definitions are used to define landscape, each one emphasising on the different landscape aspects and their relations. Some common landscape definitions used in Europe are presented by (Whelan, Fry, & Green, 2010). European Landscape Convention (European Council, 2000), defines landscape as "*an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors*" (Art. 1). Above mentioned definition shows that landscape includes both natural and man-made characteristics; the latter are mostly related to cultural heritage. (Goodey, 1995), lists the following factors contributing to landscape[75]:

- Physical factors (including geology, landform, climate and microclimate, drainage, soil and ecology).
- Human factors (archaeology, landscape history, land use, buildings and settlements).
- Aesthetics factors that can be further distinct to *visual aesthetics* (related to landscape objects' proportion, scale, enclosure, texture, colour, views) and *other senses aesthetics* (related to other senses triggered by a landscape, such as sounds, smells, taste or touch).
- Associations with historical or cultural events, sites, or personalities.

Above mentioned factors, show both the three-dimensional character of landscape, and its high level of subjectivity regarding identification and characterisation of

[75] Depending on jurisdiction, classification of the factors that contribute to landscape may vary. For example, according to the Department of Planning and Community Development (DPCD) of Victoria, the following five types of landscape values are defined to identify the significance of a landscape: aesthetic, historic, environmental and scientific, social and other values (Department of Planning and Community Development, 2013).

potential impacts. Consequently, this affects the definition of landscape protection-related regulations, which also need to be defined in relation with the above mentioned factors. A detailed list of aesthetic impact-related definitions is available in (Canter, 1996). (Goodey, 1995), distinguishes between landscape impacts (referring to changes in the fabric, the character and the quality of landscape), and visual impacts (which refer to the effects of landscape appearance changes on people). Addressing visual impacts brings on a number of problems such as (i) the lack of agreement on visual quality definition and criteria, (ii) difficulties in achieving effective communications between professionals of different fields, (iii) seasonal variations[76] in landscape quality and (iv) the diverse opinions in what is aesthetically pleasing (Canter, 1996). Apart from legal definition issues, technical impediments need also to be considered. 3D visualisation of physical landscape requires high accuracy and level of detail in order to be realistic. Therefore, excessive input data, processing time, expertise and hardware capacity are required, to provide for a compelling 3D model that will include active visual qualities (e.g. light source, glare, halo, and taillights) and their effects on objects (e.g. water, snow, glass) (Lai et al., 2010), which may result in unbalanced cost-benefit relation.

Protection and mitigation measures

In this section, common landscape protection and mitigation measures involving 3D aspects are presented. It is not within the aims of this section to provide exhaustive or elaborate technical specifications on such measures; presentation is limited to 3D-based measures. It needs to ne noted that landscape protection measures during design/planning stage are more efficient instead of mitigation ones, which pertain high costs. Additionally, the qualitative nature of landscape and visual impact characteristics (as an aggregate of qualitative characteristics or a summary of qualitative observations) needs to be addressed, in terms of defining a number of subjective reference elements (Therivel & Breslin, 2005), while mitigation measures deriving from other components of Public Law, impose further impact on landscape (Landscape Institute and Institute of Environmental Management & Assessment, 2013). Common measures are the following (Landscape Institute and Institute of Environmental Management & Assessment, 2013; Therivel & Breslin, 2005):

- Restoration of terrain, soils and vegetation to their original condition before construction.
- Minimisation of visual impacts by using of existing boundary areas and landscape features (roads, fence rows, property lines, forest edges).
- Designation of building structures to fit with existing topography.
- Grading of earthworks to tie into the existing site contours, ensuring that new earthworks integrate with the existing landform.
- Designation and allocation of above ground structures to be visually unobtrusive. Reinforcing of landscape character and distinctiveness, and minimisation of visual intrusion.

[76] Apart from seasonal landscape variations, landscape changes may also derive from its dynamic character, and the impact of physical processes or human intervention (which are not always irreversible) (Dramstad & Fjellstad, 2011).

- Retaining of existing vegetation.
- Adjustment of site levels.
- Use of structural designs, selection of materials, colour treatments and textural finishes, which contribute to the integration of buildings that cannot be screened, with their surroundings.
- Creation of strategically sited landforms together with structure planting on and/or off-site.
- Avoidance or reduction of obtrusive light.

5.6.2.2 Biological environment

Biological environment includes vegetation, wildlife, habitats, and protected, or conservation areas traced on terrestrial, freshwater, coastal or aquatic environments. Within the context of identifying existing conditions and potential impacts, also the interrelation among each of the aforementioned biological environment components with each other needs to be examined. This implies ecology analysis methods, given that scientific study of the relationships between living organisms and their environments falls within the field of ecology (Peter Morris & Emberton, 2005). Interrelation between different environmental components is very complex and may imply direct or secondary impacts, which are either non-predictable, or require high level of elaboration and expertise to be predicted. Therefore, it is not within this section's aim to present a detailed description of biological environment components and their interrelations; this section aims merely to present the 3D implications of biological environment components, and, consequently, the three-dimensional character of biological environment-related PLRs.

- Vegetation has multiple effects in a region: it defines the landscape form, along with soil characteristics and geological formations, it constitutes the habitat of specific types of fauna, while also affects water runoff, soil stability and resistance to erosion (Cafuzzi & Crippa, 2005; Environmental Protection Authority, 2016; Mabuchi & Sato, 2005; Sulaiman, Mohamad, & Idilfitri, 2013). Therefore, changes of vegetation entrain 3D impacts, thus defining vulnerable volumes due to soil instability or flooding, which require relative protection measures. Moreover, vegetation growing on specific altitude, defines volumes affected by vegetation loss, or volumes which require protection measures.
- Wildlife, in the first instance, does not seem relevant to 3D PLRs. However, the three-dimensional component also exists in case of wildlife, given that different species reside on specific altitudes, or specific depth below the land surface (or the sea level), while bird migration routes also constitute 3D zones, which can be used to impose protection or mitigation measures. Besides, they can be interrelated with other types of 3D PLRs, during the design/planning process of planned developments, to assess potential, cumulative impact.
- Protected areas are clearly defined geographical spaces, recognised, dedicated and managed through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural

values[77] (International Union for the Conservation of Nature, 2018). Such definition, sets the common ground among the variety of the different versions of "protected area" definitions, each of those provide different degree of protection and depend on different national and international classification schemes (Gillespie, 2009). Protected areas are established under the influence of international law, national legislation and policies. Given the strong interrelation of biological environment components, protected areas may incorporate volumetric zones of soil and groundwater protection, specific altitudes where species of fauna and flora reside or grow, and landscape conditions.

Protection and mitigation measures

In this section, common measures on the protection and mitigation of biological environment, involving height, depth or volumetric characteristics are presented. It is not within the aims of this section to provide exhaustive or elaborate technical specifications on such measures; presentation is limited to the types of 3D-related measures. Considering that natural environment characteristics, such as soil or groundwater, strongly affect biological environment, the cumulative effect of scheduled protection or mitigation measures needs to be considered. Besides, such interaction between different environmental components may imply exploitation of protection or mitigation measures related to physical environment to be used for natural environment protection purposes and vice versa. Common measures with 3D connotation traced in literature are the following (P. Morris et al., 2005; Peter Morris & Emberton, 2005; S. Thompson & Lee, 2005):

- Redetermination of the location of a development or project. This does not only imply location changes on planar field, but also changes on the depth of a projected development.
- Measures to minimise pollution, soil erosion and runoff.
- Reduction of barrier effects using road underpasses or tunnels.
- Collect sediments or silt in siltation traps, french drains, or siltation basins/ponds/lagoons. Use vegetated buffer zones as filters.
- Minimise surface drainage from polluted areas. Ensure isolation of waste-storage facilities and landfill sites from surface and groundwater bodies.
- Protection of wildlife species' migration routes, shelter and refuge zones.
- Measures to minimise harmful geomorphological changes (such as the construction or replenishment of shallow sloping beaches, and the use of groynes to stabilise beaches).
- Measures to avoid or minimise pollution (by reference to nutrient or toxin loadings of sediments, tidal movements, or artificial aquifer recharge).

[77] IUCN definition of protected areas is reflected, to an extent, also to the definition provided by the Convention on Biological Diversity, where protected area is defined as "a geographically defined area, which is designated or regulated and managed to achieve specific conservation objectives" (art. 2) (United Nations, 1992).

5.6.2.3 Socio-economic environment

Socio-economic environment extends to a variety of fields that reflect lifestyle, cultural characteristics, community characteristics, quality of life and health conditions in a region, along with their relation and impacts on bio-physical environment (Rutz & Janssen, 2014). Each of the above mentioned aspects groups are overlapping and interrelated, while they can be further elaborated as following (United Nations Environment Programme, 2002):

- Lifestyle pertains the way people behave and relate to family, friends and cohorts on a day-to-day basis;
- Cultural characteristics include shared customs, obligations, values, language, religious belief and other elements which make a social or ethnic group distinct;
- Community characteristics include infrastructure, services, voluntary organisations, activity networks and cohesion;
- Amenity/quality of life refers to the sense of place, aesthetics and heritage, perception of belonging, security and liveability, and aspirations for the future;
- Health conditions include mental, physical and social well-being.

Interest on socio-economic characteristics and their impact within the context of impact assessment process, starts in the 1970's, mostly reflecting concerns regarding major infrastructure projects, such as nuclear power stations in the United States, hydro-electric schemes in Canada and the oil and gas related developments in the United Kingdom (Glasson, 2005). As deriving from the content of socio-economic environment components, socio-economic indicators vary and can be differently expressed, e.g. using real values, binary or quantitatively (Rutz & Janssen, 2014). Moreover, examination of potential impacts on socio-economic environment needs to clarify the type, the duration, the spatial extent and the distribution of such impacts (Glasson, 2005). Therefore, it is evident that a broad range of highly divergent, and usually case-specific, parameters are required to define socio-economic environment[78].

Among the abundance of socio-economic parameters, those pertaining 3D characteristics and can be used within a 3D PLR context are those related to land tenure and land use, as well as infrastructures and public services (Dimitrios Kitsakis & Dimopoulou, 2018)). The latter include all roads, harbours, airports, railways, as well as all types of networks such as water and sanitation, irrigation, waste management, energy and telecommunications. Most of these networks are developed above or below the earth's surface and their operation and maintenance implies specific regulations, regarding access, security, potential overlaps with other infrastructures, protection zones, or other types of zones, defined by Public Law. Such regulations affect land tenure and land use by limiting the vertical extent of land exploitation, or by imposing specific land use types. 3D socioeconomic baseline data that can be used to estimate 3D overlaps and bypass potential defects in a project's design and development, may refer to the location of utility networks or of

[78] A general classification of socio-economic impacts can be traced in (Glasson, 2005), while other examples of case-specific socio-economic impacts can be traced in (Rutz & Janssen, 2014) (bioenergy production), (Bureau of Rural Sciences, 2005) (Marine Protected Areas) and (Binimelis, Born, Monterroso, & Rodríguez-Labajos, 2008).

zones influenced by utilities, e.g. protection zones around cables, polluted soils or groundwater zones (Figure 31).

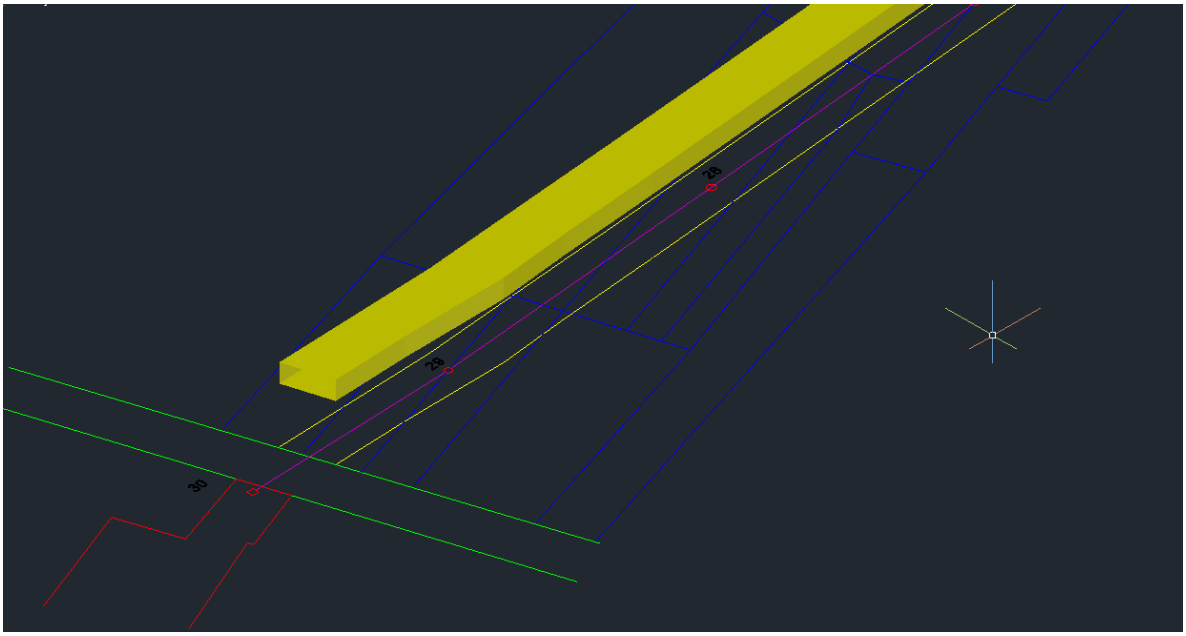


Figure 31. 3D zone of utility servitude (in yellow), as deriving from literal descriptions within Greek law, overlaid on cadastral diagram (modified Dimitrios Kitsakis & Dimopoulou, 2016b).

3D PLRs may be defined by reference to the maximum exploitable height (in case of structures on or above the ground), or the maximum exploitable depth (for underground structures). This sets an upper/lower boundary of space exploitation for horizontally overlapping land use types, but it does not define a volumetrically delimited restricted space, as it does not set the corresponding "closing" boundary of the restriction volume (lower or upper volume respectively). Schematically, an example is presented in Figure 32.

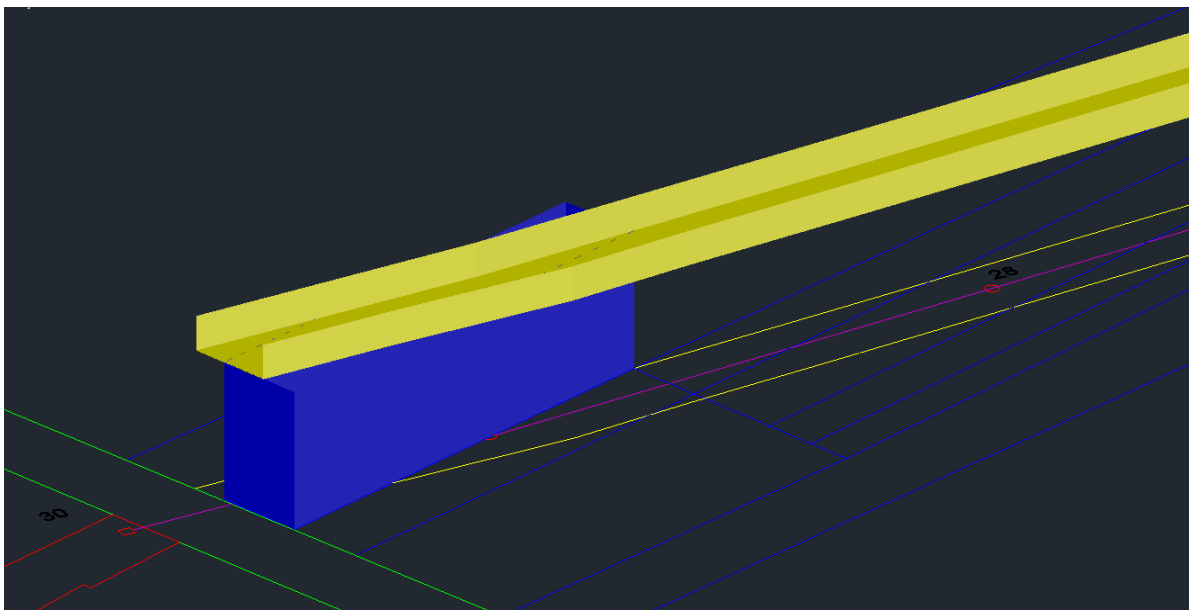


Figure 32. Example of non-closed restriction volume, regarding servitude of passage of an aerial powerline. The blue volume shows the vertical extent of exploitation of the land parcel below the powerline, while the "open", yellow surfaces represent the extent of the restricted zone of

the powerline (the example is based on Decision 3461/2009, Greek Government Gazzette, Volume on Compulsory Acquisitions and Urban Planning, Issue 33, 04/02/2009).

Protection and mitigation measures

Due to their complex interrelations, their relations to each specific project's development and the variety of the parameters defining socio-economic environment, it is difficult to define generally applying socio-economic-based 3D PLRs. Given that socio-economic environment is multiply affected by parameters of the other environmental components (natural and biological environment), corresponding protection and mitigation measures with 3D aspects described in previous sections may apply as well. For example, health protection and mitigation measures may include protection or mitigation measures against soil or groundwater pollution.

As regarding to land tenure and infrastructures or utilities, 3D PLRs may relate to:

- Building regulations, imposing specific height, depth, volume or land cover limitations.
- Spatial planning regulations, which impose specific land use types, or set requirements regarding ambient noise levels, or the protection of landmarks and significant landscapes.
- The establishment of limited real property rights for the construction, maintenance, repairing and protection of a development.

Above mentioned measures are presented in more detail in the following sections, therefore they will not be further elaborated.

5.6.3 Mines

Mineral ownership is among the first cases that have arisen, requiring real property stratification. Management of mineral ownership, exploration and extraction rights is regulated by specific legislation, introducing a primary case of 3D cadastral concept. The significance of minerals not only in terms of national economy, but also in terms of international relations and politics, has been early recognised, thus resulting in legislative separation of land from mineral ownership, to secure public benefit (Dimitrios Kitsakis & Dimopoulou, 2016). Mineral legislation can be further specified depending on the minerals' location, in terms of minerals on or below land and minerals within the sea. Special regulations also apply in several jurisdictions regarding the extraction of hydrocarbons such as oil and gas. Moreover, mineral extraction activities, apart from exploitation of the underground space, also require the establishment of technical installations and structures on land surface, while safety regulations applying to the mineral extraction area and its surroundings also pertain 3D characteristics.

5.6.3.1 Mineral tenure

In Western countries, including both Civil and Common Law jurisdictions, legislation for mineral rights is mainly based on the following systems (Liedholm Johnson, 2010):

- Landownership system, where the right to use and exploit minerals follows land parcel ownership.
- Concession system, where minerals are owned by the state and rights of use and exploitation are granted or conferred to interested parties.

- Claim system, where the discoverer of mineral deposits may acquire an exclusive mineral exploitation right.

Most commonly, legislation regulating ownership of mineral rights follows a mixed approach, combining landownership with concession or claim system characteristics, separating minerals based on their scarcity, national interest and importance. Minerals that are considered relatively scarce, and are of national interest and importance are *state-owned* minerals. Their ownership is not related to surface parcel ownership and they can be extracted even against the will of the surface parcel owner, provided that surface parcel is expropriated and its owner is compensated for the lost land's value. State-owned minerals are explicitly defined in national legislation, mainly including metallic ores and energy minerals (Department of Mining and Tunnelling, 2004). In several European Union members, state-owned minerals also comprise "free minerals". Those minerals are as well under state ownership; however, they are free in terms of the mineral extraction fee that is required for the extraction of the rest of state-owned minerals (Department of Mining and Tunnelling, 2004; Liedholm Johnson, 2010). On the other hand, low value minerals, as well as minerals with limited national value constitute the *landowner minerals*[79], owned by the owner of the surface parcel. Landowner minerals are usually negatively defined, including all other minerals apart from the state-owned ones. Ownership of minerals by the surface parcel owner does not mean that the latter may conduct mineral extraction activities, without interference of state authorities (E. L. Johnson & Ericsson, 2015). Mineral extraction permits need to be issued by the responsible state authorities, and the requirements of other legal statutes related to mineral extraction, such as environmental protection, need to be fulfilled.

In Civil Law jurisdictions, national legislation explicitly separates mineral from surface parcel ownership (Greek Mineral Code, art. 3; French Civil Code, art. 552; Spanish Civil Code, art. 339; Civil Code of Quebec, art. 951; Mining Act of Quebec, art. 3; Minerals Act of Sweden, Chap. 1, Sec. 1; Mining Act of Finland, Chap. 1, Sec. 2; Minerals Act of Norway, Sec. 7). Such ownership segregation may discriminate between specific minerals based on the state-owned and landowner distinction, or may comprise indiscriminately all types of minerals (e.g. Mining Act of Quebec, art. 3). According to the Mineral Code of Louisiana, ownership of land includes all minerals occurring naturally in a solid state (par. 5). Oil, gas and other minerals occurring naturally in liquid or gaseous form, or any elements or compounds in solution, emulsion, or association with such minerals are not included in surface parcel ownership; however, the landowner has the exclusive right to explore and develop his property for the production of such minerals and to reduce them to possession and ownership (par. 6). State-owned minerals constitute individual real property objects (Greek Mineral Code, art. 65; Mining Act of Quebec, art. 9; Mineral Code of Louisiana, par. 18) and are subject to several mining rights such as prospections, exploration permits, mining leases and mining concessions[80]. Each of

[79] Depending on jurisdiction, different terminology may be used, such as *non-schedules minerals* (Ireland), *non-claimable minerals* (Finland) and *mineral masses* (Portugal) (Liedholm Johnson, 2010)

[80] Mining Act of Quebec (art. 13) apart from mineral concession and lease, includes in statutory mining rights also leases to mine surface mineral substances, leases to produce petroleum and natural gas, leases to operate an underground reservoir, and authorizations to produce brine. Mineral Code of Louisiana (art. 16) stipulates as

these rights refers to the examination of an area for the purpose of searching for mineral substances (prospection), search for mineral substances within an area (exploration) and exploitation and development of mineral resources within an area (concession). In several jurisdictions mineral legislation distinguishes between permits and concessions, where the former are valid for a limited period of time, usually up to three years, while duration of the latter range from thirty years, up to the exhaustion of the mineral reserve (Globalaw, 2016). Restrictions may apply to each mining right. For example, mining concession may allow only for extraction of specific minerals (e.g. Brazil) (Globalaw, 2016), or minimum/maximum concession areas may be defined (e.g. Chile, Ecuador, Spain). Depending on jurisdiction and their type, mining rights are transferrable, can be jointly held in undivided shares, and can be subject to mortgage. Ortega-Girones, Pugachevsky, & Gotthard Walser (2009) include the use of mining rights as collateral, among the mining sector reforms that have proved successful in countries with long mining tradition (such as Canada, Chile, Peru and South Africa). In order to be valid, national mineral legislation requires that mineral rights are registered to cadastres, or specific mining cadastres. As Mining Cadastre can be described a cadastral system defining where mining objects, subjects and rights are located, along with overlapping surface rights, such as private or state properties, reserves, farms and settlements (Hernandez, 2003). Mining rights are spatially defined in horizontal plane, using 2D polygon boundaries which refer to the projection of mining rights' extent on the land's surface. Ortega et al. (2009), regard introduction of the Cadastral Unit object (CU) as the most innovative and efficient concept in management of mining rights. A CU requires that areas where mining activities apply, are defined in mining cadastres using quadrangular polygons of constant dimensions and of fixed position within a coordinate system. The dimensions of a CU are required to be defined as multiples of the minimum CU dimension, set by mining legislation (Ortega-Girones et al., 2009). Figure 33 schematically presents the concept of CU. Mining legislation does not explicitly define the depth of mineral exploitation; characteristic examples of stipulations providing for unlimited exploitation depth are traced in the Mining Code of Greece (art. 30, 67) and the Law on Mines of Spain (art. 75). Overlapping mineral rights are not common practice due to technical reasons. However, overlapping exploration rights can be established in various jurisdictions, providing that they refer to different mineral substances and that does not detriment on the operations of the other mining right holders (Liedholm Johnson, 2010; Ortega-Girones et al., 2009).

basic mineral rights the mineral servitude, the mineral royalty, and the mineral lease, although it does not exclude the creation of other mineral rights by the landowner.

In several jurisdictions, specific mineral legislation is repealed (e.g. Belgium), or only applies to state-owned minerals, while provisions on landowner minerals are incorporated in other legislations, such as general land use planning or environmental laws (e.g. France, Germany) (Department of Mining and Tunnelling, 2004).

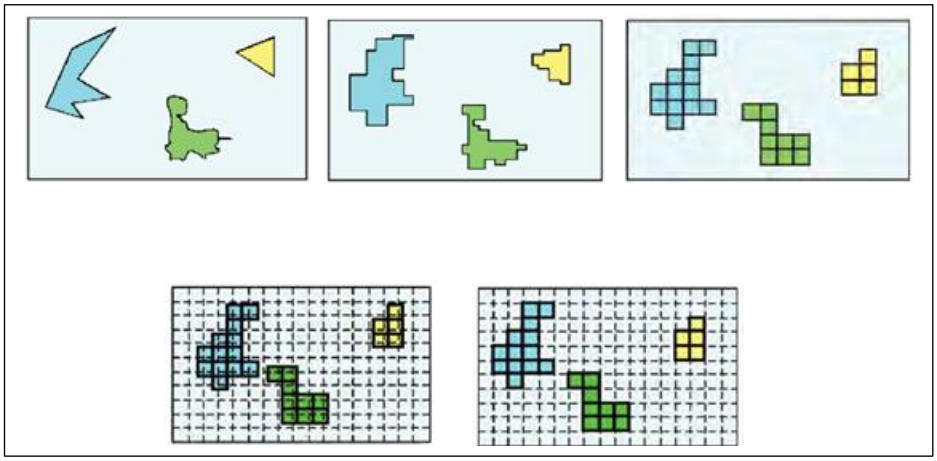


Figure 33. Concept of mineral Cadastral Unit (CU) (Ortega-Girones, Pugachevsky, and Gotthard Walser 2009).

In the event that constructions supporting mineral activities are required to be erected on the surface parcel, the use of surface land can be acquired through the establishment of servitudes, under appropriate compensation of the surface parcel owner. Servitudes can be established after agreement between the involved parties, administrative acts, court decisions, or expropriation of the land parcel. However, mineral legislation in several countries, such as Brazil, Chile, Ecuador, Indonesia and Kazakhstan, (Globalaw, 2016); (ICLG, 2018), does not provide for expropriation of surface parcel ownership. In such case, the right to exploit surface parcel space is acquired under mandatory servitudes. In other jurisdictions (e.g. Congo-D.R., Ethiopia, Gabon, Ivory Coast, Portugal, Senegal, Peru, Uruguay), mineral concessions grant the concessionaire the right to use surface parcel by establishing administrative or mining servitudes, provided that the surface parcel owner is compensated (Globalaw, 2016); (ICLG, 2018). Compensation is paid either for the deprivation of use and the damages on surface land caused by mining activities, or for the expropriation of real property. Land valuation is defined by national statutes on expropriation, taking into account the loss of real estate assets, and consequential damages that do not affect real property but its right holder personally, e.g. business resettlement costs, depreciation of remaining real property, compensation of tenants (Steinsholt, 2010; Voss, 2010). Federal Mining Act of Germany provides for additional compensation in case that economic losses not foreseeable when a decision of real property assignment was made (sec. 89), as well as for compensation regarding land use restrictions imposed on land parcels used for exploration and extraction of resources (sec. 109). Such provision applies in case of erection, expansion, alterations or changes in use of physical structures (sec. 107). Although such stipulation does not involve legal space, it leaves room for compensation of real property volumes related to physical space.

In Common Law jurisdictions, land ownership initially included subsurface minerals. However, during the years, protection of public interest along with the extensive areas held under state or crown ownership have resulted in the state/crown to retain mineral ownership when alienating land to individuals, while mineral legislation mostly focused on regulating mineral leases over public lands, also imposing obligations of public concern on mining activities (Wälde, 1988, according to (Liedholm Johnson, 2010)).

In Canada, the Constitution Act provides provincial governments' exclusive power to regulate exploration, development, conservation and management of non-renewable natural resources (art. 92). Therefore, mining regulations depend on provincial legislation. Federal mining laws vest mineral ownership to the crown that grants mining rights, in form of mining titles, to interested parties (New Brunswick Mining Act, sec. 21; Manitoba The Crown Lands Act, sec. 4; Ministry of Energy and Mines (British Columbia), 2017)). Mining titles constitute individual real property rights, separate from surface parcel ownership, reserved to the crown. Mineral rights' ownership may refer to a specific mineral or more, except of explicitly defined crown-owned minerals, such as gold and silver (Alberta Mines and Minerals Act, sec. 10). Mineral resources are usually distinguished between minerals and quarry minerals. Allocation of mineral ownership to the state can be also traced in the National Land Code of Malaysia (sec. 40) and Singapore State Lands Act (sec. 3B). Similar provisions can be traced in Australian legislation. Mining activities are regulated by state legislation; therefore mining is not regulated under uniform mineral legislation, despite the similarities between different states' legislation. Mineral ownership is allocated to the crown (Queensland Mineral Resources Act, 1989, sec. 8; Mineral Resources (Sustainable Development) Act, 1990, sec. 8; NSW-LRS, 2018)[81], constitutes separate real property from the surface parcel and mining titles are subject to transfer, lease or mortgage. In New Zealand, only gold, silver, uranium and petroleum are considered to be property of the crown, while alienation of crown land pertains reservation of all minerals on such land in favour of the crown (New Zealand Crown Minerals Act, 1991, sec. 9, 10).

Different types of licences or mining tenements can be established, conferring different rights on their holders and applying for different duration. Characteristic examples are mineral prospecting (prospect for minerals on small scale area, with potential of extracting or disturbing ground material up to a specific tonnage), exploration (exploring for minerals through geological, geophysical and geochemical surveys, drilling, sample taking for non-commercial purposes or other measures described in exploring licence/permit), and mining (extract minerals and perform mineral extraction ancillary facilities such as constructions). Other rights may also be stipulated by national legislation such as mining or mineral claims[82] (used both in Australian and Canadian states legislation, but with different content), licenses for identified minerals that cannot yet be explored or mined, erecting and operating machinery or other operations related to the mining procedures (Globalaw, 2016-

[81] Exceptions may apply in each state, mainly referring to minerals that have been granted from the Crown to a license holder, or on which a minerals exemption applies (e.g. Victoria, Mineral Resources (Sustainable Development) Act, 1990, sec. 9).

[82] An example of the different definitions of mining/mineral claim among different Common Law jurisdictions can be traced by comparing the definitions stipulated in Queensland Mineral Resources Act (1989), sec. 5, Manitoba, The Mines and Minerals Act (sec. 1) and British Columbia Mineral Tenure Act, 1996, Sec. 1.

Western Australia). One of the most significant characteristics of Australian mineral legislation is its provision for stratification of mineral real property units. Victorian Mineral Resources (Sustainable Development) Act (1990), provides that licences can be granted for a *stratum of land*, in which case, all relevant references in the Act require to be construed accordingly (sec. 14A). It is worthy of noticing that Mineral Resources (Sustainable Development) Act (1990), uses the same definition of a "stratum of land" with that of the Transfer of Land Act of Victoria, to define its 3D real property units "*a part of land consisting of a space of any shape below, on or above the surface of the land or partly below and partly above the surface of the land, all of the dimensions of which are limited*" (Victoria, Mineral Resources (Sustainable Development) Act (1990) sec. 4). In New South Wales horizontal division of land into strata is employed, to separate subsoil containing the minerals from ownership of the surface and the airspace above it, in mining areas. In such cases, substrata incorporates both the land and the minerals, while division is usually stated to be at a point '20.115 metres below the surface', instead of a specific Reduced Level in Australian Height Datum (AHD). Titles for minerals or sub-strata, are issued in terms of "Fee Simple in Substrata" (NSW-LRS, 2018). Mines and mineral rights are registered in separate, mineral registries as 2D polygons on land surface, including coal and petroleum titles. Mining polygons are located in 2D grid, defined by consecutive, equidistant meridians and parallels. For example, New South Wales Mining Regulation (2016), divides the earth's surface to sections defined by meridians and parallels at distance of 5 minutes (or multiples) of longitude and latitude respectively, that can be further subdivided at distance of 1 minute of longitude and latitude. Several registries also include other physical characteristics, such as geology, water bodies, surface geochemistry, infrastructures, protected areas and native title areas. Additional data is presented as 2D polygons on the land surface, overlaid to the polygons of the mining areas.

In the United States, the General Mining Law (1872), declares all valuable mineral deposits in federal lands of the United States, free and open to exploration and purchase, and such lands open to occupation and purchase (sec. 2319). The locator of a mineral deposit can either be entitled to an exclusive possessory interest in surface and subsurface lands, and the right to develop the minerals (unpatented mining claim), or acquire the title of land from the federal government (patented mining claim[83]) (Kahalley, Nichols, & Bassett, 2016; La Flèche, 2016). Apart from provisions of General Mining Law, United States legislation also provides for prospecting licenses and lease of specific types of minerals on federal land through the Mineral Lands Leasing Act (1920), as well as for disposal of common minerals within the Materials Act (1947). Permit applications require to be followed by 3D documentation, such as cross-section maps or a plan of the affected area (not only the mining area), while documentation of non-geometrical physical characteristics of the area may be required as well (e.g. hydrologic consequences of the mining and reclamation operations, such as the quantity and quality of surface and groundwater) (United States, Surface Mining and Control and Reclamation Act (1977, Sec. 507). In case of private land estates, individual owners are free to split their surface from mineral estates, according to state-law provisions. Upon severance of a mineral estate, it can be individually exploited as a matter of contract law, subject to

[83] Since 1994, a patent mining claim moratorium is in force, and no new patents are being issued (Kahalley et al., 2016).

the provisions of the severance contract and applying state-law. In several western states, the federal government may reserve the mineral estate when transferring ownership of the surface lands to private citizens or state governments, thus affecting their power to dispose underlying minerals (Kahalley et al., 2016).

5.6.3.2 Interrelation with other laws

Modern mining legislation is not restricted in merely regulating mineral tenure and mining operations, but, due to the nature and the impact of mineral activities, regulations on mining can be traced in a variety of statutes including environmental, water and cultural heritage protection. Regulations on securing public health and safety are also related to mineral activities. (Kokko, Buanes, Koivurova, Masloboev, & Pettersson, 2015), use the term *sustainable mining* to define both the objective and the tool to balance multifaceted social, economic and environmental considerations (Figure 34). Above mentioned provisions pertain regulations that apply to 3D space, either explicitly defined or implied, and can be used to define RRR volumes in space.

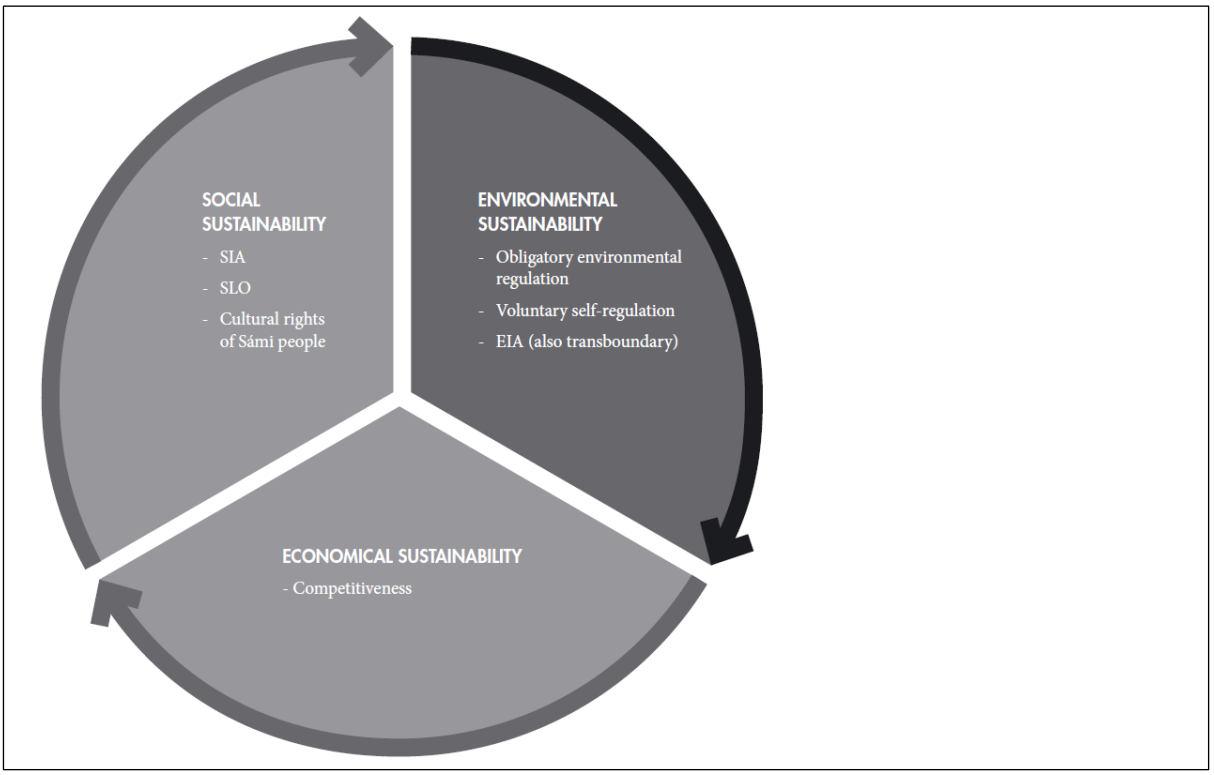


Figure 34. Sustainable development circle (Kokko et al. 2015).

This section presents the types of PLRs that impose restrictions on mining activities, apart from those imposed by mining laws, as traced on international literature (Globalaw, 2016; Kokko et al., 2015; La Flèche, 2016; Warhurst, 1999). PLRs can be classified in the following categories:

- Environmental protection laws. Such laws impose the compilation and requirements of E(S)IA regarding mining activities. They also set the framework of environmental components' protection (detailed measures are stipulated in specific laws and subordinate legislation).
- Specific laws, focusing on the protection or preservation of a particular component, by explicit regulations regarding mining activities. Characteristic

examples are laws protecting air, water or soil pollution, and laws on the protection of cultural heritage.

- Health and safety regulations. Such legislation may either set regulations to minimise the impact of mining activities on health conditions of human or of animal life in the vicinity of a mine, or may define specific safety requirements to ensure the health condition of miners. 3D regulations related to the latter include (i) the rock thickness around underground storage areas, (ii) the geometrical characteristics of excavations and the protection from groundwater or hydrological characteristics, (iii) protection from vibration and noise, and (iv) landscape protection.
- Third party rights. Such rights include rights of individual owners of land parcels above a mine, or rights deriving from the relation of indigenous population to an area. The latter may refer either to cultural sites of indigenous population (e.g. ceremony areas, or areas where cultural artefacts are located), or to the exploitation of such lands by indigenous population for residential, agricultural or pastoral purposes.

5.6.4 Civil Aviation

Aviation constitutes one of the most common conflicts between the vertical extent of the right of ownership, as defined in the Roman maxim "*cujus est solum…*", with the passage of air vehicles above real property. Such conflicts were soon resolved either through court decisions, or by legal amendments and, at international level, by international agreements, e.g. the International Air Services Transit Agreement (ICAO, 1944), in favour of facilitating air transport, as long as flights do not impede land parcel owner's enjoyment of land (Abramovitch, 1953). The origins and the historical development of the "*cujus est solum…*" maxim as applied within the context of aviation, along with views with reference to the nature and extent of private rights in the column of air above the land, are presented in (Abramovitch, 1953). Civil aviation restrictions can be classified in restrictions on constructions' height applying to the vicinity of airports, and on flight restrictions on manned or unmanned air vehicles (UAV).

5.6.4.1 Height restrictions in the vicinity of airports

This type of restrictions pertains building, or physical object height restrictions to the areas surrounding airports, as well as volumetric requirements within the area of an airport, to ensure safe take-off and landing of air-vehicles. International Civil Aviation Organisation (ICAO), has developed standards and recommended practices defining restriction zones or height limitations, while research towards generation of 3D electronic terrain and obstacle databases (eTOD) is conducted exploiting the variety of data acquisition techniques. Requirements for airspace around aerodromes[84], free from obstacles are stipulated in ICAO documentation. O*bstacles* are defined as "All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that: a) are located on an area intended for the surface movement of aircraft; or b) extend above a defined surface intended to protect aircraft in flight; or c) stand outside those defined surfaces and that have been assessed as being a hazard to air navigation." (ICAO, 2016). The volume that objects characterised as

[84] According to ICAO, the term aerodrome is used to describe "*a defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft*" (ICAO, 2009-Mendelay Aerodromes).

obstacles may extend, is delineated by *obstacle limitation surfaces (OLS)*, which can be defined as "*conceptual (imaginary) surfaces associated with a runway, which identify the lower limits of the aerodrome airspace above which objects become obstacles to aircraft operations*" (Civil Aviation Safety Authority, 2017). According to ICAO (2009), there are the following nine types of OLS, also schematically presented in Figure 35:

- Outer horizontal surface, which is defined as "*a plane located 150 m above the aerodrome elevation datum and extending from the upper edge of the extended conical surface for a distance of 50,000 m (radius) from aerodrome reference point (ARP)*" (Qiao et al., 2016).
- Conical surface, which is defined as "*a surface sloping upwards and outwards from the periphery of the inner horizontal surface*" (ICAO, 2009).
- Inner horizontal surface, defined as "*surface located in a horizontal plane above an aerodrome and its environs*" (ICAO, 2009).
- Approach surface, defined as "*an inclined plane or combination of planes preceding the threshold*" (ICAO, 2009).
- Inner approach surface, which is defined as "*a rectangular portion of the approach surface immediately preceding the threshold.*" (ICAO, 2009).
- Transitional surface, defined as "*a complex surface along the side of the strip and part of the side of the approach surface, that slopes upwards and outwards to the inner horizontal surface*" (ICAO, 2009).
- Inner transitional surface, defined as "*a surface similar to the transitional surface but closer to the runway*" (ICAO, 2009).
- Balked landing surface, defined as "*an inclined plane located at a specified distance after the threshold, extending between the inner transitional surface*" (ICAO, 2009).
- Take-off climb surface, defined as "An inclined plane or other specified surface beyond the end of a runway or clearway" (ICAO, 2009).

Each of these surfaces is described, among others, by reference to height, slope or elevation, defining specific volumes of space that need to be free from obstacles, in order to allow aerodromes' operations.

Apart from the above mentioned zones, vertical restrictions are also imposed regarding the installation of telecommunications and electronic systems, so that the operation of navigational aids, radars and telecommunication systems is not impeded by constructions. Therefore, radar coverage volumes are defined, within which regulations regarding constructions' size and materials apply. Precise regulations can only be defined on case-specific situations, based on the specifications of each aerodrome's location, e.g. topography, or type of a proposed structure (Transport Canada, 2013). Some general protection criteria, based on the regulations applying to Canada, are the following (FAA, 2000; Transport Canada, 2013):

- Height restrictions within a specific buffer zone around a radar site.

- Restriction of building height of large structures, by reference to excess from the radar horizon. Large structures are defined based on their azimuth.
- Forbidding of reflecting objects, around a zone served by a Precision Approach Radar System.
- Restrictions regarding the building of constructions that block the line-of-sight from specific types of radar antennas to any runway, taxiway, intersection, etc. Restrictions may also be imposed by reference to objects' slope ratio.
- Restrictions regarding steel towers, power lines, metal buildings, etc., based on the value of the subtended vertical angle measured from the base of specific types of antennas, within a zone around NDBs.
- Restrictions based on ground levelling and surface roughness.

Other types of obstructions with volumetric characteristics related to aviation are the following (Transport Canada, 2013):

- Bird hazard zones.
- Aircraft noise.
- Visibility restrictions
- Wind turbines and wind farms (which impact on airplanes' communication systems).
- Plumes deriving from industrial facilities.
- Impact of solar array installations (in form of (i) glare to pilots to Air Traffic Control staff, (ii) Interference with electronic navigational aids (iii) Penetration through transitional or approach/departure surfaces, (iv) Thermal plumes from the central tower of concentrated solar power installations).

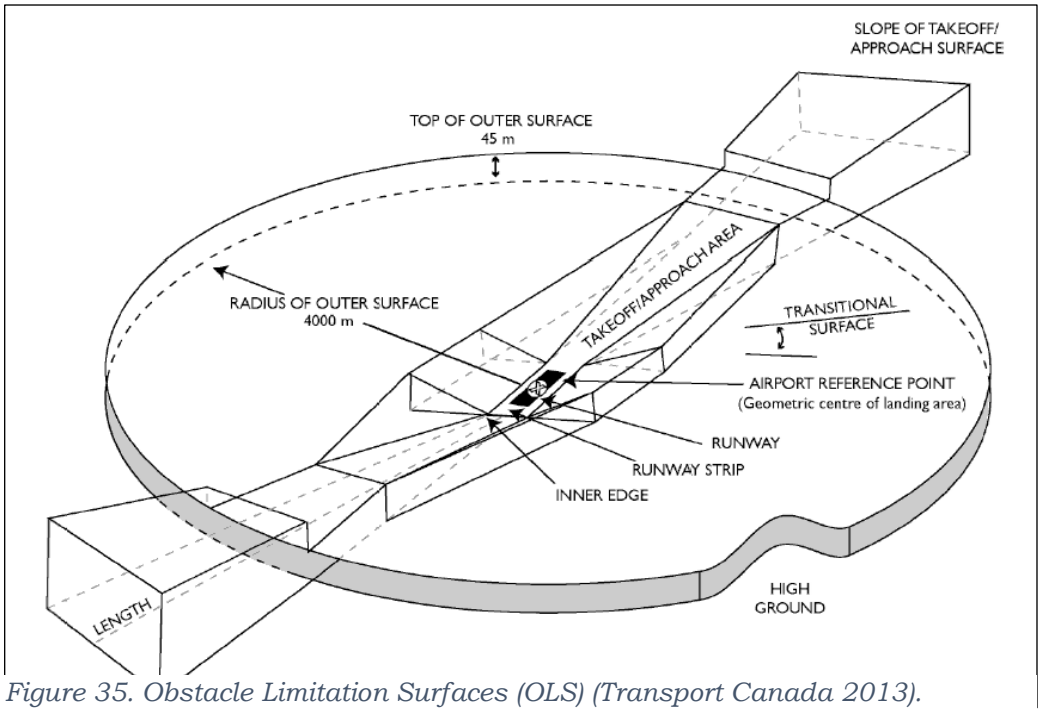


Figure 35. Obstacle Limitation Surfaces (OLS) (Transport Canada 2013).

ICAO Doc 9881 (ICAO, 2004) defines terrain and obstacle attributes to be recorded using 3D characteristics. ICAO provides a variety of eTOD GIS prototypes as well as 3D Obstacle Identification Surfaces using various visualisation tools[85] (an example of a 3D model of eTOD in 3D pdf format is presented in Figure 36). Within the same context, research also focuses on exploiting GIS capabilities with 3D modelling techniques, in order to visualise in 3D the geometries of obstacle limitation surfaces, and relative volumes where obstacle restrictions apply (e.g. S. Chang, 2016; Jadayel & Ibrahim, 2006; Qiao et al., 2016), while specific software has been developed to generate 3D obstacle limitation, or clearance surfaces (e.g. Transoft Solutions SkySafe, ESRI ArcGIS, SIMTRA Obstacle Surface Planner, ASAP PHX, ASD Aerodrome Surface Modeler (ASM)).

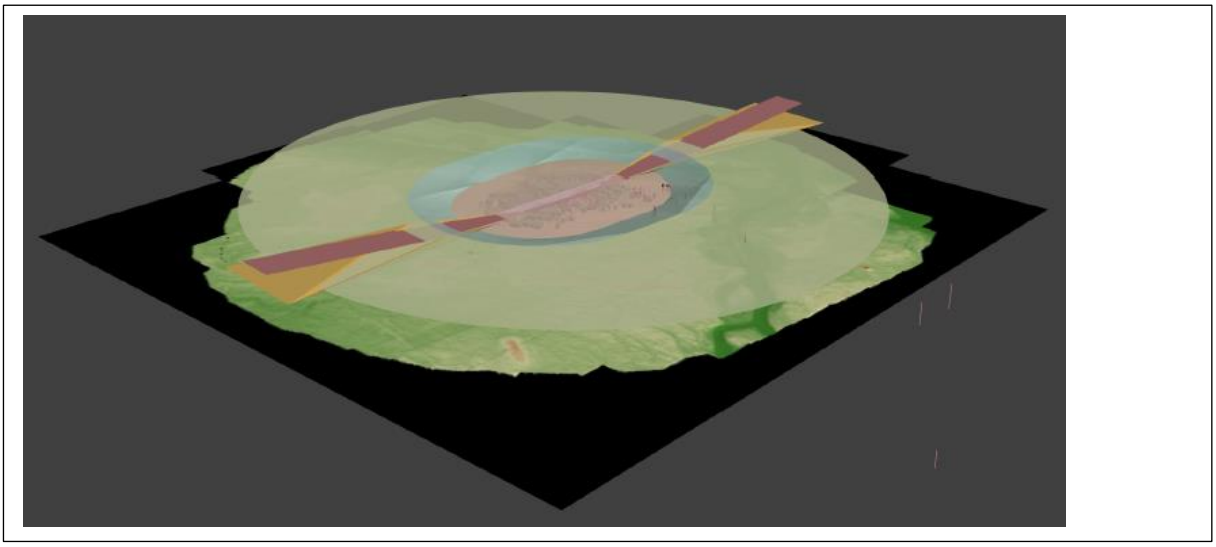


Figure 36. 3D eTOD Obstruction Identification Surfaces in 3D pdf (ICAO GIS portal, 2018).

As it can be concluded from the above, there is a variety of restrictions regarding aerodromes and constructions in their vicinity that apply to 3D space. Therefore, they can be used within a 3D Cadastre context, both during the urban planning/design stage of a development in the proximity of an aerodrome, and vice versa, as regulatory interventions regarding constructions impeding development or expansion of an aerodrome.

5.6.4.2 Flight restrictions

This subsection discusses the 3D characteristics of flight restrictions, at national level, which apply to civil aviation purposes. Issues such as the delineation of national airspace, or flight restrictions applying due to military operations do not fall within the focus of this subsection and are not discussed.

Until the early 2000s, flight restrictions referred to the definition of temporary or permanent no-flight zones, almost exclusively applying to manned air-vehicles, such as propeller aircrafts or jets. Such restrictions are defined by their coordinates, e.g. Easting/Northing, and their vertical extent, by reference to the mean sea level (MSL). However, the growing use of unmanned air-vehicles (UAV[86]) for commercial purposes

[85] For more information on ICAO's efforts on 3D electronic terrain and obstacle databases (eTOD), please refer to http://gis.icao.int/icaoetod/ .

[86] ICAO (2015), further distinguishes UAVs in (i) Remotely Piloted Aircrafts (RPA), which are piloted from a remote pilot station, (ii) autonomous aircrafts, which do not allow pilot intervention in the management of the flight, and (iii) model aircrafts, which are used for recreational purposes.

during the last decade, has introduced a number of UAV-related restrictions. Although of similar characteristics (both manned and UAV flight restrictions are defined by their horizontal coordinates and height level), the latter introduce significant effects on land use, due to their relatively lower flight height, affordability and increasing operational capabilities. This, induces issues of privacy, data protection and public safety (Finn, Wright, Jacques, & De Hert, 2014; Stöcker, Bennett, Nex, Gerke, & Zevenbergen, 2017), which require to be regulated. For example, restricted UAV flight zones need to be defined, for the protection of aerial powerlines, or definition of safety zones around people in public areas.

According to literature, the following flight restrictions are most commonly imposed[87] (FAA, 2000; FAA Guide to Low-Flying Aircraft, 2008; ICAO, 2015; Secretary of State for Transport (UK), 2007; Stöcker et al., 2017):

- Definition of minimum low-flying height, depending on the type of overflying area and its population. Usually, minimum aircraft-flight height, constitutes the maximum height allowed for UAV flights.
- Definition of minimum vertical distance between flight zone and the highest obstacle within an area.
- Flight conditions based on UAV's weight.
- Restrictions based on visibility conditions and visual contact with a UAV during its navigation.

The variety of PLRs applying to UAVs cannot be totally incorporated within 3D cadastral systems, as there is a significant number of regulations which depend on variable conditions such as public assemblies, hunt areas, areas where emergency operations take place, etc. (Dimitrios Kitsakis & Dimopoulou, 2016). This may introduce ambiguities, for example defining congested areas, so that corresponding flight restrictions are imposed (Stöcker et al., 2017).

5.6.5 Urban Planning and Construction Regulations

Urban planning and construction regulations also impose 3D restrictions on real property. Billen & Zlatanova (2003), identify the impact of geographical phenomena on land ownership, along with 3D segmentation of space and 3D spatial analysis as applications of 3D modelling to 3D Cadastre. Urban planning and construction regulations are imposed by different legal instruments, issued by different administrative bodies, in accordance with each country's administrative organisation. The different approaches regarding the nature of limitations on land exploitation and their impact on land owner needs also to be taken into account. Civil Law jurisdictions, especially in Europe, do not regard urban planning limitations on vertical land exploitation to be subject to compensation to the affected landowners (supported by stipulations of national Civil Codes stipulating that ownership is subject to limitations established by the law). On the other hand, Common law jurisdictions, especially in the United States, regard severe building height restrictions deriving from zoning regulations, to be a form of land

[87] This section does neither focus on presenting an exhaustive list of flight restrictions, nor on potential differences regarding similar statutes (e.g. different types of classification, or restrictions applying to different height levels). Its purpose is to merely present the general concepts of applying flight restrictions. For a comparative analysis focusing on UAV regulations at international level, please refer to (Stöcker et al., 2017).

expropriation thus requiring to be compensated (Renard, 2007). These different approaches not only depict the different ways that urban planning restrictions are conceived within different jurisdictions, but familiarisation of Common Law jurisdictions with the stratification of real property as well.

In this section, 3D restrictions deriving from urban planning and construction regulations are presented. Presentation of an exhaustive list of the different legal instruments, their variations, or responsible authorities does not fall within the scope of this work and is not discussed.

5.6.5.1 Urban Planning

Urban planning derived PLRs regulate a significant number of fields including land use, major infrastructure and development, implementation of special economic policies, transport, education, energy consumption, public investments, environment and traditional architecture preservation. Implementation of such policies depends on each country's legal and administrative framework. Newman & Thornley (1996), examine the factors influencing urban planning in European cities, tracing major legal and administrative differences which are mitigated by EU initiatives towards decentralisation and regionalism.

Depending on national and regional initiatives on urban development, different urban planning regulations apply, which impact on society, environment and other policies, e.g. pollution, carbon emission, land use change, and effects on environment caused by energy production and consumption (B. (Bob) Singh, Roy, Spiess, & Venkatesh, 2015). The most significant effect of urban planning regulations on land, with 3D impacts, is zoning (Dinic & Mitkovic, 2011). Zoning regulations define regions where different pollution, health and land use requirements apply, thus determining volumes of space that can be exploited and the type of their exploitation, as well as setting volumetric or height restrictions to protect or mitigate pollution.

The "Guidelines for new development in the proximity to railway operations" in Canada, stipulate mitigation measures for new structures in the proximity of railway corridors (Figure 37) regulating safety, noise, vibration and trespass issues. Similar regulations are also stipulated to New South Wales "Development Near Rail Corridors and Busy Roads – Interim Guideline" (2008). The same guide provides for vibration and excavation measures in the proximity of rail corridors and roads to prevent structures' subsidence and deterioration as well as to ensure soil stability.

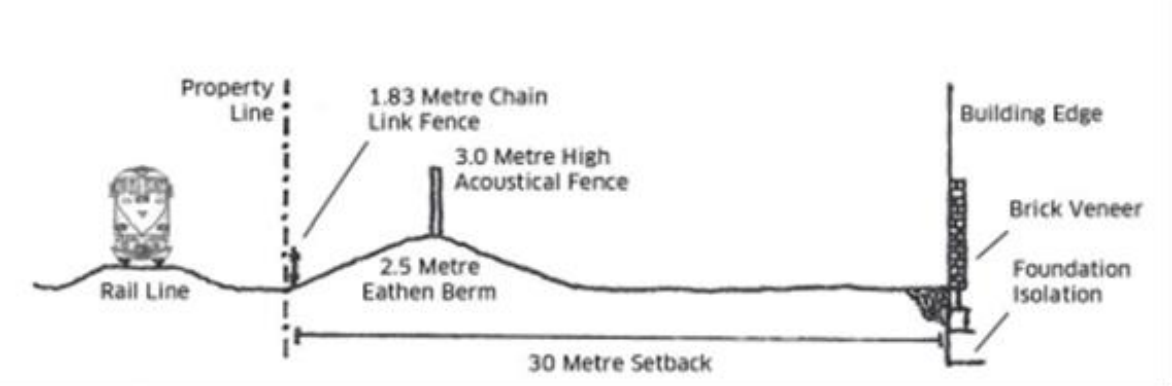


Figure 37. Mitigation measures for developments in the proximity of railway (Railway Association of Canada and Federation of Canadian Municipalities 2013).

Emissions include air pollution, noise, vibration, light, heat, radiation and similar effects on the environment affecting humans, animals, plants, soil, water, atmosphere, cultural objects and material goods (German Federal Immission Control Act, 2002 according to (UNEP, 2016)). Each of the above mentioned emissions includes 3D aspects although at different level, which can be used to define emissions falling into the field of 3D PLR Cadastre.

EU Directive 2002/49 already provides for compilation of noise maps and strategic noise maps (Art. 4) while Annex I defining noise indicators stipulates specific heights for noise indication measurements. Given its 3D propagation, noise regulations can be more efficiently managed through 3D representation (Givord, 2012). 3D data, such as building heights, noise barriers and topography are taken into account for noise calculation; however, in most cases 2D noise maps are compiled, that do not allow insight to the 3D aspects of noise (Jantien Stoter et al., 2008). To this aim, research towards generation of 3D noise maps is conducted, including 3D noise maps of the cities of Paris (Butler, 2004), Delft (Jantien Stoter et al., 2008) and Hong Kong (Law et al., 2004). CityGML Noise Application Domain Extension (ADE) has been developed to allow for 3D noise mapping along with exploitation of topological and semantic features provided by CityGML, e.g. application for noise mapping in North Rheine-Westphalia (Czerwinski et al., 2007). Public Law also regulates issues related to radio waves propagation to ensure efficient communication and broadcasting as well as protect public health and natural environment from extended exposure to electromagnetic fields. Public exposure to electric and magnetic fields and installation of antennas (for radio communication and broadcasting) are regulated through imposing restrictions to their distance from specific sites, frequency range and antenna tower heights.

Regulations on buildings' height for visibility purposes also constitute an urban planning derived PLR. There are various restrictions applying within urban landscape in order to protect landmarks and their visibility, e.g. London View Management Framework (Greater London Authority, 2012).

It can be concluded from the above, that urban planning regulations do not constitute individual regulations, but derive from environmental or other components, e.g. soil, air, noise, vibration pollution or civil aviation, that apply on urban environment. Therefore, similar mitigation measures as those mentioned in previous sections apply, adjusted to the specifications of urban environment.

5.6.5.2 Construction regulations

3D PLRs also include construction regulations. Specifically, construction regulations stipulate allowed building height, based on building's intended use, location and area of the surface parcel, thus defining permitted building volumes. Given the need of reducing energy consumption, building codes also define regulations regarding buildings' lighting, ventilation and solar exposure which pertain 3D aspects and are influenced by surrounding buildings and constructions on 3D space, e.g. shadow casting of a building to its neighbouring buildings. Such regulations, combined with the energy requirements of already built constructions can be used to export building energy demands in urban areas, which can be further exploited within urban planning regulations.

Additionally, for the protection of urban landscape, specific building regulations apply, for example to protect traditional architectural characteristics of buildings, e.g. facades, or to protect the architectural character of a neighbourhood.

Construction regulations with 3D characteristics, can be summarised to the following (Branco, Meijer, & Visscher, 2010; DEWLP, n.d.; Dinic & Mitkovic, 2011; International Code Council, 2011; Dimitrios Kitsakis et al., 2019; Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2016):

- Built surface ratio. Built surface ratio (in some jurisdictions the terms floor area ratio or built-up area co-efficient is used), defines the permitted building surface in an area. The volume of permitted building surface is further defined by the maximum building height and the building coverage ratio[88].
- Maximum building height. Maximum building height sets the highest level of a construction, and it is of twofold 3D impact. On the one hand, it sets the upper limit of a land parcel's exploitation (during design stage), while, on the other hand, it sets height or volumetric limits on other PLRs with 3D characteristics. Representative examples include the definition of minimum flight height, based on the distance between an air vehicle and the highest obstacle in case of aviation, or the definition of volumetric zones around aerial utilities.
- Building volume coefficient, which defines the maximum volume within a land parcel that is allowed to be covered by a construction.
- Building coverage ratio defines the area of a land parcel that can be covered by a construction. Therefore, it directly affects the height, the volume and the shape of an intended structure.
- Transfer of built surface ratio (in some jurisdictions also known as transfer of development rights), that allows transferring of non-depleted built surface to another land parcel.
- Impact on significant views, sight-lines or landscapes.
- Impact on cultural heritage or architectural characteristics of the neighbouring area.
- Buildings' lighting, ventilation and solar exposure.

5.6.6 Utilities

Utilities constitute, as well, a common case of overlapping rights in 3D space. 3D related utilities include aerial or underground networks, or other major infrastructures, such as underground subway lines, tunnels, pipelines or underground storage volumes. Volumetric restrictions around utilities may also need to be established for safety purposes; for example, restrictions applying to constructions' depth in case of land parcels situated above an underground pipeline. Conversely, similar restrictions may be imposed based on the potential impact of a planned underground construction to surface parcels and their elements; for example, the impact of vibration deriving from the construction and the operation of

[88] Setback distance among neighbouring buildings, or façade setback requirements above a specific building height may also be considered to affect the shape of a building volume.

an underground subway line, to the foundations of the buildings on its overlying land parcels.

Inclination towards vertical space exploitation, especially the underground, for utility purposes is evident in literature. Bobylev (2016), emphasises on urban underground space and its contribution to urban sustainability, resilience, climate change adaptation and mitigation, as well as progress towards smart, liveable, and compact cities. However, literature provides numerous examples of utilities above or below ground, traced in rural environment (e.g. (Grøv & Lu, 2011; Dimitrios Kitsakis & Dimopoulou, 2016, 2018; Takasaki, Chikahisa, & Yuasa, 2000). Masuda (2004), propose the exploitation of Tokyo's underground space, to promote city's urban renewal. In Finland, Helsinki has already developed an underground master plan (UMP) (Vähäaho, 2012), while plans of underground space exploitation are also in progress regarding other Finnish cities, such as Tampere and Oulu (Vähäaho, 2014). (Farah Zaini, Khadijah Hussin, 2014), compile a variety of cases of underground utilities from around the world, including underground subway lines, drainage and sewerage systems and tunnels.

In order to be in line with the Roman principles on land ownership, the required space for the deployment of utilities is usually provided, by statute, to the agencies that are responsible for the operation of each utility through land expropriation, establishment of utility servitudes (easements), or rights of way. Exceptions can be traced in jurisdictions where delimitation of the vertical extent of individual land exploitation is stipulated in legislation[89] (e.g. Malaysia, Singapore, Japan, Victoria), or in jurisdictions with statutory 3D real property units' legislation. In the former case, the minimum depth of land exploitation by surface parcel owners is set, leaving the rest of the underground space vested in the state; in the latter case, 3D volumes can be "carved out" of the 3D parcel volumes, where a utility is planned to be installed. In case of infrastructures situated on public-owned land, a potential limitation is that there is no need of establishing limited, or other, real property rights, therefore the legal space of an infrastructure crossing public land is not visible in the cadastre (Döner et al., 2010, 2011; Jantien Stoter, Sørensen, & Bodum, 2004). Besides, exploitation of indirect ownership or granted user rights is not always optimal and may introduce certain disadvantages, while such rights may not be suitable for such purpose (Karabin et al., 2018). Among aforementioned disadvantages is the missing visibility of rights that apply to different height levels, by different rightholders, including PLRs, which significantly impact on land value (Twaroch & Navratil, 2016). Division into 3D property units allows separation of multi-level activities with independent ownership for each one, allowing different right volumes to be mortgaged and used as collateral (Karabin et al., 2018).

Common 3D restrictions related to the establishment and operation of aerial and underground public utilities, based on literature, are the following (Dimitrios Kitsakis & Dimopoulou, 2016, 2017a; Jantien Stoter et al., 2004; Tveiten & Grepstad, 2015):

- Depth restrictions on the exploitation of surface parcels, depending on underground infrastructures' depth. Restrictions may relate to surcharge

[89] In Finland, although legislation does not explicitly define an upper or lower limit of to the extent of ownership right, interpretation of its lower extent sets a depth limitation of six metres for individual private owners (Farah Zaini, Hussin, Suratman, & Abd Rasid, 2013).

loads, excavations, pipelines and stores of combustible liquids and equipotential bounding.

- Building restrictions (height or depth limitations along network's centreline).
- Cultivation restrictions (forbidding of cultivation activities, or allow cultivation types that root down to specific depth).
- Volumetric restrictions along aerial powerlines both for powerlines' protection and to reduce radiation impacts.
- Establishment of a volumetric safety zone around utility networks to avoid damage in case of crossing networks.

It is noted that PLRs related to networks and utilities are also related to the environmental characteristics of the area where a network or utility is intended to be installed and may impact above mentioned restrictions. For example, construction of a utility on soil vulnerable to liquefaction, may affect the allowed weight or the depth of constructions on the above-lying land parcels.

5.6.7 Cultural Heritage

Stratified RRRs may also derive from legislation on the protection of cultural heritage. Cultural heritage is a collective term that encompasses archaeological sites, monuments and intangible cultural heritage[90]. Therefore, a significant number of regions are considered to be of cultural heritage interest and fall within protection regulations. Cultural heritage sites may refer to marine or terrestrial antiquities, while the latter can be traced on the ground (e.g. historical sites or monuments), or may be buried below the ground. In both cases, protection measures are stipulated in legislation, either to preserve antiquities, or to assess and mitigate the impact of planned structures and developments on the landscape, the character or the view of a region where a monument, landmark, or historical site is situated. In this work, no reference will be made on marine antiquities and relative PLRs, as they need to be examined separately within the field of Marine Cadastre. Depending on each historical period, heritage remains vary, from earthworks (for example, burial mounds, hillforts and field banks), to buildings (e.g. buildings, canals, bridges and roads), or artefacts (Braithwaite, Hopkins, & Grover, 2005). Underground archaeological treasures are in many cases combined with surface cultural and archaeological sites (e.g. Greece), as shown in (Papageorgiou, 2015), or are exploited for tourist, underground parking, or recreational purposes. (Reynolds & Reynold, 2015), present characteristic cases of the development of underground spaces' exploitation in London and New York, while (de Stefano, di Pinto, & Gerundo, 2015), display similar cases applying to the ancient caverns below the city of Naples, dating from the Greek and Roman period.

Cultural heritage objects are strongly related to their location, reflecting their integration with local environment specifications, emanating their distinctive character and "spirit". To this aim, it is preferred by the responsible authorities that

[90] Terminology defining cultural heritage and its components is defined in several documents and by different organisations, at national and international level. Although a common sense of the scope of heritage and its components has been internationally agreed, there are still differences among national connotations of the finer terminology of "heritage" (Ahmad, 2006). For more details on international documentation defining "heritage" and its development please refer to (Ahmad, 2006) and (Vecco, 2010).

archaeological and other cultural heritage resources are not removed from their location. This also accords with the prevalent philosophy on preservation of underground archaeological resources, which opts for leaving archaeological resources intact to be exploited by future generations, with more efficient and safer methods (Marriott, 1997). Consequently, the solution of establishing buffer zones around cultural heritage, on which protection restrictions apply is encouraged. Operational Guidelines for the Implementation of the World Heritage Convention explicitly provide for the establishment of buffer zones in case of World Heritage properties (UNESCO, 2017). Within this context, a buffer zone is defined as "*an area surrounding the nominated property which has complementary legal and/or customary restrictions placed on its use and development to give an added layer of protection to the property. This should include the immediate setting of the nominated property, important views and other areas or attributes that are functionally important as a support to the property and its protection. The area constituting the buffer zone should be determined in each case through appropriate mechanisms. Details on the size, characteristics and authorized uses of a buffer zone, as well as a map indicating the precise boundaries of the property and its buffer zone, should be provided in the nomination.*" (UNESCO, 2017 art. 104). Although buffer zone is not explicitly defined in 3D in this definition, its volumetric character is inferred, either through the reference on 3D characteristics, such as views, or by the stipulation of other areas or attributes that are functionally important to the support and protection of heritage sites. Stipulations on establishment of, horizontally delimited, heritage protection buffer zones, can be traced in legislation of several jurisdictions (among others, Greece, United States, United Kingdom, Romania, Norway, Sweden, Denmark and Slovenia). Buffer zones do not set a volumetric protection zone around a site; instead, they are defined as radial distances around the site, where specific restrictions or regulations apply. However, separate volumetric restrictions are imposed on land by specific legislation, especially in case of underground antiquities; for example, Athens' subway line in Greece, was developed at depth starting from 15 metres below the earth's surface (Papageorgiou, 2015), to protect above lying layers of archaeological interest. Therefore, two stratified volumes are created: a volume where construction is restricted due to the existence of underground antiquities, and a second volume where construction of the subway line is developed. A third volume may also occur in case of construction of underground utility networks, constructed, approximately, at one metre depth below the ground surface. Similar examples can be traced wherever underground antiquities exist, which need to be preserved in situ[91].

Cultural heritage PLRs do not constitute individual cadastral entities and do not have individual spatial extent. Restrictions are usually not recorded to cadastral registers, or a notification of the restriction may be registered to the involved land parcels. Cultural heritage sites are in most cases registered to themed cadastres, e.g. archaeological cadastres, presenting in 2D the extent of heritage areas, or point representations of monuments and landmarks. Archaeologically sensitive areas may also be presented in 2D maps, while reference to the type or the vertical extent of each restriction is available only by reference to the legal document imposing such restriction. Even in this case, most archaeological repositories emphasise on the heritage objects, rather than on the restrictions imposed on real property (Dimitrios

[91] Preservation *in situ* means that an archaeological site requires to be left undisturbed (Braithwaite et al., 2005)

Kitsakis & Dimopoulou, 2016). Characteristic examples of archaeological cadastres' maps globally, are presented in figures 38 (a-e).

Figure 38. (a) New York City Landmarks Preservation Commission (New York City (LPC), 2018), (b) New York Cultural Resource Information System (New York State, 2018), (c) Historic England (Historic England, 2018), (d) extract of archaeological zones and listed buildings map (Canton of Zurich) (Canton of Zurich, 2018), (e) extract from the Cultural Heritage map of Estonian Land Board Geoportal (Estonian Land Board Geoportal, 2018)

Common cultural heritage-related restrictions with vertical connotation, traced in literature (Australian Heritage Commission, 2009; Bourdillion, Braithwaite, Hopkins, & France, 1995; Braithwaite et al., 2005; Draye, 2008; Dimitrios Kitsakis & Dimopoulou, 2016) follow:

- Delimitation of buffer zones and implementation of appropriate zoning and planning regulations.
- Easements and other similar rights over land in the vicinity of an ancient monument.
- Agreements concerning ancient monuments and land in their vicinity.
- Land parcel expropriation.
- Restrictions in real estate property uses concerning those that may destroy or harm the monument directly, or indirectly, as well as restrictions on mineral exploitation, and extraction, establishment of telecommunication equipment, industrial and commercial installations and constructions in the vicinity of monuments.
- Restrictions in constructing new buildings, alteration, restoration and use.
- Preservation of cultural heritage objects in situ by (i) rerouting of planned developments, (ii) integration of cultural heritage object to the design of a planned development as an open or recreational space, (iii) agreeable level of cultural heritage object's destruction.
- Vertically circumvent cultural heritage objects by constructing a planned development at a deeper or lower level.

6 Critical Analysis

Examination of the legal issues on 3D Cadastre as described in Chapter 5, depicts the variety of different approaches on stratifying real property, as well as the main characteristics of the legal instruments that are employed to stratify real property, in accordance with the rule of accession, deriving from the principles of Roman law. This section elaborates on the findings of Chapter 5, by comparing different solutions, and identifying their possibilities and limitations as regarding to real property stratification. The section is structured in six subsections, each one focusing on the aspects examined in subsections 5.2-5.6.

6.1 Definition of land

Investigation of the definition of land falls within the interest of 3D Cadastre research as it determines the content of land. Therefore, specific spaces or objects that are excluded from its definition, could provide for a preliminary way of land stratification.

Chapter 5.2 examined stipulations defining immovable, land, real estate or real estate property on national Civil Codes, Land Codes and Cadastral Laws. Immovable or immovable property is the most common term used among the examined stipulations; Polish and Czech Civil Codes refer to real estate, while Swedish Land Code uses the term real property. Immovables consist of land and constructions that are lying on it. Rights on land, as well as mines or quarries are also included in several of the definitions used. Land definitions in Swiss, German, Russian and Louisiana's Civil Code refer to "*parcels on land*", "*plot of land*", "*land plots*" and "*tracts of land*" respectively. Such reference is directly related to land parcellation under means of subdividing abstract land into definite units. Buildings, facilities and constructions are also included in land definition, provided that they are of permanent nature. This is indicated through different stipulations including "*buildings thereon* [land parcels]", stipulations specifically referring to buildings that "*are permanently attached to the land*", or "*connected with ground by a firm foundation*", or others that refer to constructions[92] "*joined to the ground*", "*of permanent nature*" or "*for permanent use*". The Russian Civil Code uses the broader definition including, along with land plots and land plots with mineral deposits, "*everything else closely connected with the land*". This stipulation leaves some, limited, room for interpretation. When it comes to buildings, Dutch Civil Code, Civil Code of Louisiana, Polish Civil Code and Swedish Land Code relate land and building ownership, allowing for separate ownership, under specific provisions, of land and buildings.

In Common Law jurisdictions, depending on each law, different definitions of land exist, while more detailed descriptions are used. This provides more flexibility concerning land management as land is defined within the context of a law that regulates a specific situation. On the other hand, different stipulations may become elusive, especially for the public. In most of the examined definitions land includes "*messuages, tenements and hereditaments, corporeal and incorporeal, of any tenure or description*" and "*every estate or interest therein*". Specific components such as paths, passages, ways, watercourses, liberties, privileges, easements, mines minerals and quarries are also included within land definitions. In New South Wales,

[92] Apart from "constructions" reference may also be made in "things", "constructions of all kinds", "utilities", "fences and other facilities".

Alberta and Manitoba land definitions provide that any of these components can be "*specially excepted*".

Condominium Act of Florida clearly stipulates that land may constitute of airspace or subsurface volumes, under condition that such spaces lie within legally identifiable elevation, separate from surface parcels.

Singaporean legislation relates land with airspace and subterranean space that can be reasonably necessary for the proprietor's use and enjoyment, leaving room for distinction of the remaining airspace and subterranean spaces. State Lands Act, defines an explicit depth limit as regards to use and enjoyment of subsurface space. Buildings and things attached to the earth or permanently fastened to anything attached to the earth, as well as estates and interests are considered as land components, regardless if they are held separately from land surface.

Regardless of jurisdiction, the right of ownership is acknowledged as the strongest right that can be imposed on a real property. The restrictions imposed on the right of ownership emphasise on securing community living among the right holders and the duties of the owners against the state. In terms of real property stratification in relation to the right of ownership, the following should be noted:

- Given the content of the right of ownership, legal stipulations cannot prevent stratification of real property in case that there is no conflict with third-parties' rights and statutory legislation is not infringed. Assuming that third-party rights include servitudes (or easements), mortgages and obligational rights, while legal restrictions include Public and Private Law restrictions, a real property where neither limited rights or encumbrances are established, nor legal restrictions apply, can be considered that it is allowed to be subdivided to volumes. Besides, the right of ownership provides its holder the capacity to dispose the real property as he sees fit. Subdivision and disposal of a volume of real property falls within this capacity. Stipulation defining the vertical extent of real property (refer to section 5.3.1) only limits the space within which an owner may exercise his power on a parcel, not the content of such power. However, this does not comply with everyday practice, especially in case of Civil Law jurisdictions. Therefore, limitations need to be identified and addressed through legal amendments, case law, or different interpretation of law.
- Considering third-party rights, impacts of real property stratification can be distinguished in those on the rights of neighbouring land parcels, and on parties holding limited rights on a land parcel that is to be stratified. As far as the former are concerned, the same restrictions as in case of a non-stratified land parcels need to apply to each of the stratified real properties. For example, restrictions deriving from the Law of Neighbours would still bind stratified real property. In case of limited rights of third parties on a land parcel, these can be classified based on their establishment, prior or after real property stratification. In the former case (where limited rights are established before real property stratification), third parties' rights are not affected; according to the time precedence, their rights shall encumber newly created stratified real properties. In the latter case (where limited rights are established after the stratification of real property), existing regulations on the

establishment of limited real rights could apply individually to the stratified real property units, taking into account their vertical extent.

- Coming to the relation between real property stratification and statutory legislation, it seems that the greatest impediment has to do with the stipulations defining real property to include buildings and structures erected on land for permanent use. However, this entitles real property owners to dispose parts (volumes) of their real property since everything permanently situated on land is included within surface parcel's ownership. Similarly applies in case of Public Law Restrictions (PLRs), since stratification of real property would not release stratified volumes from imposed restrictions applying to horizontal plane. Therefore, if only a specific part, or volume of land needs to be protected by a restriction, such restriction encumbers the whole land parcel, instead of such parcel part, or volume.

6.2 Land parcels and 3D cadastral objects

6.2.1 Land parcel

Land parcel and its equivalents, is defined in different laws in each jurisdiction. There are also jurisdictions where different laws provide different definitions of land parcel, to reflect parcel's meaning based on the purpose of each law. The laws defining land parcels can be grouped in the categories presented in Table 7. Civil Law jurisdictions examined, define land parcels in Land and Cadastral laws. Common and Common Law based jurisdictions involve legislation on land titles, tax and valuation, law of property, and laws on land subdivision into buildings and cubic spaces.

Table 7. Classification of laws defining land parcels.

Categories of laws defining land parcels	Other laws and subordinate legislation	Civil Law/ Civil Law based jurisdictions	Common Law/ Common Law based jurisdictions
Land Code	-	Sweden	Malaysia
	Land Law	-	Israel
Cadastral Law	-	Argentina, the Netherlands Norway, Poland, Spain	-
	Technical Requirements on Cadastral Survey	Greece	-
	Federal Regulation on Land Registers	Switzerland	-
	Rules for Cadastral Survey	-	New Zealand
	Boundaries Confirmation Act	-	(Canada) New Brunswick
Land Title Act	-	-	(Canada) British Columbia, Australia (Queensland)
	Land Titles (Strata) Act	-	Singapore
	Land Tax Act	-	(Australia) Victoria

Tax and Valuation Laws	Land Valuation Act	-	(Australia) Queensland
Law of Property Act	-	-	(Canada) Alberta
Strata Schemes Development Act	-	-	(Australia) New South Wales

Examining land parcel definitions presented in section 5.2.1, it can be concluded that each of these focuses (i) on land parcels' physical characteristics as a delimited part of land; (ii) on their legal characteristics as a part of land where rights apply; (iii) on land parcels' administrative character as basic spatial entities recorded to cadastral maps (Fig. 39).

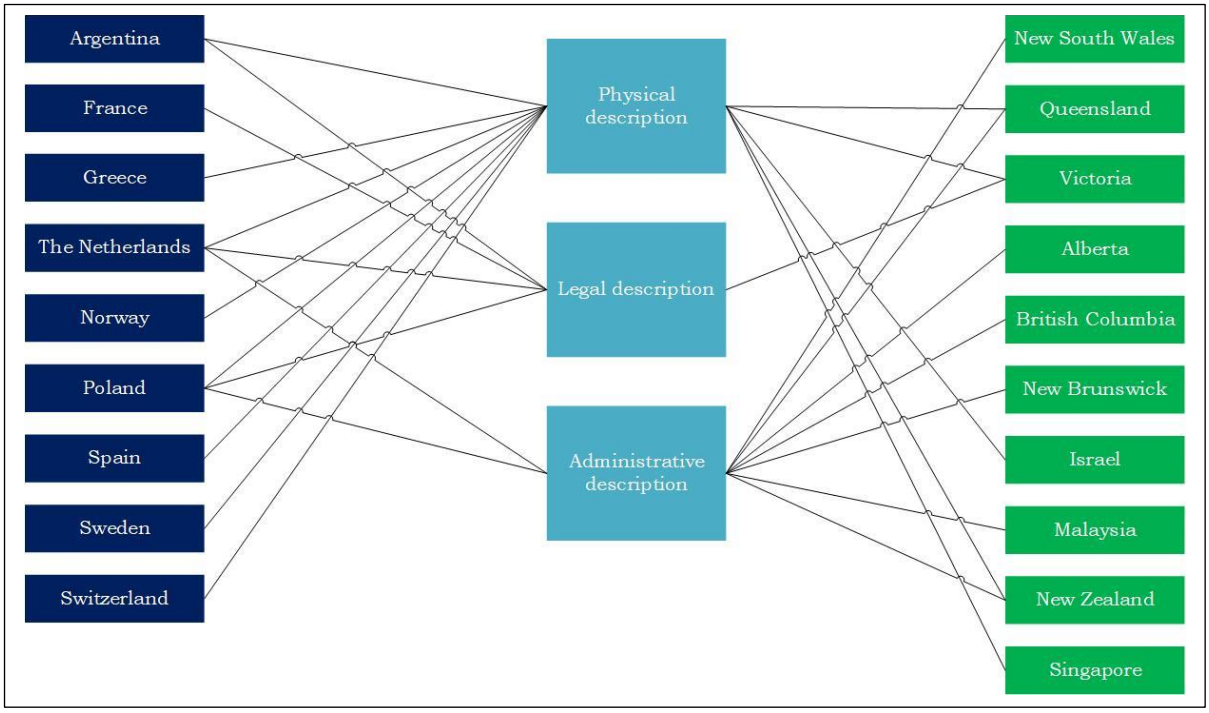


Figure 39. Description of land parcels' definition (blue: Civil Law/ Civil Law based jurisdictions, green: Common Law/ Common Law based jurisdictions).

This classification is in accordance with the classification of (Arvanitis, 2000) to the following generic types of definitions:

- Minimum individual part of the earth's surface that is separated from its neighbouring equivalent parts by physical or artificial boundaries (de facto definition).
- Minimum individual part of the earth's surface, against which unique real property rights apply and such rights are recorded in a cadastral system (de jure definition).
- Minimum individual part of the earth's surface that can be registered and presented to cadastral basemaps.

Based on the content of each definition, its basic characteristics can be summarised in the following:

- Continuity of the piece of land

- Unique identification
- Delimited boundaries[93]
- Homogeneity of rights applying to land
- Definition in a registered plan

Definitions of Civil Law based jurisdictions mostly focus on the spatial characteristics of land parcels (continuity and delimitation), while also referring to their ownership status. On the other hand, Common Law based jurisdictions emphasise on the unique character of land parcels and their definition or description on a registered document such as a plan or a certificate of title. Spatial reference on land parcels' definition does not involve their continuity, but their character as land divisions.

Definition of the vertical extent of land parcels is not clear neither in Civil nor in Common Law based jurisdictions. Swedish Land Code provides a broad definition that comprises both 2D and 3D real property units through the stipulation of horizontal or both horizontal and vertical land delimitation. Reference on the vertical extent of land parcels is made in the Cadastre Act of Norway, although without using specific delimitation; delimitation is made based on the extent of private land rights according to general rules. Despite that Swedish and Norwegian land parcel definitions do not explicitly set an upper or lower limit of land parcel ownership, they refer to vertical delimitation of land (Sweden) and on restrictions deriving from creation of 3D parcels (Norway), leaving room for vertical stratification of real property.

In Common Law based jurisdictions, lots in Singapore explicitly acquire 3D characteristics as they are defined as "stratum" units. New Zealand and New Brunswick definitions also recognise the 3D aspects of parcels as they explicitly refer to "air-space parcel" (New Brunswick) and "space" (New Zealand). Given that air-space parcel concept of New Brunswick does not refer to underground volumes, New Brunswick's parcels cannot be used in case of 3D real property units located under the earth's surface. Common Law jurisdictions relate parcels, under means of basic cadastral units, with subdivision into strata units which hold volumetric characteristics (e.g. New South Wales' lots, Queensland's volumetric and building parcels), thus facilitating land stratification.

6.2.2 3D real property units

Definition of 3D real property objects globally is significantly varying, in terms of terminology and of the number and the content of each type of 3D property objects. It is noted that 3D real property is in many cases related only to condominium or apartment ownership. This section does not examine such concepts as they are well established and operate efficiently for many years (Jenny Paulsson, 2007). Besides, 3D real property units cover a more extended field of applications, such as PLRs, cross-boundary infrastructures or non-material legal spaces, constituting individual real property units above or below surface parcels.

Classification of 3D real property units presents a high divergence among national approaches both in terms of terminological aspects and of the content of national 3D

[93] Despite the stipulations of delimited boundaries, apart from New Brunswick, Malaysia and Sweden there is no reference made on vertical or volumetric aspects of land parcels.

real property units. Table 8 summarises the terms used for 3D real property units and their content as defined in national legislation.

Table 8. Statutory established 3D real property units.

3D property units	Jurisdiction	Content
3D property unit 3D property space	Sweden	- A property unit which in its entirety is delimited both horizontally and vertically - A space included in a property unit other than a three-dimensional property unit and delimited both horizontally and vertically.
3D parcel	Norway	A building or structure, or a delimited physical volume for which planning and building permission has been granted, that has been subdivided as a separate property.
Air space parcel	New Brunswick	Volumetric parcel of air space, whether or not occupied in whole or in part by a building or other structure
	British Columbia Manitoba	Volumetric parcel, whether or not occupied in whole or in part by a building or other structure, shown as such in an air space plan
Standard parcel Building parcel Volumetric parcel Remainder parcel Restricted lot	Queensland	- parcels unlimited in height and depth - parcels defined by reference to floors, walls and ceilings - parcels fully limited by bounding surfaces remainder of a standard base parcel after subdivision of building or volumetric parcels - lot restricted by height or depth, either by reference to a defined distance or by defined planes
Stratum	Victoria	A part of land consisting of a space of any shape below, on, or above the surface of the land, or partly below and partly above the surface of the land, all the dimensions of which are limited
	Singapore	Any part of land consisting of a space of any shape below, on or above the surface of the land, or partly below and partly above the surface of the land, the dimensions of which are delineated
	Malaysia	A cubic layer of underground land
Stratum lot	New South Wales	A parcel restricted in height and/or depth
Strata space	Alberta	Volumetric space, whether it is (a) located below or above or below and above the surface of the land, or (b) occupied in whole or in part by any structure, and that is shown as strata space on a strata space plan
Unit	New Zealand	A part of the land consisting of a space of any shape situated below, on, or above the surface of the land, or partly in one such situation and partly in another or others, all the dimensions of which are limited, and that is designed for separate ownership

As presented in Table 8, one or more types of 3D real property units may be provided by national legislation, to accommodate different cases of real property stratification. In Australia, Queensland has developed a sophisticated approach including five different types of 3D real property units. Each of those focuses on specific types of real property development, while also leaves room for the establishment of 3D RRRs and PLRs on land. Similarities in the definition of Queensland's restricted lot with stratum lot concept of New South Wales needs to be noted. In Sweden, two different types of 3D property units have been established, to facilitate both 3D subdivision of real property and "carving" individual 3D spaces within traditional 2D parcels.

As regards to terminology and content of 3D real property concepts, differences are clear; the same term is used in different jurisdictions although with different content, or different terms are used to define 3D property units of similar, or of the same content. Classification of the terms used and their respective content is schematically presented in Figures 40-42.

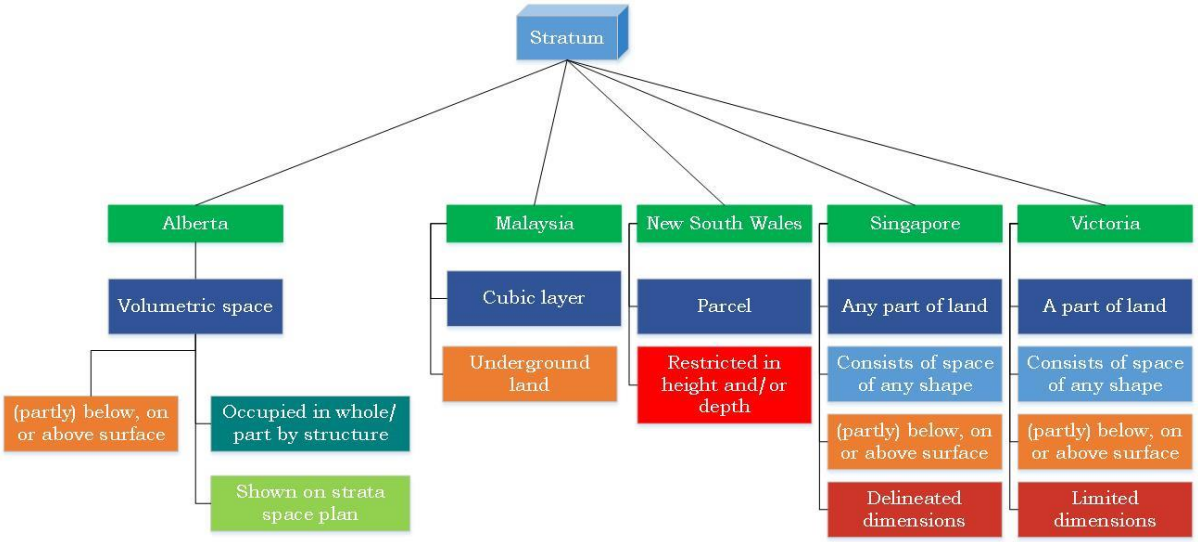


Figure 40. Jurisdictions where real property is stratified through "stratum" units and "stratum" content.

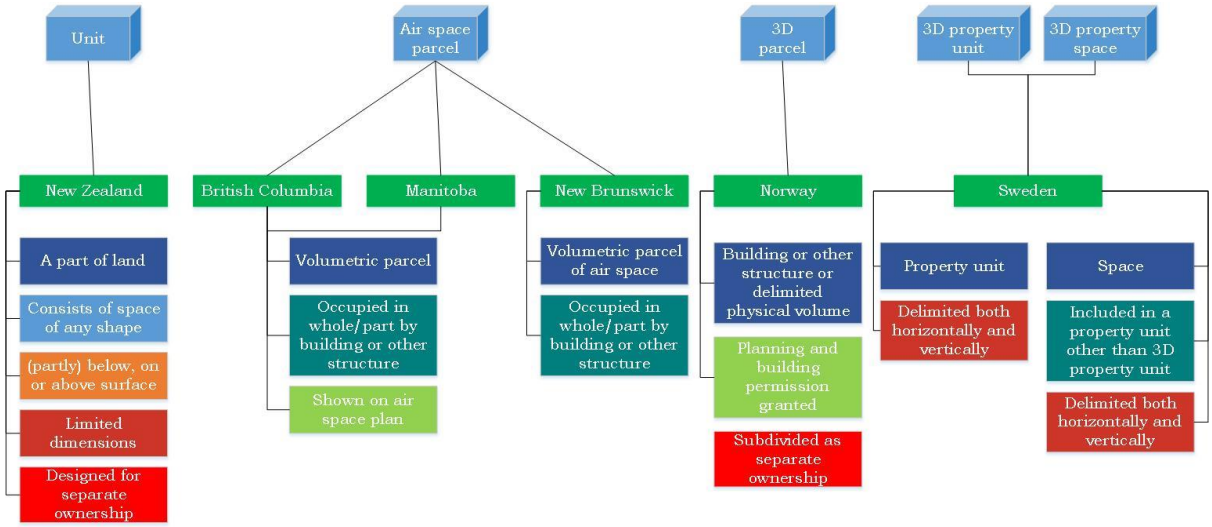


Figure 41. Types and content of 3D real property units internationally.

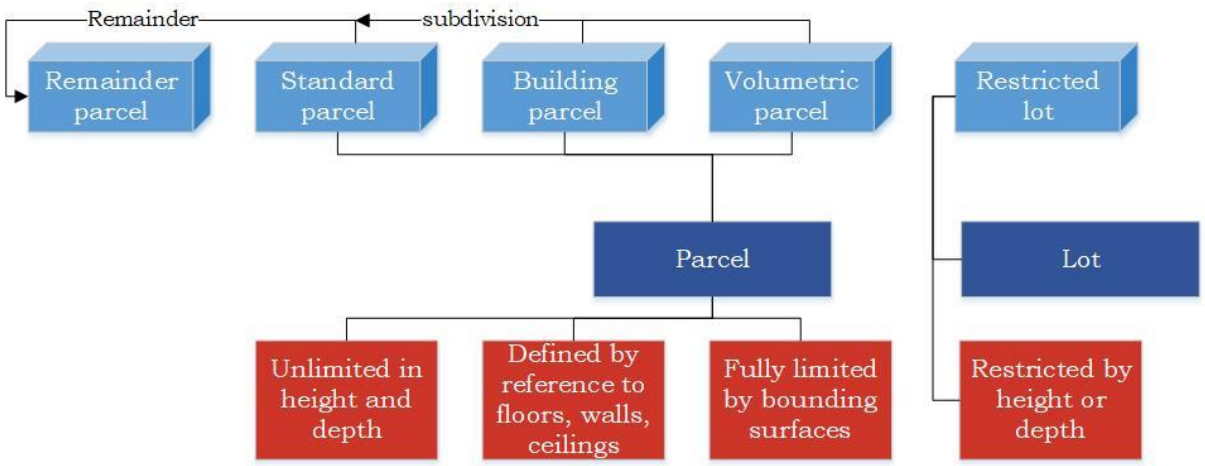


Figure 42. Types of 3D real property units in Queensland, Australia.

In Canada, 3D real property units share similar content. Air space parcels in New Brunswick are explicitly defined as volumetric parcels of air space, thus excluding subsurface units, while British Columbia and Manitoba do not explicitly refer to volumetric parcels of air space, although they require that air space parcels are shown as such on an air space plan. Strata space of Alberta explicitly includes volumes located either above or below land surface in a more comprehensive definition of 3D real property.

The state of Victoria in Australia, along with Singapore and New Zealand constitute a second group of 3D real property units with similar content, but, in case of New Zealand, different terminology. Both in Victorian and in Singaporean legislation stratum units consist of spaces of any shape below, on, above or partly below and partly above the surface of the land with limited (or delineated, in Singapore) dimensions. New Zealand legislation, uses a slightly different stipulation regarding the location of 3D real property units (situated below, on, or above the surface of the land, or partly in one such situation and partly in another or others), while also adding that such units are designed for separate ownership. The term unit is used in New Zealand's legislation, instead of Victoria's and Singapore's stratum.

In Malaysia, the concept of stratum is limited to underground cubic spaces. Definition of 3D real property units by reference to a broader concept that is not explicitly defined in legislation, cubic layer or cubic space, applies in Malaysia and New South Wales respectively.

6.3 Relation between 3D real property and surface property

Analysis in Chapter 5 distinguishes the following approaches on the relation between 3D real property units and traditional land parcels:

- Generic restrictions that mainly aim to secure that each of the involved real properties will not inhibit the operation of the other.
- Implied easements, so that 3D and traditional real property units serve their purpose even without formal registration of a statutory easement.
- Specialised provisions, where relation between 3D real property units and land parcels is regulated in detail.

Generic restrictions are established in Nordic countries' legislation as well as on the examined Canadian provinces. This approach seems to promote individual agreements between the beneficiaries of the involved 3D and traditional real property units, within a generic framework. Norwegian legislation mostly emphasises on restricting the rights of individual real property units in order to ensure that each real property unit is able to be exploited without being obstructed. Explicit reference that provisions on land may also apply to space is made on Swedish and Canadian provinces' legislation. However, the latter seem to emphasise on protection of the surface parcel, given the explicit reference that no easements or covenants are implied in favour of 3D real property units.

Provisions for implied easements can be considered as a means of securing flexibility regarding operation of 3D and traditional real properties, without requiring an agreement for establishment of statutory easements among the involved beneficiaries. Implied easements may apply for support (New South Wales), support and access of services (Queensland, Victoria, Singapore) or support and passage of services (New Zealand) purposes. Australian implied easements are in favour of lots and common property in a building. Implied easements in such cases are restricted to reasonable use and enjoyment of the dominant parcels. Legislation of New Zealand prefers a distinct terminology to describe implied easements, while also assigns them all ancillary rights and responsibilities to be effective. Singaporean legislation provides a detailed framework stipulating conditions ensuring the operation both of the dominant and the servient tenement.

Specialised regulations are not very common among the examined legislation. Only Malaysian National Land Code regulates in detail the relation between surface parcels and underground 3D real property units, or between 3D real property units on different depth levels, also providing for conditions of protection, support and access from underground land to surface land. Even in this case, there is no reference made on vertical or volumetric characteristics of 3D real property units. Conditions on depth of alienation or lease of underground land, as well as conditions for protection, support and access of 3D real property units are vested to be decided by State Authority.

6.4 Distinction between 3D objects and other real property rights

Section 5.5 presented the legal instruments used by national legislation to support community living and economic exploitation of immovable property, remaining in accord with the Roman principles on real property. To compare the characteristics of limited real property rights and 3D real property units, the 3D requirements that legislation should support were used, as defined by (Karki, 2013). However, such requirements operate within a generic legal framework, supporting registration and capturing of 3D cadastral objects. Therefore, they were adjusted to reflect the specifications of 2D-based, real property legal framework. Adjusted requirements examine (i) the stratification in multiple layers, (ii) whether created real property units can be further subject to limited real property rights, (iii) whether stratification requires to be for specific purposes, (iv) whether specific conditions apply for the exploitation of limited real property rights, (v) whether relation to physical object is required, (vi) whether stratified real property units need to be related to a surface parcel, and (vii) whether limited real property rights can be used to impose 3D PLRs

on real property. The features of each of the examined limited real property rights and special objects examined and their compliance to the above mentioned requirements are summarised in Table 8.

Despite the fact that limited real property rights have proved efficient for centuries [the right of emphyteusis dates back to the fourth century BC (Rome, 2008)], their capacity to provide and secure rights on scarce natural resources and on an increasingly denser urban environment seems to be limited. Considering the needs for real property stratification, the following deficiencies can be traced among the aforementioned legal instruments:

Servitudes (easements) are established to provide specific benefit to their holder. Therefore, servitudes are related to a specific purpose and imply a specific type of exploiting the servient parcel. This, combined with the *numerus clausus* principle, significantly limits the power that can be exercised over the servient parcel and limits real property stratification to the installation, repairing and maintenance of utilities. Servitudes (easements) are considered to encumber the whole of the servient land parcel, although they can be exercised only to a particular, 2D, part of it, introducing ambiguities to their registration and representation to the cadastral maps. In most cases, legislation does not prohibit the establishment of more than one servitudes (easements), of the same or of different type, on a land parcel. However, new servitudes apply to the "remaining" part of the encumbered ownership right, thus being lesser compared to those established earlier (Triantos, 2000). Restricted easement concepts, as applying to Common Law jurisdictions, circumvent such ambiguities. However, this does not circumvent the need of multiple registration of each part of a network to all the parcels that the network is crossing, while introduces further ambiguities due to the lack of "overlapping owners" in case of networks crossing state owned land (where servitudes need not to be registered). Finally, servitudes (easements) constitute limited real rights upon which no other property rights can be imposed, nor can they be used as collateral, thus limiting land exploitation capabilities.

Usufruct provides its holder extensive power over an immovable that in some cases can only be compared to the right of ownership. However, in terms of real property stratification, the right of usufruct remains lacking. Its duration, which is based on the lifetime of the right holder, as well as the requirement of managing the immovable properly and preserving its substance, makes usufruct a less desirable right for real property stratification. Besides, usufruct still remains a right that cannot be applied at different levels; provisions regarding divisibility of usufruct may be traced in several jurisdictions (e.g. Greek Civil Code, art. 1144). However, this right cannot be used neither for stratification of real property, nor for imposing restrictions based on height, depth or volume.

Similarly to usufruct, *rights of superficies* dissociate land parcel ownership from ownership of constructions on, above and, in some jurisdictions, below it. Compared to usufruct, the right of superficies carries the advantage of being independent from the lifetime of the right holder, while providing ownership of buildings or constructions on the land parcel as well. Rights of superficies are already used for infrastructures and underground networks in The Netherlands (Ploeger & Stoter, 2004; Jantien Stoter & Ploeger, 2003; Jantien Stoter, Ploeger, & van Oosterom, 2013), while different types of rights of superficies can be traced in national laws,

serving different purposes such as the subordinate superficies, the superficies of owners and the housing superficies in Germany (Ye, 2013). Since the holder of the right of superficies owns the constructions built on the encumbered parcel, he is allowed to impose on such structures other limited real rights, e.g. mortgages, thus allowing to be used as collateral. On the other hand, rights of superficies are related to physical objects, therefore they cannot be used in case of non-physical, legal spaces related to Public Law Restrictions (PLRs). Even in case of physical structures, right of superficies actually allows for one or two individual volumes of stratified space: the one above and/or the one below the land surface. Therefore, it cannot serve the purposes of multi-level real property stratification. Further limitations on real property stratification through the right of superficies apply in jurisdictions where a restricted number of rights of superficies can be established on a land parcel.

Emphyteusis, given its resemblance either to the right of superficies or to usufruct, depending on national regulations applying to each jurisdiction, shares similar disadvantages in terms of real property stratification. Emphyteusis remains a right related to buildings or constructions, either built or to be built; therefore, it cannot be used in case of legal spaces with no physical counterpart. Compared to usufruct, emphyteusis is not related to the life time of its holder, while both provide for exclusive use rights on the buildings lying on the encumbered land.

Composite ownership rights constitute a way of creating stratified real property units without breaching the *superficies solo cedit* principle. Composite ownership rights provide versatility in creating distinct, mortgageable, overlapping real properties especially for residential purposes. However, delimitation both of real property units and common spaces may introduce ambiguities. Different approaches are followed in each jurisdiction, each pertaining different problems. Use of the middle of structural elements separating exclusively owned real property units can only be defined in building's structural plans, while reference to the interior or exterior building faces, either reduces the power of an owner to make even the slightest modification to a structural element (for example, hang a nail on a wall that constitutes a boundary), or increases individual owners' maintenance costs. Composite ownership rights are related to existing or to be built constructions. Apart from residential and commercial purposes, composite ownership has not been exploited for other cases of real property stratification. In such case, limitations related to the stratification of legal spaces need to be examined; for example, limitations that have to do with the implementation of the tripartite structure of composite ownership rights on non-physical spaces, especially regarding shared ownership of the land parcel and administration through owners' associations.

The use of *indirect ownership* rights on real property stratification shows significant problems regardless of the purpose that the real property is to be used. Relation of indirect ownership rights' holders to real property is achieved through acquisition of shares within the collective association, corresponding only to rights of exclusive use within a development and, in most cases, cannot be used as collateral. In case of the establishment of non-material legal spaces, these are out of the scope of indirect ownership rights therefore, indirect ownership is not suitable for real property stratification purposes.

Special rights and *special objects* constitute particular rights or objects that are used to specific cases. Additionally, given their national, mostly commonly even regional,

character it is difficult to be applied within statutory legal and administrative context. Special rights mostly regulate the relation between the involved parties to minimise conflicts and facilitate parcels' exploitation but cannot be used neither in cases of multilevel stratification, nor to create "layers" of rights applying to different legal or physical spaces. The concept of *land objects,* if adopted and enriched with 3D characteristics, can prove very useful in the field of real property stratification and 3D Cadastre. Legal and physical land objects can be used both in case of legal and physical space, as well as in cross boundary infrastructures. Introduction of such a concept would, however, require reconfiguration of land and cadastral legislation from parcel-based to land object-based.

Table 9. Capabilities and restrictions of limited real rights in real property stratification.

	Servitudes (easements)	*Usufruct*	*Right of superficies*	*Emphyteusis*	*Composite ownership*	*Indirect ownership*	*Special Real Property Rights -*	*3D real property units*
Stratification on multiple layers	✗	✗	✗	✗	✓	✗	✓	✓
Subject to limited real property rights	✗	✗	✓	✓	✓	✗	✓	✓
Specific purpose/ content	✓	✓	✗	~	✓	✓	✓	~
Applicable under conditions	✓	✓	✓	✓	✓	✗	✗	~
Necessary relation to physical object	✗	✗	✓	✓	✓	✓	✗	~
Related to surface parcel	✓	✓	✓	✓	✓	✓	✗	~
Can be used to impose Public Law Restrictions	✓	✗	✗	✗	✗	✗	✗	~

~ depending on jurisdiction

6.5 Public Law Restrictions

3D PLRs influence land administration to a significant level, while such influence is growing due to the increasing number of restrictions imposed on land and on the space above and below it. 3D restrictions on real property are either directly stipulated in 3D, or they can be implied, by reference to physical, or even to non-geometrical characteristics. However, the lack of statutory 3D Cadastre framework does not allow functional operation of 3D PLRs, for example by establishing volumetric restrictions. Volumetric characteristics of PLRs can be traced only in legal documents or 2D maps, which leads to ambiguities in registering, mapping and interrelation with other 3D restrictions. It is noted that several PLRs, especially environmental protection ones, are imposed on an environmental component, based on the value of another component. For example, groundwater table level may require to be lowered, in order to protect soils of low density and strength from erosion. This relates to the type of each designed development, thus resulting in case-specific PLRs that change dynamically, depending on the relations between environmental

characteristics and structural requirements of each development. Table 10, summarises PLRs traced in literature research and their actual mapping, where applicable.

Table 10. Types of 3D PLRs and their mapping in relative records (modified, Dimitrios Kitsakis & Dimopoulou, 2016b).

Legislation	Types of restrictions	Mapping (2D/3D)
Mines	• Separation of land and mineral ownership	2D
Cultural heritage	• Establishment of protection buffer zones • Parcel (or parcel's part) expropriation • Establishment of servitudes • Land use restrictions	2D (restrictions in height may also be defined)
Environment	• Distances from agricultural, rural etc areas • Existence of groundwater/ level of groundwater table • Protection from air pollution • Protection from noise pollution • Geological and hydrogeological conditions	2D
Aviation	• Establishment of no-flight zones • Minimum flight height • Definition of Obstacle Limitation Surfaces	2D/3D
Urban Planning	• Protection from air pollution • Protection from noise pollution • Protection of landmarks' view • Limitations in height, built-surface ratio, shadow casting	2D (restrictions in height may also be defined) 3D noise maps
Utilities	• Restrictions along centre-line	2D

At international level, there are several databases recording PLRs either as themed cadastres and integrated spatial data registries, or in the form of PLR cadastres, such as the cantonal Swiss PLR cadastres. However, both themed and PLR Cadastres regard PLRs as 2D projections on land surface. Recording of PLRs definitely promotes efficient Land Administration, although 2D-based approaches of PLR recording results in similar issues faced already by 2D real property cadastres when it comes to multiple, stratified restrictions.

Definition of PLRs in 3D space within a legal framework that supports real property stratification would constitute an efficient tool to clarify complex cases of vertically overlapping restrictions, present the exact space where a restriction applies, encumber specific 3D spaces instead of a whole land parcel and facilitate efficient 3D space exploitation and operation of the land market (Dimitrios Kitsakis & Dimopoulou, 2016). Constitutional stipulations on the protection of ownership need to be compromised to those on multi-level exploitation of land, for example through mines, quarries, protection of archaeological sites and monuments. Serving public benefit is the criterion either to deprive privately owned land, or to oblige surface parcel owners to withstand activities above or below surface parcels, under condition that such activities do not inhibit normal land exploitation. Although legislation on the establishment of infrastructures and Civil Code stipulations are in accord with constitutional stipulations, definition of "normal exploitation" of real property is open to interpretation. Such ambiguities, may result in land use conflicts, especially in cases where exploitation of a real property over a public utility needs to expand in

new, greater depth. In such case, the agencies that are responsible for the establishment and management of underground utilities benefit from their exploitation, while surface parcel owners are either deprived from their property through expropriation, or face restrictions on exercising their ownership rights with no relative benefit (Dimitrios Kitsakis & Dimopoulou, 2017b). Legislation defining restrictions that apply in 3D space along with relative compensation would address delays of infrastructure projects due to the lack of expropriation funds, the reluctance of land surface parcels' owners to be deprived of their property, or even their objections to estimated compensation values. Similarly applies in other cases of PLRs that are imposed on land parcels as a whole, although referring to specific volumetric parcel parts. This is the case for heritage protection restrictions, especially regarding underground antiquities which need to be preserved in-situ. Examples of 3D protection zones, based on different case studies are presented in (D. Kitsakis and Papageorgaki 2017; Dimitrios Kitsakis and Dimopoulou 2016b, 2017, 2018).

PLRs on rural environment areas also extend on 3D space; however, they are mostly defined by non-geometric, or implied 3D characteristics and need to be interrelated with the specifications of each planned development. Restrictions are mainly established in the form of servitudes (easements) of passage or rights of way, in case of under or above ground infrastructures, or as protection zones on horizontal plane. Exploitation of legal instruments of private law, such as servitudes (easements), introduces the same deficiencies on real property stratification that are presented in section 5, while they apply only in relation to a construction. In Common Law jurisdictions, this problem can be circumvented by conservation easements that can be used to set protective restrictions on specific land. However, conservation easements only apply to a number of Common Law jurisdictions, therefore they cannot be of use in Civil Law jurisdictions, due to the *numerus clausus* principle. Moreover, conservation easements share the same typical characteristics with the rest of easements' types, therefore, they cannot be used for stratification for conservation purposes. This would require to incorporate the concept of restricted easements (also applying to Common Law jurisdictions), so that volumes intended for conservation purposes could be defined. Similar limitations can be identified in the other types of legal instruments used for real property stratification (apart from 3D real property units).

Building regulations, within 3D Cadastre context, define in detail the permitted legal volume of each construction, according to the geometrical characteristics and the area of the land parcel to which it pertains. Regulations on the protection of architectural heritage and physical environment are also stipulated within building regulations.

On the other hand, legal volumes defined through building regulations do not directly correspond to the "as-built" construction (physical space). Deviation between physical and legal space along with methods of their interrelation and modelling has been of significant scientific interest (Aien et al., 2013; E. Dimopoulou et al., 2015; Efi Dimopoulou & Elia, 2012; Karki, Mcdougall, & Thompson, 2010b; Shojaei, Rajabifard, Kalantari, & Bishop, 2014; Ying, Guo, Li, & He, 2012).

Given that PLRs mostly extend to multiple land parcels and, in most cases, only present the permitted or non-permitted 3D space of specific uses or activities within

a region, such restrictions can be presented through the concept of legal space, as they are not directly related or presented through a physical structure. On the other hand, physical space can prove more useful on larger scale projects, e.g., land parcel or a building, where the real situation is required to clarify ambiguities and present the real situation concerning a structure and its constituent parts (E. Dimopoulou et al., 2015).

Administrative organisation and cadastral infrastructure also affect 3D recording and presenting of building regulations. Depending on each country, building regulations are defined in national, regional or municipal level, while cadastral systems are, in most cases, centrally maintained an updated at national level. Consequently, efficient cooperation among different agencies at different levels of administration may be required.

7 “Best practices”

Discovering “best practices” constitutes a common pursuit in the scientific, governmental, industrial and societal fields. During the last years, the abundance of information has allocated interest from information acquisition to information management, thus resulting in search of general guidelines of efficiency, in the forms of best practices and standards. Literature presents a variety of examples suggested as best practices. However, it is difficult to define what a best practise is. Characterising a practice to be the “best”, can raise many objections, given that there is no uniform way to achieve the same goal under different conditions. Besides, what may be considered as optimum in one place, may be undesirable in another (O’Dell, Grayson, & Essaides, 1998). Patton (2001), highlights that in order to characterise a practice as “best”, the question “*from whose perspective and under which criteria?*” requires to be responded. Identification of best practices, derives from a process of evaluating different practices. (Baird, 1998), emphasises on four central issues when evaluating the performance of an organisation or a system:

- Well-defined objectives (defining what is to be achieved).
- Clear strategy (explaining the way objectives are to be reached).
- Monitorable indicators (assuring that the process is on track).
- Evaluation of results (for accountability and learning).

A system cannot be evaluated as a whole. It needs to be further subdivided in smaller units, setting performance indicators, which can then be evaluated against an “ideal” system, based on intended objectives, or compared to other projects, or by a combination of both (Steudler, Rajabifard, & Williamson, 2004). In the field of Land Administration, literature provides several examples of research on systems’ evaluation and identification of best practices (Bandeira, Sumpsi, & Falconi, 2008; Barnes, 2002; R. Bennett, 2007; Enemark, Bell, Lemmen, & McLaren, 2018; Holstein, 1996; Steudler et al., 2004; UN HABITAT, 2003; I. P. Williamson, 2001; I. Williamson & Ting, 2001). Such examples focus on the broader issue of Land Administration including policy, management and operational level, as well as external factors and their components. Steudler et al. (2004), identify the features of a generalised evaluation framework as presented in Table 11.

Stratification of real property and 3D Cadastre fall into the land tenure component of Land Administration. Land tenure refers to the different types of tenure that exist in a jurisdiction, the parties who benefit from new interests as well as the parties that are bound by new interests, and the best way to describe and classify RRRs in a holistic way (R. Bennett, 2007). Williamson (2001), identified seven major components of best practices in land administration, constituting the “Land Administration Toolbox”. Identified components were classified in the following categories: land policy principles, land tenure principles, institutional principles, land administration and cadastral principles, spatial data infrastructure principles, technical principles, and human resource development and capacity building principles (I. P. Williamson, 2001). In his elaborate work to expand the capabilities of the “Land Administration Toolbox” proposed by (I. P. Williamson, 2001), (R. Bennett, 2007), refined the principles of the land tenure component of this toolbox, taking into account real property stratification and highlighting the need of flexibility of land tenure. Within this context, the layered public and private interests’ concept is acknowledged, also supporting the “property object” model within a flexible

administrative framework. A publication on best practices regarding 3D Cadastre was published in 2018, presenting an inventory of the developments in several countries globally, regarding all aspects of 3D Cadastre research, such as legislation, initial registration of 3D parcels, 3D cadastral information modelling, spatial

Table 11. Evaluation framework for Land Administration systems (Steudler, Rajabifard, and Williamson 2004).

Area	Aspects	Possible Indicators (not detailed and not exhaustive)
Policy Level	**Land policy principles**	• Existence of a government policy for land administration (y/n) • List of statements for land administration system role • Existence of independent land board (y/n) • …
	Land tenure principles	• Existence of formal recognition and legal definition of land tenure (y/n) • Security of tenure (no. and solution of disputes) • Social and economic equity (underrepresented groups) • …
	Economic and financial factors	• Cost/benefit and fee structures, land tax revenue • Economic indicators (value and volume of land market) • Funding and investment structure • …
Management Level	**Cadastral and land administration principles**	• Adequate protection of land rights • Support of land market (secure, efficient, simple, at low cost) • …
	Institutional principles	• List of responsible departments and ministries • Central or decentral organization • Number of institutions and offices • Private sector involvement, no. and volume of contracts • …
	SDI principles	• Standards arrangements, core data • Access network, pricing • Data definition, modelling • …
Operational Level	**Technical principles**	• Data properties (capture method, quality and accuracy) • Data maintenance, timeliness • …
External Factors	**Human resources**	• Number of personnel (public and private) • Professional association • …
	Capacity building	• Number of universities and students • Funding structure for capacity building • On-going education (no. of workshops, seminars) • …
	Research and development	• Number of research institutes in the land administration field • …
	Technology	• Freedom of systems and methods (y/n) • Regular review of new technologies on market and assessment of fitness for use (y/n) • …
Review Process	**Assessment of Performance**	• User satisfaction indicators • Degree of satisfaction of objectives and strategies • Existence of a regular review process (y/n) • …

database management systems for 3D cadastres, and visualisation (P. van Oosterom, 2018; P. J. M. van Oosterom, 2018).

This publication provides insight on the approaches followed in different countries, including those that have moved or are in transition towards a 3D cadastral system. However, despite the notable reforms on several countries, a national full[94],

[94] In the full 3D cadastre, rights are no longer established on parcels, but on well-defined, surveyed volumes (Jantien Stoter, 2004a).

operational 3D cadastre has not yet been established[95] (Ho, Rajabifard, Stoter, & Kalantari, 2013; Kalogianni & Dimopoulou, 2018; Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). Consequently, it is difficult to define "identical" approaches. The situation is getting more perplexed, given the significant differences in cadastral terminology, legislation, administrative structures and procedures employed in each country.

Based on the legal issues regarding stratification of real property that were identified in section 5, the main deficiency has to do, first, with the creation of independent 3D real property units that are capable of fulfilling the eleven instances of ownership as described by Honoré (Hodgson, 2013) and, second, by imposing PLRs on 3D space. Enhancing the concept of traditional land parcels to support real property stratification is also required, so that existing land parcels can be separated to 3D volumes, if needed.

7.1 Partition of real property

Partition of real property to horizontally overlapping 3D volumes that may serve as independent real property units, is related to the definition and the content of real property as defined in national legislation. This has to do with setting upper and lower boundaries to privately owned space above and below a land parcel, and with providing landowners the capability of further subdividing volumes of space within their privately owned space and use them for transactions, as applying to traditional parcels.

Legislation on Civil Law based jurisdictions, recognises as land components the soil and every artificial object that is permanently fixed on it. Minerals are in several jurisdictions regarded as part of the land, although mineral rights are regulated by mining laws. Separation of the concept of land from mere physical space, and relation to the abstract, non-material, legal space can be traced in several Civil Law jurisdictions, where real rights on immovable property are as well regarded as immovable property. Common Law based jurisdictions, employ a more detailed definition of land, by referring to the particular objects that are considered as land components. Incorporeal interests are also included within the concept of land in Common Law jurisdictions. However, definition of land may pertain objects that are owned separately from the land surface (e.g. United Kingdom or Singapore). This distinction constitutes an explicit stipulation separating ownership of specific objects or structures from land surface ownership. It is noted that only a limited number of Common Law-based jurisdictions explicitly refer to the column of airspace above a land parcel, on their legal definition of land.

Definition of upper and lower boundaries of land parcel ownership is not common neither in Civil, nor in Common Law-based jurisdictions. Most jurisdictions refer to the extent of ownership above and below the land surface, through abstract reference to the interests of the landowner, either to exploit space, or to object to its exploitation by a third party. Despite its vagueness, relation of the vertical extent of ownership to permissible height or depth exploitation cannot be overridden. Potential types of land exploitation depend both on local conditions and on the specifications of a potential

[95] Exception to this can be considered Shenzhen city in China, which, however, is characterised as Special Economic Zone, therefore, it is regulated under special legal regime.

development (Georgiadis, 2012), which may impose Public Law Restrictions in 3D space. Therefore, despite its functionality, the concept of a uniform, pre-determined vertical range of land parcels is not feasible. It is noted that maximum height range of land parcel ownership is, according to this view, related to maximum building (or constructions') height, e.g. (Efi Dimopoulou & Elia, 2012; Karabin, 2014; Ying et al., 2012). However, the extent of real property ownership does not necessarily coincide with the allowed height or depth of a construction. Reference of Civil Law to the interests[96] of the land parcel owner (especially in stipulations regarding the extent and the content of real property ownership), results in private volumetric zones that are not always related to constructions. For example, flight of UAVs within the "privately owned" volume of a land parcel, may be considered a trespass of personal privacy, regardless of the existence of a construction or not, while such volume may extend to different height, compared to the maximum allowed height of constructions within the land parcel. The concept of defining a specific height or depth of "exclusively owned" space can be traced in the legislation of a small number of Common Law jurisdictions (e.g. Singapore, state of Victoria in Australia). However, even in these cases, such provisions apply only in case of underground land, while different regulations apply, based on the type of alienated land (e.g. Crown land in Victoria), and on the stipulations of the state title issued (e.g. Singapore). As regarding to the ownership of the airspace above a land parcel, abstract stipulations referring to "reasonably necessary for lawful enjoyment and use of land" are used.

In Common Law jurisdictions, the concept of the "bundle of rights", as described by Honoré (Hodgson, 2013), provides greater flexibility to separating of land components form surface parcel ownership, compared to the more strict concept of indivisible, absolute ownership that applies in Civil Law ones (Renard, 2007). In the United States, air rights, or lateral support and surface rights are, among others, considered to be included within Honoré's list of incidents (D. R. Johnson, 2007). This shows that the limitations of the "unlimited" vertical extent of ownership, can be addressed through the introduction of rights that allow vertical stratification of ownership and apply to 3D defined land objects. Such requirement is covered in specific, both Civil and Common Law, jurisdictions by the introduction of 3D real property units. The difference is that in the former, legislation aims to provide legal instruments for the stratification of real property, while in the latter, legislation's aim is to optimise the operation of an already existing legal capacity.

The aspects of 3D real property units have already been presented in section 5 (subsections 5.3-5.5). In this section, the efficiency of 3D real property units in real property stratification is assessed. The criteria for this assessment are based on the aims of development 3D Cadastre legislation, as they have been defined in international literature, including both jurisdictions that have already established statutory legislation allowing real property stratification, and those that discuss legal amendments towards this direction. Such criteria can be summarised to the following (Caine, 2009; Karki, 2013; Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018; Onsrud, 2002c; Jenny Paulsson, 2007):

- Facilitation of investments,

[96] This includes stipulations regarding both the positive (the right of the landowner to use and exploit his/her real property according to his/her will) and the negative (the right to exclude others from his/her real property) aspects of the right of ownership.

- overcome difficulties with overlapping building situations,
- allow transactions between 3D objects,
- "compatibility" and relation to traditional real property units,
- distinction from other types of real property units.

7.1.1 Facilitation of investments

As regarding to the *facilitation of investments*, it is clear that all types of 3D real property units contribute to this direction, since they allow for the development of separate ownership volumes, which can be managed separately from the land parcel. Compared to traditional legal instruments for real property stratification (e.g. limited real rights), 3D real property units provide more flexibility, allowing for stratification of real property in multiple levels, while also providing for owned volumes of space that are more attractive to investors. Land rights impact on the incentives and the scope of land market transactions in land and credit, by providing incentives to efficient land use and investment, as well as by reducing uncertainty and ensuring credit market efficiency (Feder & Feeny, 1991). 3D land rights create "new" property units, which are legally secure and can be exploited similarly to those in traditional 2D real property units, while acquiring of a spatial volume instead of a whole land parcel significantly reduces acquisition costs (Jesper M. Paasch et al., 2016). Volumes of real property can be sold by the surface parcel owner, or expropriated, when needed, minimising time and cost, while offering full ownership of the spatial volumes instead of limited real rights on the surface parcel, usually established by administrative acts. Haim Sandberg (2003), presents a characteristic example of such a case in Israel, the Akunas case, where expropriation of volumes under privately owned land was required in order to construct a tunnel[97]. Compared to 3D real property units, contemporary concepts of real property stratification, e.g. limited real rights, or indirect ownership, provide inferior legal safeguards to real property and the powers that their holder may exercise on land are dictated either by his/her contractual agreement with the landowner or they are subject to property law (Jesper M. Paasch et al., 2016). This means that the beneficiary may only exploit real property within the aforementioned limits, which makes such rights less attractive to be used for investments (Ekback, 2011).

7.1.2 Overlapping building situations

Overlapping building situations refer to different constructions, extending on multiple levels above or below the earth's surface, which are horizontally overlapping. It may also relate to building new structures above existing buildings, or of buildings partly situated on top of each other (Dimitrios Kitsakis, Apostolou, et al., 2016; Papaefthymiou et al., 2004; Jenny Paulsson, 2007). Within contemporary legal regulations, such cases are addressed by limited real property rights, special or customary rights (mainly region-based), apartment rights, transfer of development rights and, in several Common Law jurisdictions, air rights. However, each of these concepts introduces several limitations to the stratification of real property.

[97] Although the Court has recognised in this case the possibility to separate surface from subsurface ownership in case of expropriation, it did not provide a principled explanation for that recognition, leaving the issue of 3D real property subdivision by surface parcel owners, as well as the legal instruments that could be used for such type of subdivision unresolved (Haim Sandberg, 2003).

Rights of superficies, and emphyteusis, just separate the ownership of surface parcels from their over or below lying structures. Therefore, they are solutions that can be used in simple cases, where there is no intense stratification of real property, on different levels and by different beneficiaries. Moreover, such solutions are strongly related to physical space, therefore they cannot be used in situations that involve legal spaces, e.g. volumetric restrictions, instead of constructions.

Use of special and customary rights constitutes a solution that is both case and region-specific, as it applies on particular types of objects, mainly reflecting ownership situations as applying a long time ago, on specific regions, even within the same country. Therefore, they are neither consistent with modern cases of underground or above the earth structures, nor can they support real property stratification concepts extending in multiple levels. Moreover, in most jurisdictions such types of objects are limited in number, while special rights are repealed or apply only in cases of already existing special objects and no new ones can be established (for example Greek SRPO).

Use of apartment rights (condominium schemes) and transfer of development rights (TDR), constitutes a way of providing ownership rights on multiple levels to different owners. Depending on jurisdiction, different uses can be allowed within an apartment rights' scheme (e.g. commercial and residential). However, it is a solution that is strongly related to residential use, although several jurisdictions have introduced different types of condominium schemes serving different purposes. Another limitation of condominium schemes in real property stratification purposes is that they involve, apart from apartment's ownership or right of exclusive use, ownership of the surface parcel (and of the building's common property). Therefore, it cannot serve the creation of individual stratified real properties. Within a similar context, transfer of development rights, refers to restricting to a specific height the vertical exploitation of land parcels and transfer of the remaining, non-constructed, building rights to another location. Hence, it is again related to a building (physical space) on a new location, corresponding to the deprived physical space on a protected area. This introduces issues of assessing the "equivalence" of the transferred space between those different locations, which brings out further complexities related to regional dynamics, which cannot be foreseen and are susceptible to change (Renard, 2007). Air rights in Common Law jurisdictions, especially in the United States, follow a similar concept, also related to surface parcel ownership (Schwartz, 2015). The main difference between Civil and Common Law jurisdictions is not traced in the regulations subdividing airspace, but in the fact that urban planning, especially zoning, restrictions in the latter are regarded as severely restricting land use and landowners need to be compensated for the loss of their building rights, while in the former, such restrictions are considered to be restricting the power that can be exercised by the landowners, thus they are not liable to compensation.

Both statutory and proposed 3D real property units aim to address the limitations that derive from overlapping building situations, despite their differences regarding terminology and definition. Swedish three-dimensional property space, is used to separate ownership of a volume of space from traditional land parcels. Similarly applies in case of Norwegian 3D parcels. It is noted that in both cases, 3D real property units need to be related to an existing or a planned construction (for which a building permit has been granted). This means that 3D parcels cannot be used to impose PLRs extending to 3D space. A similar approach is also followed in the 3D

cadastral parcel concept, proposed by (Karabin, 2014), where 3D cadastral parcels with specified spatial range can be created. In this proposal, 3D cadastral parcels are regarded as legal spaces, where physical spaces need to be embedded. Definition used, does not preclude the use of 3D cadastral parcels to other types of RRRs, not related to physical constructions. Chinese legislation as well, allows for separate ownership of constructions above or below the land surface, independent from surface buildings (Guo et al., 2013). Stipulation of the Property Law of People's Republic of China implies the potential of different uses between above and underground space from those of the land surface and that the parcel space may be multi-level, across boundary, or without geometrical limitation, thus leaving room for local Chinese governments to further regulate land use, depending on their region's particular needs (Guo et al., 2013).

Overlapping building situations within Common Law jurisdictions can be addressed within the context of 3D real property units. Regardless of each country's legal framework, 3D units cover a delineated volume of space. Depending on each country, explicit stipulations exist, providing if such delimited spatial volumes should comprise of a building (or other structure), or if no relation to a construction is required. Volumetric spaces referring to buildings can be further subdivided into building units or apartments through strata titles (or similar legal instruments used to subdivide ownership rights within a building, but with different terminology, e.g. lots or parcels).

7.1.3 Transactions between 3D real property objects

Transactions between 3D cadastral objects refers to the management of real property, by subdividing, amalgamating it and imposing secondary rights. Transactions between traditional real property require a number of formalities to be followed, regarding the creation and exchange of documents between the involved parties and the responsible agencies (Gerhard Navratil & Frank, 2007). Ferlan, Radoš, & Mattsson (2007), distinguish two categories of processes that need to operate effectively in land market to support development: those for changes of ownership and those for property formation. The former include:

- land policy control (setting the framework in which land can be exploited, reflecting the general objectives of the society),
- marketing activities (negotiations between vendors, buyers and creditors regarding sale, acquisition and funding of purchasing a real property),
- pre-contracting (legal binding of the involved parties before the finalising of an agreement), contracting (binding commitment of agreement between the involved parties), and
- registration (entering the changes of property rights to a public register, ensuring transparency and protection of third parties),

while the latter are further categorised in:

- land policy control (compliance of newly formed real properties with society's land policy),
- preparation of case (by defining new real property boundaries and management of existing or newly created rights),

- cadastral decision (ratification of the formation of a real property unit by a specialised authority, assigning force of law to the newly formed real property unit), and
- registration (entering the legal extent and the content of both the new and the original real property to a public register so that they are known to the market and the public authorities).

Relating the categories of Ferlan et al. (2007) processes to the context of real property stratification reveals the capacities of 3D real property unit-based legislation against the handicaps of contemporary real property units.

As regarding to the processes related to ownership changes, setting the framework that regulates land exploitation (land policy control) processes, both contemporary real property units and 3D real property units reflect the need of separating the uniform owned space above and below a land parcel to individually owned volumes. In the former case, this is pursued through limited real property rights and specialised legislation for particular cases of land use exploitation and developments[98], while in the latter, the same aim is achieved by different types (depending on national legal framework) of 3D property units, which provide different levels of flexibility regarding stratified land exploitation. For example, 3D real property units in Sweden and Norway are required to be related to a construction, while in Queensland different types of 3D real property units exist, which can be used to the formation of different types of physical and legal spaces, while also comprising a variety of different types of real property delimitation (by reference to floors/walls/ceilings, bounding spaces, height/depth). Other limitations may also be imposed regarding the location that stratification within a land parcel is allowed (e.g. only to underground land (Malaysia), or whether stratified real property may refer to the development of a physical construction (as applies in Swedish and Norwegian stipulations), or may also apply to "empty" volumes of air-space. Stratification capabilities also affect marketing activities, given that each of the involved parties seeks to maximise its profits and/or ensure its investment. Within this context, stratification of real property to individually owned volumes of space can be more attractive to all involved parties, given that investors may acquire ownership of a specific volume of space instead of a whole land parcel, thus limiting acquisition costs, without losing the capability of using such space as collateral. On the contrary, limited real property rights do not provide ownership rights to the involved parties, therefore they cannot be used as collateral (except of specific cases of limited real property rights, such as the rights of superficies or the right of emphyteusis, although even in such cases limitations apply), while further limitations regarding registration and presentation of the space where limited real rights are imposed, using 2D maps and documents emerge. Restrictions deriving from Public Law should not be unnoticed in cases of marketing activities. Within the context of contemporary real property concepts, such restrictions may prohibit specific types of developments on significant portions of land, thus affecting market prices as well as land management. On the contrary, imposing restrictions on particular volumes of space (e.g. volumetric zones for the protection of underground antiquities, or of underground construction developments) could set significant

[98] For a presentation of the limitations of using limited real property rights for real property stratification purposes, please refer to section 6.

volumes of land free for exploitation, which otherwise would remain underexploited or unexploited.

Processes of pre-contracting and contracting are influenced by the types of real property rights that can be established on a piece of land, the powers that can, or cannot be exercised by a right holder to his (or her) land, and the geometrical extent that such rights apply. This also relates to the registration of ownership rights to a public register, so that the knowledge on such rights and limitations is accessible to the public. Consequently, the different capacities that apply to different height or depth levels, need to be adequately described, both in terms of content and geometrical extent. Registration of ownership rights' changes can be supported by land registries, even in case of stratified objects established by contemporary real property rights. However, either merely the existence of several real property rights assigned to different stakeholders is recorded to land registries, or, in particular cases (e.g. apartment rights, servitudes or rights of superficies) individual drawings may be attached to corresponding deeds or titles. Nevertheless, the 3D features of overlapping rights, even those applying to the same land parcel, are not reflected to cadastral dataset, thus they cannot be queried, managed or interrelated. Stoter et al. (2016, 2017), presented the most notable, so far, real case implementations of 3D cadastral registrations within the Dutch legal framework, based on limited real property rights. Despite the successful accomplishment of such 3D cadastral registrations, legal limitations and challenges have been acknowledged. Specifically, the effect of the "specialisation principle" in case of multi-level ownership situations during cadastral registration, which requires the 2D division of the involved land parcels according to the projections of property rights under and above ground is highlighted (Jantien Stoter et al., 2016). This results in multi-fragmentation of the surface parcel on the cadastral map, while many "mini-parcels" deriving from such fragmentation may even be entirely located above or below the land surface. Additionally, the status of 3D legal volumes remains unclear, under means of whether they should be treated as individual real property objects or not (Jantien Stoter et al., 2016). It is noted that the 3D parcels formed during the Dutch 3D cadastral registration follow the characteristics ascribed by the definition of (P. van Oosterom, Stoter, Ploeger, Thompson, & Karki, 2011). Within this context, real property rights are considered to create individual 3D parcels within the volume of a land parcel, thus circumventing the lack of statutory defined 3D parcels by Dutch property and cadastre laws. This approach provides an intermediate solution for registration of multi-surface properties related to a major development that comply with the existing land registration system, without the need of extensive changes on the legal, technical and administrative framework regarding land tenure and cadastral registration (Jantien Stoter et al., 2017). However, limited real property rights are time-based or are subject to lapsing after certain transfers or legal transactions (Ekback, 2011). Further limitations related to transactions of limited real property rights include the increased costs, as well as the need of the property owner's consent for transferring of limited real rights, thus increasing the procedural requirements and the time required for a transaction to be completed (Ekbäck, 2011).

On the contrary, 3D real property units provide a stable background for marketing activities and registration that serves contemporary situations of real property

stratification and better fits within the concept of a future full 3D Cadastre[99]. 3D real property units form a framework that provides pre-contracting or contracting parties a clear (precise and without ambiguities) depiction of the spatial extent of real property rights. This allows for clear understanding of the substance of contractual agreements with spatial components. 3D real property units need to be accompanied by 3D documentation, depicting side, lower and upper boundary limits of each 3D real property unit using isometric diagrams (Figure 43). The fact that all jurisdictions with statutory 3D real property units allow for treating of 3D property units the same with traditional land parcels, eliminates potential ambiguities to the public and professionals, regarding the use and the powers that can be exercised on 3D property. Therefore, the spatial extent where different RRRs apply is clearly identifiable, depicting the full range of exploitable and restricted spaces.

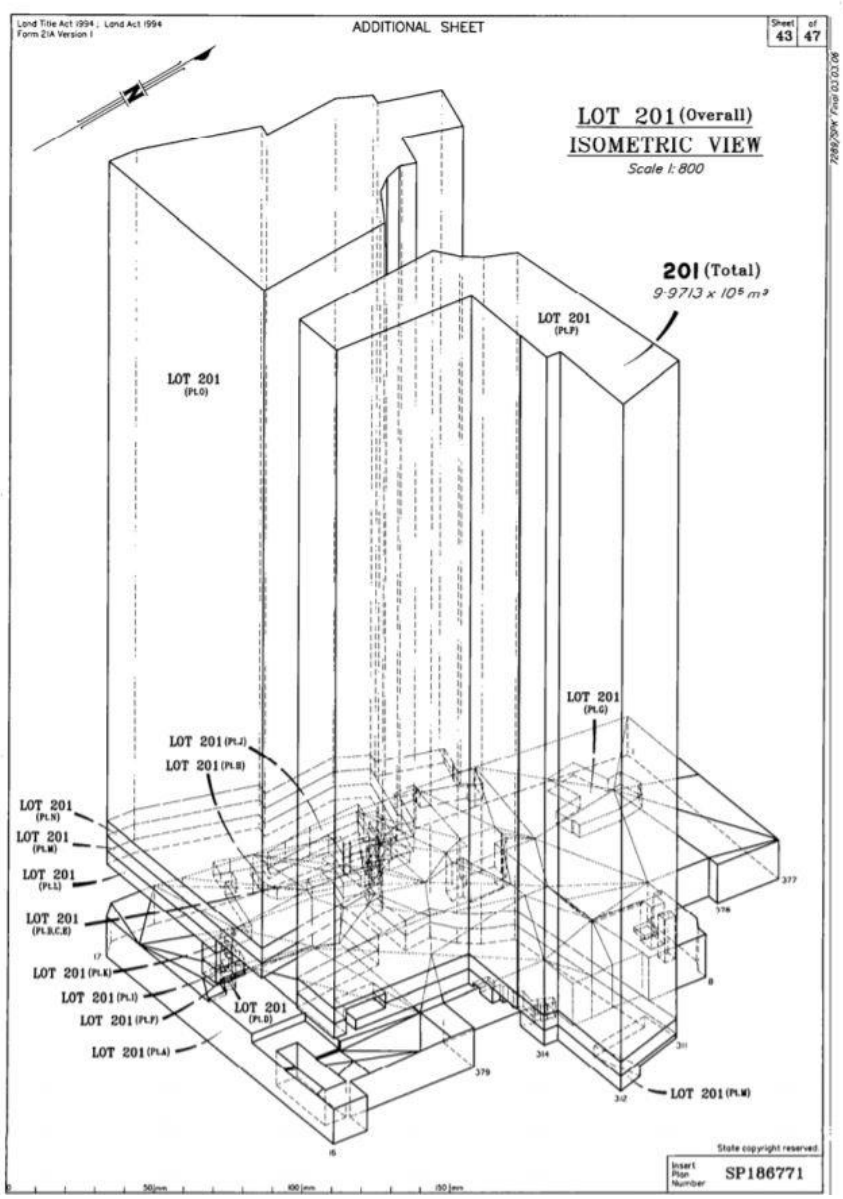


Figure 43. Air space subdivision plan (Peter van Oosterom, Ploeger, and Stoter 2006).

[99] According to (J. Stoter & van Oosterom, 2005), the concept of a full 3D Cadastre includes traditional (infinite) parcel columns and individual volumes of space, serving as primitive real property units.

Consequently, contracting parties can be aware of the complete legal situation applying to a particular land parcel or space volume, thus facilitating the pre-contract or contract negotiations. As regarding to registration of changes on property rights, 3D real property units present a much clearer depiction of the spatial extent that a right apply, hence unique spaces where unique real property rights are imposed can be identified. Karki (2013), notes that despite the 3D documentation of 3D real property units in the Australian states, the problem regarding transactions with 3D real property units is that 3D content is not included in the cadastral database[100]. This means that interrelations between neighbouring 3D real property units (that do not pertain to the same surface parcel) cannot be identified, while reference to paper, or digital 3D plans is required to identify the stratification of real rights. The same issue is also traced in the Norwegian and Swedish real property units, where existence of 3D units to the cadastral map is identified by special symbology and descriptive references are made to denote them on the cadastral database (FIG working group 3D-Cadastres, 2018). The only fully operational example of transactions and registration of 3D real property units can be traced in the city of Shenzhen in China[101]. Cadastral database records RRRs on specific spatial volumes using 3D coordinates, 3D volumes and spatial relationships, while cadastral maps present the 3D models of 3D units (FIG working group 3D-Cadastres, 2018). Moreover, research has resulted to further enhancing of the 3D cadastral administrative system by issuing 3D parcel certificates (Ying et al., 2014). Despite that such capabilities still face several challenges, e.g. regarding data integrity and amendments on the regulatory framework for complete 3D data organisation (Ying et al., 2014), they support 3D land administration processes in terms of changes of property rights, providing protection to titles establishing rights on 3D space. Interpretation of stratified real property units as land, means that such units are subject to all secondary rights applicable within national legislation. Secondary rights on 3D real property units also comprise rights for the support of constructions, shelter or protection and rights of way (in case of utilities) within a 3D real property unit. In Australian states, such rights do not need be established based on mutual agreement among different stakeholders (ratified by a contractual agreement), but are "automatically" assigned to stratified real property volumes in the form of implied easements. On the contrary, Canadian provinces' legislation does not provide for any type of implied easements and leaves up to the owner of the 3D real property unit to acquire such rights.

As regarding to the processes related to property formation, the following characteristics of 3D real property units and of stratification using limited real property rights can be identified.

Land policy encompasses a set of basic principles, guidelines and rationale upon which land legislation, together with the strategies and infrastructure for their implementation, can be developed (Mbaya, 2000). EU Task Force on Land Tenure

[100] This does not mean that 3D real property units are not presented in any form to the national cadastral databases and cadastral maps. Both states of Queensland and Victoria represent 3D real property units as 2D projections (the former) or by using layers (the latter) (FIG working group 3D-Cadastres, 2018).

[101] It is noted however, that Shenzhen is regulated by special regulatory regime, since it constitutes a Special Economic Zone, and a prototype 3D Cadastre system has been established to support the city's rapidly growing development (Ying et al., 2011).

(2004), elaborates on the content of land policy stipulating that it "*defines the principles and rules governing property rights over land and the natural resources it bears as well as the legal methods of access and use, and validation and transfer of these rights. It details the conditions under which land use and development can take place, its administration, i.e. how the rules and procedures are defined and put into practice, the means by which these rights are ratified and administered, and how information about land holdings is managed. It also specifies the structures in charge of implementing legislation, land management and arbitration of conflicts*". Within this context, both limited real property rights and 3D real property units serve the purpose of real property stratification and the policy for multi-surface exploitation of land property. However, such purpose is not equally served by both types of legal instruments in terms of efficiency. Limited real property rights allow a person, other than the surface parcel owner, to use, hold, or exploit a real property or part of a real property, to the extent defined by legal statute. As already argued in sections 5 and 6, real property stratification by limited real property rights can be functional in simple cases of overlapping rights that do not extend on multiple levels above or below the land surface and are related to constructions (or other types of land exploitation, e.g. agriculture), whereas they cannot be used to impose restrictions that would create "empty" volumes of space. Connotation of the, almost, indivisible property column, above and below a surface parcel, combined with the 2D based concept of registering and mapping rights on land, also affects the regulations and procedures for real property registration and management. Characteristic examples are the segmentation of land parcels on cadastral map representations based on the projections of limited property rights on the land parcels, and the imposing of restrictions, which may even require property expropriation, of land parcels as a whole, for the protection of natural, physical or artificial environment characteristics, or other types of objects, which are located to a specific volume of space. On the other hand, 3D real property units provide more versatility to the formation of stratified real property units, thus constituting legal instruments that fit better to the implementation of national land policies. The provision for RRRs identical to those that apply in 2D, allows for a more specialised addressing of land policy requirements that are related to multi-level land exploitation and management, compared to traditional 2D RRRs. Such provision, also reduces potential misapprehensions of the RRRs that can be imposed on spatial volumes, by the public and professionals, while also allows 3D real property units to be further encumbered by secondary rights (FIG working group 3D-Cadastres, 2018; Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). Provisions for easements with 3D delimitation (e.g. restricted easements or easements restricted in stratum that are stipulated in the states of Queensland and New South Wales in Australia respectively) allow for restrictions to be imposed on the particular spaces, instead of the whole space column of a land parcel. However, limitations to the allowed easement types, restrict potential use of 3D delimited easements; for example, in the state of Queensland, easements for view, or for environmental purposes are not considered acceptable, while the right granted by an easement must not be vague, imprecise or indefinite and must be for a matter which is capable of being the subject of a grant (Registrar of Titles and Registrar of Water Allocations, 2009). What is more, only a limited number of PLRs are explicitly defined in depth, height or volumetric terms, e.g. restrictions related to UAV flights, or constructions in the vicinity of airports, thus depicting the lack of a full 3D regulatory framework to support land policies (Dimitrios Kitsakis & Dimopoulou, 2016, 2017a).

Processes related to the "preparation of case", as defined by (Ferlan et al., 2007), introduce new requirements and challenges mainly in terms of modelling the boundaries of the new, stratified real property units. R. James Thompson, van Oosterom, Karki, & Cowie (2015), classified spatial units in the following types:

- 2D spatial units. 2D spatial units are defined by their 2D boundary points (x/y or latitude/longitude), thus constituting an unbounded space prism above and below 2D defined land surface. This does not preclude limitations on the extent of real property ownership; however, there are no explicit upper and lower boundaries of the spatial unit.
- Building format units. A building format unit is legally defined by the structure of the building that contains the unit. Boundaries of such units are defined by reference to the outside, inside, median or other location of a building's structural elements, such as floors, walls or ceilings.
- 3D spatial units. 3D spatial units are defined by a set of bounding faces, which are themselves defined by a set of 3D points and an interpretation. Based on the definition of their shape, 3D spatial units are further sub-classified to (R. J. Thompson et al., 2015):
    - unspecified top (to the depth of …),
    - unspecified bottom (below the depth of),
    - two horizontal planes defining top and bottom (a "slice"),
    - two (potentially non-horizontal) surfaces defining top and bottom,
    - faces restricted to horizontal or vertical,
    - textually described face(s),
    - single valued (for any XY position, only one range of Z permitted),
    - presence of caves and/or tunnels,
    - moving face(s) (ambulatory),
    - non-planar (curved) faces,
    - non-contiguous volumes

Above mentioned categories derive from cadastral regulations of several jurisdictions internationally, and constitute the cadastral objects recognised by cadastral authorities (R. J. Thompson et al., 2015). The variety of spatial units reflects the variety of 3D real property unit definitions globally, as well as the different "translation" of such definitions to cadastral objects. 2D spatial units reflect the traditional perception of the continuous, indivisible column of real property. This concept is the most common regarding the registration and the representation of real property units on cadastral databases and maps. It provides a simple, clear and cost-effective way to depict the rights that different beneficiaries hold on land. The lack of vertical delimitation of 2D spatial units complies with the vague definition of the vertical extent of real property, as defined in the Civil Codes of most Civil and Civil Law-based jurisdictions (the upper and lower boundaries of real property in each region, derive from local land use policies and corresponding Public Law restrictions), but do not provide insight on the complete legal situation of each land parcel (e.g. boundaries of vertical exploitation or other 3D spatial restrictions). The main ways of registering and representing overlapping real property rights on cadastral maps within the 2D spatial objects concept, is through tags (e.g. polluted soil or underground networks in The Netherlands) or specific symbology (e.g. Sweden, Norway) (Figure 44). This allows interested parties to be notified of the existence of (particular types) of stratified interests, or restrictions, but does not provide a complete and clear representation of the legal status that applies on a land parcel and the space above and below it. Complexities are intensified in case of cross-parcel stratified rights, which require significant cognitive effort to mentally reconstruct the real legal situation that applies to all the involved parcels. Cadastral registration of buildings usually requires submission of cross-section diagrams, showing the vertical extent of stratified real property units.

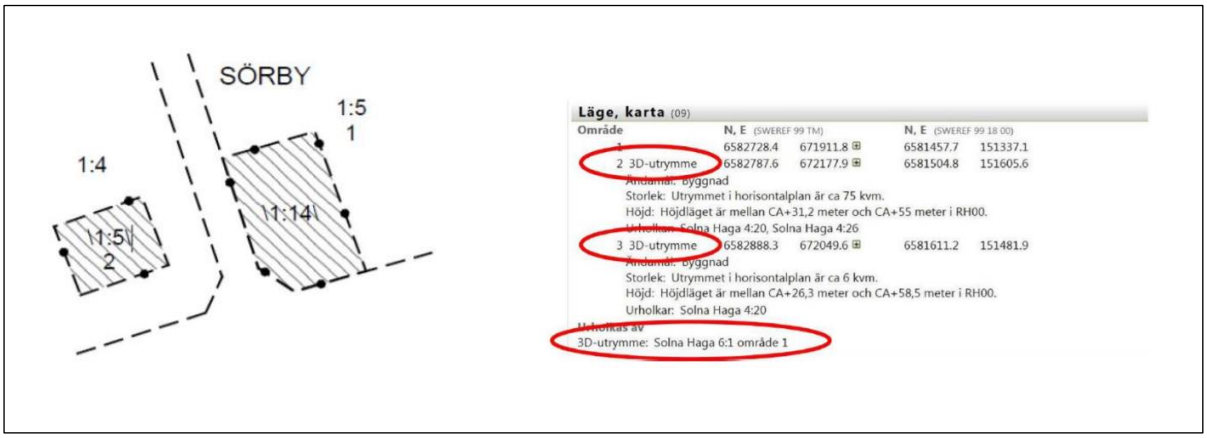


Figure 44. Left: Representation of 3D property units in the Swedish cadastral index map (Efi Dimopoulou et al. 2018). Right: textual information of 3D real property units in the Swedish Land Register (Mohamed El-Mekawy, Paasch, and Paulsson 2014).

Several researchers internationally have identified deficiencies in using 2D methods to define overlapping RRRs on land (Aien et al., 2013; Karabin, 2012; Dimitrios Kitsakis & Dimopoulou, 2014; Rajabifard et al., 2014; Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013; Jantien Stoter et al., 2016, 2013; Jantien Stoter, Van Oosterom, et al., 2012). Ho (2014), summarises such deficiencies to the following:

- Textual descriptions can often be confusing to the reader, who is assumed to be visualising real property identically to the surveyor.

- 3D RRRs spanning on irregular shapes and multiple levels cannot be easily represented as floor-plan projections, or as cross-section diagrams. In case of complex RRRs presented by multiple 2D plans, increased cognitive load is required by non-experts to decipher the 3D content of such plans.
- Complex 3D RRRs are not sufficiently mapped and visualised through 2D parcel-based cadastral data (especially in case of cross-parcel developments).

Consequently, the need of 3D visualisation of real property boundaries has emerged for stratified real property units, in jurisdictions with or without statutory 3D real property legislation, both in Civil and Common Law. In the Netherlands, although there is no specific requirement regarding 3D description of stratified real property rights (except of the general principle that such rights need to be identifiable), sketches and more detailed drawings (including cross-section diagrams, or 3D PDF drawings) can be registered during land registration to clearly reflect the legal situation (Jantien Stoter et al., 2013). However, attachment of sketches or 3D drawings is optional, while, to be legally binding, they need to refer to reliable and observable reference points, as well as to be declared by all parties involved to a transaction, that the 3D boundaries reflect their intentions (Jantien Stoter et al., 2013). Dutch examples of 3D cadastre registration presented by Jantien Stoter et al., (2016) and (Jantien Stoter et al., 2017), exploit the BIM models of objects' physical space, further enhanced to be used for demarcating their corresponding juridical boundaries, since physical boundaries are not identical to the juridical ones. The use of BIM models in real property rights' modelling and land administration has been studied by several researchers during the last years, e.g. (Atazadeh et al., 2016; Atazadeh, Kalantari, Rajabifard, Ho, & Ngo, 2017; Mohamed El-Mekawy et al., 2014).

Building format and 3D spatial units are spatial units traced in jurisdictions where statutory 3D Cadastre legislation is established. Both these types of units reflect the spatial connotation of real property stratification, based on the geometrical definition of the shape of each type of volumetric real property. In case of real property volumes related to a construction, such volumes may be defined by reference to its structural elements. 3D spatial units are more flexible since they do not need to be related to a construction, so they may refer to rights with no physical component or PLRs. On the other hand, 3D spatial units need to be defined by a set of 3D points. Isometric views of 3D real property units are commonly shown on survey plans, although not recorded to the cadastral databases. Use of isometric views provides a clearer representation of the legal situation, compared to traditional 2D plans. However, it reflects the situation applying to surface parcel-level cases of real property stratification, thus it cannot be used for cross-parcel, stratified real property rights. Additionally, although isometric views provide better insight on the 3D aspects of real property rights in strata, they still constitute 2D projections of 3D space, therefore, they cannot be subject to 3D management procedures, e.g. querying, or interrelation with other 3D units.

Definition of boundaries also relates to the distinction between general and fixed boundaries. Atazadeh, Kalantari, Rajabifard, & Ho (2017), classify the taxonomy of boundaries by reference to the middle, the interior, the exterior, or other location of

walls, floors and ceilings, as a component of the structural type[102] of general boundaries. The concept of general boundaries, mostly adopted by Common Law jurisdictions, provides a relatively easy way of demarcating real property units, by reference to visible landscape features, instead of high precision measurements. General boundaries provide a clear, cost and time-effective way of identifying and mapping real property boundaries, fully compliant with the concept of 2D representation of real property and of the "indivisible" column of real property rights on land. However, when it comes to describing the extent of real property units that are situated on different levels, and on which different real property rights are imposed, reference to specific landscape features becomes challenging, if not impractical. Although the definition of planar boundaries in relation to characteristic landscape features is feasible, this is difficult to apply to the upper and lower limits, as neither do physical landscape characteristics exist in different height levels (or if they exist, they do not coincide vertically with real property units), nor are real property units always visible (e.g. underground real property units), to be interrelated with landscape features. In Australia, the state of Queensland, provides for definition of 3D real property objects by reference to real world objects[103], while in the state of Victoria, reference to real world objects may pertain floors, walls or ceilings of a 3D parcel above or below ground level. Legislation in Canadian provinces requires 3D spatial units to be defined by horizontal and vertical planes (depending on jurisdiction, boundary definition using inclined planes, arcs or other shapes may be allowed), using geodetic elevation (Alberta Land Titles Act, Sec. 86; New Brunswick Air space Act, Sec. 4; British Columbia Land Title Act, Sec. 144). In Civil Law jurisdictions general boundary definitions are not very common. Exceptions can be traced in several countries, mainly regarding separation of apartments within condominium schemes, by reference to apartments' floor level (e.g. Switzerland-FIG working group 3D-Cadastres, 2018). The above show that the general boundary concept needs to be enhanced by mathematically defined planes, in order to ensure distinct real property object boundaries of stratified real property units. In contrast with general boundaries, the concept of fixed boundaries involves the precise definition of a real property unit's boundaries on a coordinate system. Consequently, this increases requirements in time and cost for the demarcation, measuring and registration of fixed boundaries, but ensures parcels' shape and position, minimises boundary disputes, and provides reliable data for spatial planning purposes (G. Navratil, 2011). Within the context of stratified real property units' registration, fixed boundaries may ensure the accuracy of stratified real property units' boundaries, but introduce increased costs and ambiguities in surveying non-material boundaries. It is noted that although the majority of cadastral systems worldwide are based on coordinates to register and survey real property boundaries, only a limited number of jurisdictions attribute authoritative character to registered coordinates, e.g. Austria, China and Singapore (Andreasson, 2006; FIG working group 3D-Cadastres, 2018; Gerhard Navratil, 2008). (Grant, Mccamley, Mitchell,

[102] According to the classification of (Atazadeh, Kalantari, Rajabifard, & Ho, 2017), general boundaries compose of three categories: the structural (that are defined and measured by considering the building itself or a part of it), the ambulatory (that are defined based on observing the movement of dynamic natural features), and the projected boundaries (that are mainly delineated by extending structural boundaries in both horizontal as well as vertical directions).

[103] However, reference to natural world objects is incidental and bounding surfaces need to be capable of being defined mathematically (Department of Natural Resources and Mines, 2013).

Enemark, & Zevenbergen, 2018), highlight several reasons behind this, both of technical and practical nature. Characteristic examples are land deformation (which results in gradual boundary movement in the course of time), the (cognitive) separation of boundaries from physical landscape objects (such as fences, pegs etc.) to imaginative, non-physical coordinate boundaries, and the need of continuous legal processes for the ratification of ground control points' geodetic readjustment, or the change to a different coordinate system (Grant et al., 2018). The same defects also apply in case of stratified real property units, probably to a greater extent. Identification and demarcation of legal volumes, not related to physical constructions can easily apply to computer environment, but their implementation in the field requires the use of positioning system technology. This also relates to precision levels of height measurements that can be achieved by different positioning systems. Brown (2011), supports the concept of a legal, coordinate cadastre, pertaining 3D characteristics, although within the context of a hybrid approach as presented by Jantien Stoter (2004a), instead of a full 3D Cadastre system, supporting the creation of stratified real property units. Reluctance towards legal, coordinate boundaries is also reflected by Singaporean system of authoritative cadastral boundaries, where boundary coordinates are not guaranteed by the State, as it would be expected (Andreasson, 2006). In stratified developments, especially in urban areas, 3D boundary issues are considered to be less controversial, since involved parties identify boundaries in terms of constructions (or structural elements) and are less interested in the exact position of legal boundaries (Andreasson, 2006). For 3D cadastral purposes, the concept of legal, coordinate cadastre only applies in China (FIG working group 3D-Cadastres, 2018). Legal interests related to a physical object, or just to volumes of airspace can be established through 3D coordinates to safeguard the legal rights of each stakeholder, even supported by the issuing of 3D certificates (Guo et al., 2014). However, limitations deriving from supporting laws and regulations are still identified and inhibit practical application and handing of complex cases of real property stratification (Guo et al., 2014).

Cadastral decision and registration processes are linked, since registration of real property to the cadastral registry takes place after the approval of the documentation supporting real property formation. Each country follows different procedures and sets different requirements so that formation of a new real property gains force of law. Therefore, there will be no elaboration on the specifications of the cadastral procedures of different countries, but focus will be given on cadastral procedures' characteristics that are related to 3D real property formation.

Cadastral procedures regarding the approval and registration of real property formation, do not distinct between stratified or non-stratified real property units. In Civil Law jurisdictions where no 3D real property legislation is established, only submission of the documentation stipulated by law is required. If such documentation follows the requirements prescribed in legislation, the real property formation is approved and the new real property is registered (J. A. Zevenbergen, 2002). The most significant requirement for real property formation, is to clearly present real property boundaries in the cadastral survey plans, e.g. Swiss Ordinance on Official Cadastral Surveying (1992), Art. 7; Cadastre Act of Norway (2005), Section 7; Swedish Real Property Formation Act (1970), Sec.2; Greek Law 2664/98, Art. 11. (4), thus reflecting the "specialisation principle". However, there is no provision regarding 3D presentation and documentation of real property boundaries. This derives either from the fact that legislation does not explicitly provide for 3D real

property formation (which applies in most Civil or Civil Law based jurisdictions), or from the legal provisions that are based on technological capacities of 2D drawing and recording systems. Such restrictions can be traced not only in Civil law, or Civil Law-based, jurisdictions that do not support 3D stratification of real property, but also in those that have already introduced legislation supporting stratified real property units. For example, in Sweden digital building plans are provided by the entrepreneurs to the cadastral authorities and are often used in the 3D property formation process, but they are used as input for 2D analogue cadastral boundary plans. Therefore, despite the existence of digital information on 3D boundaries, such information is not stored available in the national cadastral index map or in other centralised registers (Mohamed El-Mekawy et al., 2014; Larsson, Paasch, & Paulsson, 2018). Similarly applies to Norway, where volumes are merely registered and represented in 2D, using specific marking to denote their three-dimensional nature (FIG working group 3D-Cadastres, 2018).

Among the Civil Law and Civil Law-based jurisdictions' cadastral approval and registration context, the Dutch and the Chinese legal framework do not follow aforementioned two-dimensional approach, but opted for procedures that support three-dimensional characteristics. The Dutch approach, aims to integrate the capabilities of 3D technology to the existing legal framework, by maintaining the widely-used 2D registration system and without need of legal amendments to support 3D registration of stratified real property units (Jantien Stoter et al., 2017). Such concept, includes registration of 3D volumes in pdf format as described in (Jantien Stoter et al., 2016, 2017). 3D registration is based on extracting legal volumes out of 3D BIM models. Registration procedure follows the same process with traditional 2D real property units, but including 3D data, both in form of a 3D pdf drawing showing the geometries of the legal volumes, and 3D data are stored and are publicly available to the public registers (Jantien Stoter et al., 2017). Dutch approach of 3D real property registration constitutes an efficient way of registering stratified real property units within the Civil Law cadastral framework. Despite its advantages, such system still carries Civil Law limitations related to the formation of stratified real property units. The advantages and limitations identified in the Dutch registration of stratified real property units' formation are summarised in Table 12[104].

Table 12. Summary of advantages and disadvantages of the Dutch approach on 3D registration of stratified real property units.

Advantages	**Limitations**
-Clear representation of complex, multi-level property rights -Operating within existing legal framework (no need of legal amendments) -Better insight of multiple overlapping real property unit cases -Increased accuracy and elimination of mismatches between 2D and 3D parcels -Reduction of costs	- Reluctance towards the use of 3D - Legal value of 3D data against traditional 2D data - 2D formalities co-exist with 3D - Problems in assigning ID to stratified units - Limitations in case of non-explicitly defined legal spaces (e.g. PLRs not related to physical space) - Technical issues regarding requirements of 3D drawings' registration

[104] Advantages and disadvantages are based on the findings of (Jantien Stoter et al., 2016, 2017) and on evaluation by the author of this thesis.

On the other hand, in China a 3D registration framework is in force[105], integrated within the 2D one, also enriched with specific requirements regarding registration of 3D real property units (FIG working group 3D-Cadastres, 2018). Such requirements refer to the validity of 3D objects (for example being closed volumes, not overlapping with neighbouring 3D objects). Chinese registration system provides for separate[106] registration of land and buildings, in accordance with the Chinese concept of state-owned land. Only land use rights can be acquired by individuals, along with ownership rights on buildings or structures constructed on state land (Xu, 2015; Z. Zhang et al., 2017). According to article 138 of the Property Law of People's Republic of China (2007), contracts concerning the right to use land for construction are required to clearly demarcate the space used for buildings or constructions (Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). Within the same context, Regulations of Shenzhen Economic Special Zone on the Registration of Real Estate (1993), require, among others, that the location, the coordinates and the shape of each real property are recorded for the registration of real estate (art. 8). Article 30 of the same document, explicitly requires the submission of 3D building drawings for the registration of ownership rights on a building or construction. Cadastral database of Shenzhen allows for 3D modelling and visualisation of stratified real property units, performing queries on the 3D objects (FIG working group 3D-Cadastres, 2018), as well as issuing of 3D certificates on rights that apply to 3D legal objects. Chinese 3D based registration system (in the regions where it is fully applicable), safeguards the legal rights of a beneficiary (as applies in case of contemporary 2D registration systems), by clearly describing the spatial shape and the related right information of a 3D legal object (Yu et al., 2012). This entails that spatial and property rights' information, both on 3D space and on 2D land, need to be recorded to the cadastral registries, so that relation of 3D land objects with traditional 2D land objects can be derived. Modern methods of cadastral surveying and mapping allow for easy, cost-effective and high-precision 3D data acquisition, thus serving the needs of three-dimensional objects' representation. However, since cadastral registration does not refer to physical objects, but to legal ones (which in most cases are not identical to physical objects), 3D real property boundaries cannot be directly surveyed and mapped. (Jantien Stoter, 2004a), argues that planar 2D coordinates can be used, combined with height and depth limitations of the 2D boundaries on the land surface, to generate the 3D boundaries of real property. This may be the case in simple legal object geometries, with vertical facades on the land surface. Conversely, limitations arise in case of more complex legal object geometries and PLRs. Guo et al. (2014), note that, even within the Chinese 3D cadastral framework, the shortage of different types of 3D data, such as under and above ground networks or PLRs, allows for 3D verification only between land-related cadastral objects, thus inhibiting complete 3D verification between all different types of 3D RRRs. Table 13, summarises the advantages and the limitations of implementing a 3D real property registration system, as applies in China.

[105] Even within the Chinese cadastral system, such capabilities do not cover all the land parcels of the country. Most such capabilities are supported within the cadastral system of Shenzhen (FIG working group 3D-Cadastres, 2018).

[106] According to art. 62 of the amended People's Republic of China on Urban Real Estate Administration, joint registration of land use rights and building ownership rights is allowed (Xu, 2015).

Table 13. Advantages and limitations of Chinese 3D real property registration.

Advantages	Limitations
- Statutory 3D RRRs - Clear representation of complex, multi-level property rights - Better insight of multiple overlapping real property unit cases - 3D management of real property (registration using 3D coordinates, 3D querying, 3D certificates) - 3D procedural pipeline	- Need of legal modifications to property and cadastral laws - Need of 3D cadastral databases - 3D surveying difficulties (lack of 3D data, limitations regarding 3D survey of legal spaces not identical to a physical construction)

In Common Law, or Common Law-based, jurisdictions, legislation regulating the registration and approval of real property units' formation processes are better adjusted to the formation of stratified real property units. This mainly derives from the fact that a significant number of Common Law, or Common Law-based, jurisdictions have amended their legal statutes to incorporate stratified real property units, and to the nature of the "estate" system in these jurisdictions, which entitles specific proprietary rights in respect of land, which can be subject only to crown or state ownership (contrary to the absolute character of the ownership right that applies in Civil Law).

Canadian legislation stipulates specific requirements regarding approval and registration of stratified real property units. In Alberta, Land Titles Act, stipulates the requirements for the registration of a survey plan. Requirements of survey plans for registration are stipulated in Sec. 77(1), and for stratified real property units ("strata space" according to Alberta's terminology) in Sec. 86(5)[107]. Therefore, in order for a strata space survey plan to be registered, strata space boundaries need to be related to monuments of known elevation or survey control markers, and their location should be related to the external boundaries of the parcel within which strata spaces lie (sec. 45). Similar stipulations can be traced in the province of British Columbia. Land Title Act requires, among others, that "air space" plans should present the lateral, the upper and lower boundaries of stratified real property units, as well as the geodetic elevation the ground surface parcel and of the air space parcels (sec. 144). In Australia, state legislation supports formation of stratified real property units, as well 3D data acquisition and registration of 3D objects. Legislation regarding 3D real property units in the states of Australia, treats 3D objects similarly to traditional 2D cadastral objects (Karki, 2013). Depending on each state, 2D and 3D plans (in form of cross section or isometric diagrams) are required to be submitted for registration[108], although the 3D content of such plans is not registered to the cadastral database of each state. Similarities can be traced also in Singapore, Malaysia and New Zealand. In Malaysia and Singapore, despite that legislation provides for stratified real property units, registration of such type of real property, although permitted, is confined within the conventional 2D registration framework; 3D characteristics are presented in analogue survey plans (using parcel footprint, cross section, or isometric diagrams), but are lost in vector format, since they are not registered in the cadastral database (Khoo, 2011; Rajabifard et al., 2018). In New

[107] According to both of the above mentioned provisions, survey plans should be in accord with the Surveys Act.
[108] Examples of stipulations requiring 3D diagrams for 3D real property registration can be traced in (Department of Natural Resources and Mines, 2013), (NSW-LRS, 2019).

Zealand, 3D survey data is included in cadastral plans, although it is not captured in Landonline[109] (T. Gulliver, Haanen, Goodin, & Zealand, 2016). The main difference of Australian and New Zealand survey plans is that parcel boundaries are defined by bearings and distances, structures, or natural boundaries, which may or may not contain coordinates (FIG working group 3D-Cadastres, 2018 Victoria, Queensland; T. F. D. Gulliver, 2015; Karki, 2013). Despite the lack of 3D data registration in Australia and New Zealand, their statutory provisions that allow for the formation of stratified 3D real property units, lay the ground for improving registration and representation complexities of overlapping RRRs, in accordance with the directions for cadastral reform and innovation in Australia which are set in Cadastre 2034 (Intergovernmental Committee for Surveying and Mapping, 2015). Research is already conducted on developing 3D cadastral registration systems in several states of Australia as well as in New Zealand. Atazadeh et al., (2016); Atazadeh, Kalantari, Rajabifard, & Ho, (2017) exploit 3D digital modelling, specifically BIM, to support management of complex ownership interests in multi-level buildings, within the legal framework of Victoria in Australia. Shojaei, Olfat, Rajabifard, & Kalantari (2018), present a roadmap for the development of a fully digital 3D cadastre in Victoria, setting two goals. The first goal, is a short-term vision of developing infrastructure and services enabling registration and submission of digital data ePlan) for all 2D cadastral plans. The second goal, sees in the long-term, aiming to develop registration and submission framework of 3D cadastral plans (Shojaei et al., 2018). Land Victoria has already implemented a 3D prototype where legal and physical objects created by a building subdivision plan can be stored, visualised and queried (Fig. 45).

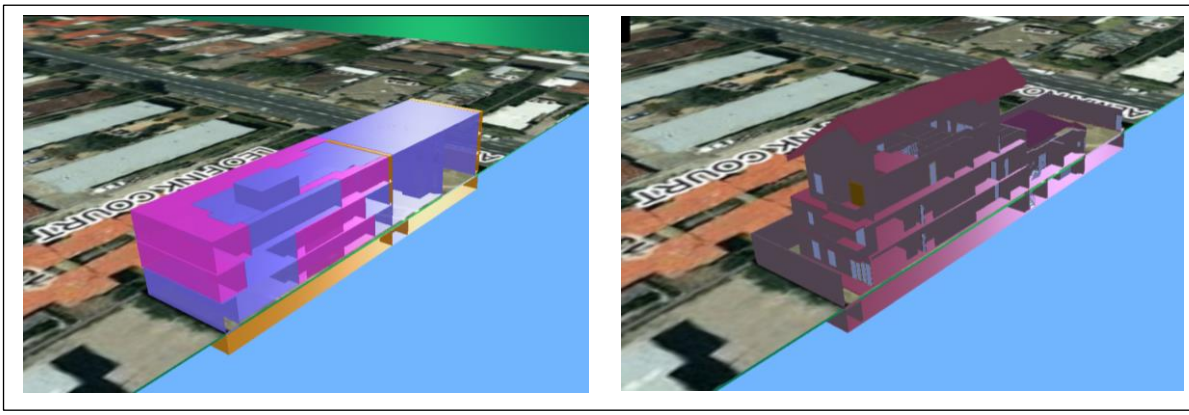


Figure 45. Left: Cross-section of 3D legal objects in Land Victoria's 3D ePlan prototype. Right: Cross section of 3D physical objects in Land Victoria's 3D ePlan prototype (Land Victoria, 2019).

In Queensland, cadastral plans present various information regarding the survey, such as dimensions, reference marks, geodetic control points, encroachment information, details of past surveys, isometric views, leases and covenants. Such details are not presented to the digital cadastral database, which simply shows the parcel polygon and other attributes such as tenure type and ownership details including all other RRRs on land parcels. Therefore, despite the abundance of information on analogue survey plans, the DCDB constitutes merely a graphical representation of the information from the cadastral plan and the Titles office (Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). To modernise the

[109] Landonline is the designated electronic facility for receiving, storing and managing cadastral survey datasets (T. F. D. Gulliver, 2015)

cadastral system, using 3D digital models, thus allowing enhanced spatial data analysis and more efficient and accurate public and private decision-making (ACIL ALLEN Consulting, 2017), the 3D Queensland project has been designated. Emphasis is given to the format and the validation[110] of the 3D digital geometries during registration process, so that 3D models can be managed and queried, also maintaining their credibility.

In Israel, where specific legislation introducing 3D real property units is under parliamentary discussion, cadastral registration is required to be conformant with existing cadastral reality: surface parcels can be subdivided into spatial subparcels bounded and defined by a 3D outline and extending on a specified volume, preserving the title rights on the surface parcel; spatial subparcels will be included in the existing registration block as a part of the surface parcel (Shoshani et al., 2004). Within this context, Adi et al. (2018) offers corresponding technical pipeline of the 3D registration process, starting from 3D planning points to the creation of spatial parcels and export to 3D database.

7.1.4 Relation of 3D real property objects to traditional real property units

Given that stratified real property units cover the smaller part of national land administration systems compared to the traditional real property units, and that they derive by vertical subdivision of the latter, both concepts need to be "compatible". Moreover, it is required that both concepts are functional even when applied to the space of the same land parcel, so that the one does not inhibit efficient operation of the other.

Within this concept, limited real property rights seem to be more efficient, since their operation is fully compliant with the traditional concept of real property ownership and allocation of rights to individuals other than the surface parcel owners. All types of limited real property rights provide to their holders, the right to exploit the space above and/or below the land surface. Regulations based on the specifications of each different right's type are stipulated, offering a clear and efficient regulatory framework regarding such rights. For example, in composite ownership concepts, the extent of the rights on exclusive ownership (or of exclusive use), as well as the rights on the surface parcel and the common parts are well defined, while explicit provisions regulate the encumbrance of composite ownership units by secondary rights. Similarly applies to the rest of limited real property rights. Therefore, in view of the relation between surface parcels and stratified real property units (deriving from limited real property rights), limited real property rights provide a robust and functional regulatory framework[111]. This efficiency may explain, to an extent, the reluctance showed by Civil Law jurisdictions in modifying their legal framework to introduce independent 3D real property units.

The same goal, integration of 3D real property units to contemporary land parcel framework, is also aimed by Common Law jurisdictions with statutory 3D real property units (the same also applies to the Civil Law jurisdictions of Sweden and

[110] An initial categorisation of 3D real property units is conducted by (R. J. Thompson et al., 2015), while (Karki, Thompson, & McDougall, 2013) propose a set of validation rules to single geometric objects, to the relationship of objects on a single survey plan, and to objects that are independently defined on separate plans. Elaboration on the ways to store and validate 3D cadastre data can be traced in (Janečka et al., 2018).

[111] However, this does ignore the limitations of limited real property rights considering real property stratification.

Norway which have, as well, introduced stratified real property units). Extending the concept of real property to the third dimension and allowing vertical subdivision of real property, introduces new, more complex, spatial relations among the subdivided real property units, which need to be regulated. Since, in several jurisdictions, "empty" real property volumes, not referring to a construction, are allowed to be created, regulations between this type of real property units and the rest are also required. Such relations are addressed through generic restrictions, mainly by reference to statutes regarding surface parcel rights (considering 3D real property units equivalent to land), through stipulations of implied easements, which regulate specific aspects of neighbouring real properties' relations, or through explicit regulatory provisions.

The variety of approaches followed by jurisdictions with statutory 3D real property units, clearly reflects the different perceptions in regulating the relation between 3D real property units and surface parcels, even though each of them aims to integrate 3D property to the traditional real property framework (in order to avoid potential ambiguities). Treating stratified real property units as contemporary land parcels, requires that regulatory legal statutes are applied in proportion to the three-dimensional character of stratified real property units, which is open to interpretation. Full regulation of the relations between 3D real property and surface real property units by statute, also introduces the risk of ambiguities regarding application of the prescribed regulations, as well as of cumbersome administrative procedures. Moreover, statutory provisions may be limited to specific aspects, leaving aside other aspects. The same limitation also applies to the case of partial regulation of the relation between stratified and traditional real property units; regulation of specific aspects by statute allows for clear relations between stratified real property and traditional land parcels (such as lateral support or access), although leaving non-regulated aspects open to interpretation.

7.1.5 Distinction between 3D real property and limited real property rights

Distinguishing stratified real property units formed using limited real property rights from those formed as individual 3D real property units is required, as each concept ascribes to its holder different legal powers, while it is subject to different limitations on its use and interrelation with other types of RRRs, thus clarifying the role of stratified real property units as individual real property units or as "derivative" units created under subordinate rights.

As regarding to Civil Law jurisdictions with no statutory 3D real property provisions, only the concepts of composite ownership and special real property rights and objects can be regarded as individual stratified real property units. This allows their holders to subdivide specific volumes of space on different height levels as individual real property units (although subject to the requirements of corresponding legal statutes or customary law), which are also subject to secondary rights. Rights of superficies and emphyteusis also provide for individual ownership of constructions above or below a surface parcel, also subject to secondary rights. As already mentioned above, rights of superficies are used in The Netherlands for the establishment of underground infrastructures. However, their inherent limitations, including that they are purpose-based, as well as their establishment that is subject to conditions, their necessary relation to a land parcel and their limited duration, limit their suitability as a means of real property stratification. Besides, none of them allows for stratification of real property on multiple levels for different right holders. Servitudes

(or easements) only provide specific use rights on real property owned by another individual. Although servitudes (or easements) are not necessarily related to a physical construction and may refer to the space above and below land's surface, they are still related to the surface land parcel, while also subject to content limitations and cannot be applied in multiple height levels, or be subject to other limited real property rights. It can be concluded that limited real property rights cannot create individual, stratified real property units; limitations on land parcel ownership can be imposed in favour of a person other than the surface parcel owner, while remaining inferior compared to ownership rights. Exceptions can be traced in case of composite ownership rights, special real property rights and objects, as well as of constructions erected under emphyteusis or rights of superficies concepts, with the limitations and disadvantages mentioned above.

Jurisdictions where 3D real property units are provided by statute, which include Common Law jurisdictions as well as Sweden and Norway, explicitly define stratified real property units as individual real property units, which should be dealt as land. Depending on jurisdiction, 3D real property units may be subject to limitations, some of which are similar to those applying in case of limited real property rights, such as limitation of 3D parcels within the horizontal boundaries of the surface parcel, or necessary relation to a construction. Despite these limitations, 3D real property units constitute separate legal entities, which overcome the restrictions related to stratification through limited real property rights (they allow stratification of real property on multiple height or depth levels, they are subject to subordinate rights and, in most cases, they are dissociated from the existence of a construction and they can be used to create "empty" RRRs' volumes). Swedish provision regarding use of 3D real property units only in cases where other types of real property rights are not suitable, constitutes the most characteristic example of the separation between stratification concepts through limited real property rights and from statutory 3D real property legislation.

7.2 3D PLRs

3D stratification of PLRs constitutes a best practice per se, considering that the aim of Land Administration Systems is to contribute to the efficient land management, by presenting the full range of RRRs that apply on land. Instead of merely registering restrictions that are imposed on land parcel level, stratification of real property allows for more efficient exploitation of land, as restrictions can be imposed on specific volumes (not on the land parcel as a whole), thus providing for more space available for exploitation, and allowing for "spatially-specific" regulations (e.g. archaeological, or environmental protection volumes). Definition of PLRs in 3D space, should not be perceived to be prescribing the formulation of policies; on the contrary, it serves as a tool for precise identification of the space where special RRRs apply, thus contributing to more efficient implementation of land-related policies.

As presented in section 5.6, PLRs cover various scientific fields and derive from different, highly divergent qualitative and quantitative parameters. Currently, each country has established different, separate or integrated, repositories and registries either regarding environmental components (physical, biological, socioeconomic environment and cultural heritage), or presenting zones where restrictions apply, due to local environmental characteristics (e.g. proximity to an archaeological area). The type and the way of the information recorded, depends on the level of development of national spatial data infrastructures. PLRs are presented as points, 2D polygons or tags, with reference to the legal document that imposes a restriction on land (which is defined descriptively in various terms[112]) (Figure 46). In European Union, integration between datasets among member-states is aimed through the INSPIRE initiative. Although INSPIRE does not constitute a registry of PLRs, it records several components that are related to PLRs, therefore, it can be exploited for PLR purposes, to some extent (Dimitrios Kitsakis et al., 2019).

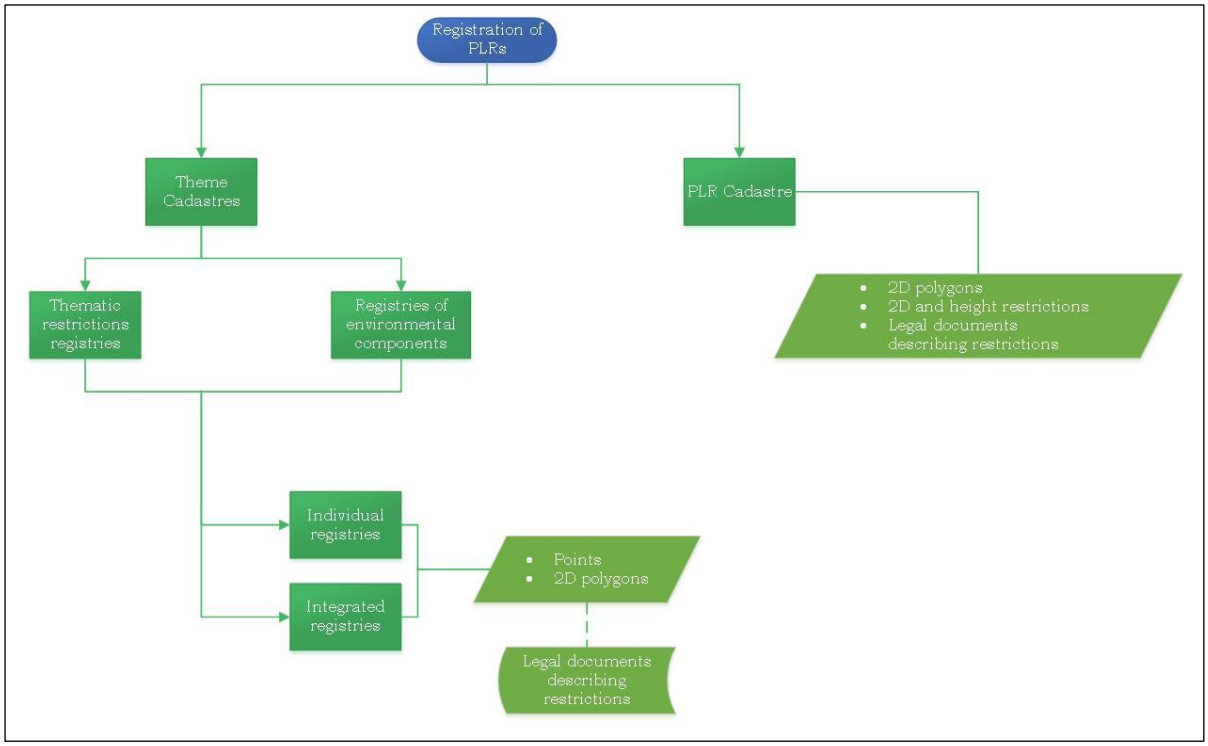


Figure 46. Ways of PLR registration.

The main issues with current way of imposing PLRs that extend to 3D space, can be summarised in the following (D. Kitsakis & Papageorgaki, 2017; Dimitrios Kitsakis & Dimopoulou, 2016; Jesper M. Paasch et al., 2016):

- *Definition of PLRs.* PLRs refer to different natural, physical, biological or other aspects, thus they are defined using different components. Therefore, spatial (2D or 3D) definitions are used, or others based on the concentration of pollutants on soil, air and water, or other critical values.

[112] These can be on horizontal plane, depth or height, concentration of pollutants and others. For characteristic cases of 3D PLRs defined by qualitative or quantitative components, please refer to (D. Kitsakis & Papageorgaki, 2017; Dimitrios Kitsakis & Dimopoulou, 2017a, 2018; Dimitrios Kitsakis et al., 2019).

This means that components which are not explicitly defined spatially, need to be "translated" in spatial terms.

- *Delineation of PLRs.* PLRs are mainly demarcated on horizontal plane. In fewer cases, planar boundaries of PLRs are supplemented by reference to height or depth restrictions. Regardless the case, the exact location where PLRs apply cannot be identified merely based on cadastral registration recordings[113].
- *Registration of physical characteristics instead of PLRs*. Registered data may refer to qualitative or quantitative values of an examined attribute, for example annotation of the existence of a monument or of polluted soil, or of levels of pollutants' concentration on air within a specific range. However, such information is indicative and does not provide insight on the RRRs deriving from the examined attribute's value.
- *Lack of 3D real property management capabilities*. Treating land as a vertically indivisible legal entity inhibits efficient management of real property, as 3D restrictions are not limited to a specific volume of land but affect a land parcel as a whole. Similarly, there is no "volumetric" expropriation applying. Private land parcels, or parts of them, are compulsory purchased by the state as a whole (even when only a, under or above ground, volume of space is involved).

Considering that PLRs in most cases refer to a 3D space (which may be directly or indirectly defined), it is clear that implementation of land policies would be improved by expanding RRRs to 3D space. This implies that stratified real property units can be used for all different types of RRRs, instead of being established exclusively for construction projects. This concept mainly applies in Common Law jurisdictions with statutory stratified real property units, such as Australia and Canada (FIG working group 3D-Cadastres, 2018; Dimitrios Kitsakis, Paasch, Paulsson, Navratil, et al., 2018). Within the concept of environment and heritage conservation, Common Law framework provides also for conservation easements. This concept has been already discussed earlier (section 3.2.1), along with its limitations when referring to 3D PLRs (6.5).

Civil Law jurisdictions do not provide for volumetric excision, or encumbrance, of land for PLR purposes. Restrictions are imposed on a land parcel as a whole, while if such restrictions are unduly burdensome to the real property, real property is expropriated (wholly or partially, not allowing expropriation of delimited volumes of space). According to the FIG working group on 3D-Cadastres, (2018), Civil Law jurisdictions relate 3D spatial units to physical constructions or objects[114]. However, there are several exceptions identified; most of these refer to mineral rights and

[113] The fact that only a limited number of PLRs are registered in cadastral databases increases complexities, as interested parties need to refer to various registries recording the different types of PLRs. The lack of a centralised PLR repository, does not allow identification of multiple PLRs that apply to the same location, while even in case that such repositories exist and provide overlay capabilities, e.g. integrated registries, or the PLR cadastre of Switzerland, the lack of 3D registration results in limitations on the vertical interrelation of overlapping PLRs.

[114] However, even among these countries (where 3D spatial units are required to be related to physical constructions or objects), the need of spatial units referring also to airspace or subsurface volumes is noted, regardless of the existence of a physical construction or object, (e.g. Germany).

building height restrictions in the vicinity of airports, while in fewer cases, e.g. China, Croatia and Finland, reference is made to 3D spatial units not related to physical constructions or objects. In Portugal, 3D spatial units referring to crops, underground water and water bodies exist (de Almeida, Ellul, & Rodrigues de Carvalho, 2013), which although do not constitute PLRs, they can serve implementation of 3D land-related policies (such as groundwater or soil protection). Jurisdictions of Civil Law with statutory 3D real property framework (Norway and Sweden) limit the use of stratified real property units to construction objects, thus 3D spatial units cannot be exploited to serve implementation of PLRs.

It needs to be noted that existence of 3D RRR capabilities provides the legal instruments to impose volumetric PLRs on real property, thus facilitating implementation of land policies (many of which have explicit or implied 3D connotation), but does not resolve the issue of "translating" implied or qualitative PLRs to 3D volumes (Dimitrios Kitsakis & Dimopoulou, 2017a, 2018). Research on the uses of 3D modelling techniques to represent physical characteristics (e.g. of soil or groundwater) is already in progress, with effective results and 3D analytical tools are already used for environmental studies. 3D geological and soil models are used to better reflect geological and soil aspects, providing improved visual information of geological and soil information (Jarna et al., 2015). 3D geological modelling techniques and the use of these tools in bedrock, geophysics, urban and groundwater studies in Norway are described by (Jarna et al., 2015), while (Lin, Zhou, Lv, & Zhu, 2017), describe a method of developing 3D geological models from 2D geological maps. 3D subsurface maps are already available in several countries, such as Belgium, Switzerland, the United Kingdom, Australia and Canada (Fig. 47). Similar examples can be traced regarding other 3D physical characteristics related to PLRs, such as mapping hydrogeological features and 3D modelling of groundwater systems (Chesnaux et al., 2011), vulnerability to groundwater contamination (Ducci & Sellerino, 2013), air and noise pollution (Sheng, 2011). Therefore, it can be concluded that technology allows for cost-effective development of 3D PLR models, which can serve to bridge the gap between the, non-explicitly 3D, PLR framework and the traditional 2D-based real property and cadastral framework.

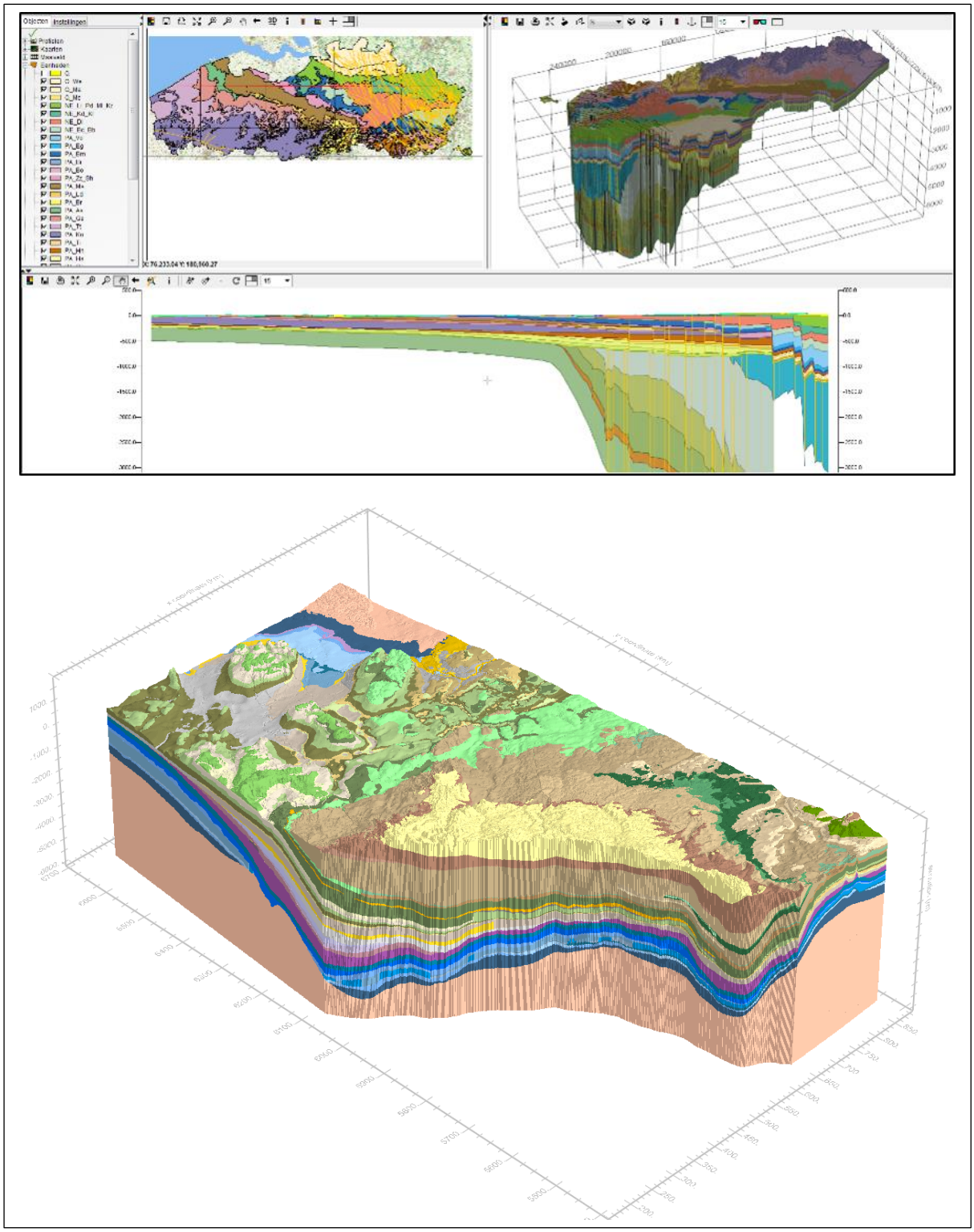


Figure 47. Examples of 3D geological models of Belgium (top) (Vlaanderen, 2018) and province of Alberta in Canada (bottom) (AGS-AER, 2018).

8 Conclusions

The aim of this thesis, as defined in section 2.1, has been to identify the legal impediments for real property stratification, to detect legal amendments that could address such impediments. It is evident that no uniform approach can be followed, as the legislation of each jurisdiction has been developed by different religious, cultural, historical, social and other influences, thus reflecting specific societal values. Moreover, national legislation impacts on administrative structures, and procedures. In the field of land-related legislation, the need of a non-volatile legal framework, which secures the stable operation and the growth of land market, needs to be taken into account. This means that the long-term stability of the legal framework regulating real property, has resulted to well-established procedures and cognitive perceptions of land and RRRs, both to the public and the professionals, which are difficult to be modified without impact on land administration and land market. The length of the process of changing all related primary and subordinate legislation, which also pertains lengthy discussion between experts from different fields needs also to be taken into account.

This section addresses this thesis' aim, by responding to the research questions which were defined, based on five research objectives that were set. In the following subsections, the achievement of each of the research objectives is described and discussed. Further research issues conclude this work.

8.1 Research objective 1

The first research objective of this thesis was to "*Review the cases of overlapping RRRs internationally*". In Section 3, the different cases of overlapping RRRs were presented. Overlaps were traced to derive from:

- Apartment ownership,
- the development of complex overlapping and interlocking structures,
- the development of under and above ground infrastructures and networks,
- concepts of customary tenure and special rights,
- Public Law Restrictions.

Above defined cases of real property stratification, include both constructions (physical space) and, non-material, right space volumes. It is evident that, apart from the region-based customary tenure concepts and special rights, there are no significant differences regarding the cases of real property stratification internationally. Depending on each country's level of development and land exploitation policies, simpler or more complex cases of overlapping RRRs exist. Exploitation of land through development of multi-storey buildings sets apartment rights as the most common case of stratified real property internationally. Infrastructures and utility networks extend above or below the land surface and affect surface parcel property in different ways, depending on their type and scale. Infrastructures' development brings to light the issue of the vertical extent of real property above and below the land's surface. Concepts of customary tenure and special rights refer to cases that are limited in number, they apply to specific jurisdictions or regions within a jurisdiction, while they are gradually repealed. Public Law Restrictions cover a very broad range of fields, of complex nature as their

spatial component is defined not only by geometrical terms, but also by non-geometrical, physical characteristics, or by non-qualitative characteristics.

8.2 Research objective 2

Research objective 2 involved the "*study on the legal instruments used for real property stratification*". This issue is dealt with in section 3. The variety of legal families worldwide is also examined in this stage, as each jurisdiction treats issues of real property stratification under different perspective, based on its legal tradition.

It is clear that real property stratification is in most cases perceived as the capacity of separating land surface ownership from this of constructions lying above or below it. This leaves little room for subdivision of the 3D space above and below a land parcel to individual volumes of RRRs. Identified legal instruments used for real property stratification, are servitudes (or easements), usufruct, composite ownership and indirect ownership schemes, rights of superficies and emphyteusis, as well as special real property rights. Each type of these legal instruments, has been developed in different historic periods, thus serving different purposes and, in most cases, can only regulate simple cases of real property stratification. The common feature of traditional real property rights used for real property stratification is that they separate surface parcel ownership from ownership of buildings or other constructions (existing or not yet built). This implies that a "dual" subdivision takes place, creating two separate rights: one regarding the surface parcel and another regarding buildings or constructions above or below it. Multiple separate ownership or other types of rights are only available in case composite ownership concepts (usually apartment rights) or special real property rights and objects. Therefore, limited real property rights inhibit stratification of real property to multiple owners on multiple levels above or below the earth's surface.

Servitudes (or easements) is the most common type of traditional limited real property rights used by a third party to use another's land, therefore they are considered as appropriate to stratify real property. Servitudes (or easements) are mainly used in case of infrastructures, although each jurisdiction provides for different types of rights, or restrictions, which are imposed on a land parcel that benefits or that is encumbered by a servitude. Servitudes may have explicit 3D characteristics, as applies in several Common Law jurisdictions, or their 3D nature may be implied (which is the case in utility servitudes in most of Civil Law jurisdictions). Limitations to the types of servitudes that can be established derive from the "numerus clausus" principle in the majority of Civil Law jurisdictions, However, even in those that such principle does not explicitly apply (Common Law and in a few Civil Law jurisdictions), administrative authorities (including courts and cadastral authorities) are reluctant to recognise servitudes that are of different nature to those existing on statute. Provision of conservation easements in several Common Law jurisdictions, is a legal instrument with no equivalent on Civil Law, which allows for environment and cultural heritage conservation, of implied spatial 3D characteristics.

Usufruct and life estate (the most resembling Common Law right to Civil Law's usufruct) is also considered appropriate for real property stratification. Power of use and enjoyment of an immovable is given to a person other than the owner, for a specific period of time. Conditions regarding the exercise of the usufruct may apply,

based on the agreement of the involved parties. The most significant difference between usufruct and life estate concepts is the retaining of the right of disposal by the bare (or naked) owner, in contrast with the assuming of all rights and obligations related to the life-estate interest by its holder. Exploitation of such rights for real property stratification purposes, mainly lies to the separation of the right of disposal (or of the remainder interest) from use and enjoyment of real property (or from the right to possess an immovable real property in Common Law jurisdictions).

Composite ownership schemes can be traced both in Civil and Common Law jurisdictions, under different terminology and specifications and constitute the successors of indirect ownership schemes, which mainly served accommodation purposes by granting to members of a collective entity, occupancy rights to buildings owned by the collective entity. Regardless of national specifications, composite ownership comprises individual ownership of a specific unit within a building, shared ownership of the land parcel and of the building's common parts, as well as membership to an owners' association. Delimitation of the extent of individually owned units within a building and of the common parts is of importance in case of composite ownership types, following the "specialisation principle". Boundaries may extend to the middle, the interior (or the exterior) of floors, walls or ceilings, or other locations may be defined. Definition of boundaries, affects the RRRs which are related to ownership of individual and common property ownership, as well as cadastral registration procedures. Although composite ownership concept is in most cases combined with residential or commercial ownership purposes, there are several jurisdictions, both of Civil and Common Law legal tradition, that provide for the use of composite ownership schemes for alternate purposes, such as unenclosed ground space, airspace, spaces filled with water, mooring space and caravan sites. However, application of such types of composite ownership schemes is limited (especially in Civil and Civil Law based jurisdictions), while most of such types are not designated to serve the purposes of real property stratification.

Rights of superficies are by definition used in Civil Law jurisdictions to dissociate ownership of a land parcel from ownership of constructions (either existing or not yet constructed) above or below it. This explains the fact that rights of superficies are used in several jurisdictions for the establishment of networks. Duration of such rights varies, depending on jurisdiction, from statutory defined minimum and maximum time period, to indefinite time period. Rights of superficies of indefinite time period bear great resemblance to the right of ownership; however, there are several restrictions limiting secondary rights that can be imposed on constructions owned under rights of superficies. The most equivalent concept of the right of superficies in the context of Common Law is the leasehold estate, conferring exclusive possession of land to a lessee for a duration decided by the involved parties. Leasehold estates are more versatile, given that there are several leasehold estates that can be established on the same piece of land, while they are subject to secondary rights, as long as the duration of the primary leasehold is not exceeded.

The right of emphyteusis also allows for separation of ownership from holding and using of an immovable. Emphyteusis provides almost identical rights over an immovable with the personal servitude of usufruct. However, their main difference is that the duration of emphyteusis is not connected to the lifetime of its holder. Typologies and use types of emphyteusis rights differ per jurisdiction, setting different requirements for its establishment and operation.

Finally, special real property rights and objects constitute specific legal stipulations, which can be based on statute or on custom, that are used to address specific cases of overlapping real property. Depending on jurisdiction, this type of rights or objects differ, reflecting the different social needs and the different perception of law by each society. Different types of special property rights and objects allow for separate ownership of specific types of objects from surface parcel ownership. Such types of rights and objects apply only to specific countries, or even regions within a country, regulate a limited number of real property units (thus they cannot be used for the broad range of real property stratification cases) and many of them are gradually repealed.

8.3 Research objective 3

Research objective 3 of this thesis was the "*analysis of the legal issues on 3D real property units, based on applied legislation and international literature*".

This objective is addressed in two parts, extending to sections 4 and 5. In the first part, the relation between physical and legal space was examined, along with well-known models of organisation and visualisation of real property related data. The second part, emphasises on the issues regarding real property stratification, which were identified in international literature and in jurisdictions discussing transition towards 3D real property units.

Real property rights form intangible legal spaces within which powers deriving from the content of such property rights can be exercised. On the other hand, tangible physical spaces are constructed, which need to be contained within their corresponding legal space. Given that physical space does not coincide with legal space, introduces ambiguities in the formation and registration, especially of overlapping real property units.

In chapter 4, the variety of real property registration systems was presented. It is evident that real property registration systems were formed, based on the traditional (2D) land parcel concept, leading to inconsistencies between literally defined legal spaces and their physical counterparts. The concept of land objects was presented, which has been proposed to replace the concept of land parcel, incorporating the legal and spatial characteristics of land entities. Given that cadastral and real property registration infrastructure and legislation have been long established, replacing of land administration systems' basic unit (land parcel) with another type of object (land object) would require radical legal, technical and administrative changes. This is considered to add significant cost and ambiguities to the involved stakeholders. To this aim, different systems of real property data registration, modelling, management and exchange have been developed.

LADM, and its proposed extension LCDM, have been designed taking into account 3D Cadastre requirements, therefore they can sufficiently support 3D-delimited, both Private and Public Law-based RRRs (Lemmen & van Oosterom, 2014). Although LADM sets the background for clearly describing 3D real property, it is considered as a legal model that gives less emphasis on physical objects (Atazadeh, Behnam; Rajabifard, 2017; Atazadeh, Kalantari, Rajabifard, & Ho, 2017) and on their relation to their corresponding legal counterparts (Mohamed El-Mekawy, Paasch, & Paulsson, 2015). Karki et al. (2010b), regard LADM as a middle ground, integrating

physical land parcel models to RRRs and interests of each of the involved parties in land.

Use of semantic models for 3D Cadastre purposes can be characterised as a challenging task. Research on exploiting BIM/IFC for 3D Cadastre purposes has proved efficient in handling building information as well as relating legal space to its physical counterparts. However, this approach requires modification of the IFC model to be enhanced with legal information. This results in case-specific solutions and interoperability problems. Furthermore, 3D modelling or analysis using BIM may only apply on building level and it is strongly related to physical constructions. This excludes analysis regarding non-material, legal spaces (e.g. PLRs), as well as analysis on geographically extended developments, while the lack of LoD in BIM results in models with redundant information that require significantly increased processing power (Dimitrios Kitsakis et al., 2019).

CityGML data model combines semantic with GIS characteristics. In contrast with BIM/IFC data model, CityGML is structured to model and manage constructions and built spaces at city scale, thus responding to the limitation of BIM/IFC in performing analysis at building level. On the other hand, CityGML does neither provide for legal information, nor does it support vertical separation of buildings. Therefore, the data model needs to be extended (either by ADE or by generic city objects), to support stratified real property units (Rönsdorf et al., 2014). Moreover, the model is strongly related to physical objects' modelling, inhibiting visualisation and management of legal spaces with no physical counterparts. Exploitation of existing CityGML elements is an option for legal space modelling and management. However, such elements need to be dissociated from physical structures. Issues of data redundancy are relevant as well, since LoD4 models are required for the creation of hollow spaces (e.g. tunnels), increasing files' size and required processing power.

Chapter 5 presented the legal issues related to real property stratification, which were identified in international literature. Legal issues identified, cover the definition of land (real property or immovable property) in legal documentation, the definition of land parcel and of 3D parcels and their relation, as well as the distinction between rights related to 3D real property units and the other types of limited real property rights. Finally, issues of real property stratification deriving from Public Law need also to be taken into account.

Legal definition of "land" sets the background for any type of real property transaction. The way that land is defined delimits the spatial extent and the associated objects against which RRRs are imposed.

Land parcels constitute the basic administrative units registered within land registration systems and reflect the physical space within which specific RRRs apply. Therefore, definition of land parcels is of significant importance to real property stratification. Stipulations prescribing land parcels unlimited in height and depth do not restrict subdivision of real property in height and depth, as long as legislation provides the legal instruments for volumetric subdivision and allows formation of volumetric parcels or volumetric RRRs, lying above, below, partly above or partly below the land surface. This brings to light the need of regulating the relation between contemporary, and most prevalent types of real property units, traditional land parcels and of stratified real property units. Given that traditional land parcels cover the majority of real property cases, 3D real property units should operate as

an extension of the existing real property concept (which is comprehensible by the public and professionals) to accommodate complex vertically overlapping RRRs, instead of a radical change towards the transition of cadastral parcels to 3D.

Considering that limited real property rights were (and in many jurisdictions are still) used for purposes of real property stratification, the distinction between them and 3D real property rights is required. Each type of such rights operates differently and serves different purposes. However, the long-term use of limited real property rights may perplex understanding of the operation of each real property right's type and their interrelations (for example, encumbering 3D real property units with limited real property rights).

Public Law imposes a number of restrictions on land exploitation and use, many of which refer to 3D space. However, the lack of a 3D, spatial legal framework does not allow for restrictions to be imposed on specific volumes of space, but affect the land parcels as a whole, thus restricting implementation of national policies of spatial connotation.

8.4 Research objective 4

Research objective 4 of this thesis was the "*critical analysis of legal instruments used for real property stratification*".

This issue is dealt on Chapter 6, where the different approaches regarding each of the legal issues identified in Chapter 5 were examined, to detect their possibilities and limitations regarding real property stratification.

8.4.1 Definition of land

Although different terms are employed in each jurisdiction, land is stipulated to include the ground and everything that is permanently attached to it. Depending on jurisdiction, definition may be broadened to include rights, mines or quarries, as applying to several Civil Law or Civil Law-based jurisdictions. Common Law and Common Law-based jurisdictions use more detailed definitions for land, enumerating the components that are regarded as land. Several Canadian provinces provide that any of the enumerated land components can be "specially excepted", which constitutes a primitive way of stratification (in terms of separating of a land component from the rest of land constituents). Examples of delimitation of "land" to a specified extent can also be traced within Common Law, which can be of qualitative (by reference to the airspace or the subterranean space reasonably necessary for the proprietor's use and enjoyment), or of quantitative description (by definition of an explicit depth limit for the underground exploitation by individuals).

8.4.2 Land parcels and 3D cadastral objects

Regardless of jurisdiction, definition of land parcels reflects their physical, legal or administrative characteristics. Definition of parcels in Civil Law or Civil Law-based jurisdictions emphasise on their spatial characteristics (as continuous and delimited parts of land), while Common or Common Law-based focus on their unique and administrative character (as basic spatial entities shown on cadastral plans).

Definitions of land parcel, makes poor or limited reference to their vertical extent. Within Civil and Civil Law-based jurisdictions examined, only Swedish and Norwegian statutes make reference to the vertical delimitation of land parcel

boundaries. However, both these jurisdictions have introduced 3D real property units to their legislation. Therefore, such stipulations fall within the context of supporting real property stratification and do not constitute pre-existing provisions allowing the formation of volumetric land parcels. In Common Law and Common Law-based jurisdictions, reference to the vertical extent of land parcels is made through terms with 3D connotation, such as "stratum", "space" or "air-space". Most of the Common Law and Common Law-based jurisdictions, relate parcels with subdivision to (volumetric) strata units, thus connecting the concept of parcel with real property stratification (even for specific use cases).

8.4.3 3D real property units

There is no uniform approach in the number and the content of 3D real property units in different jurisdictions. Definitions of 3D real property units comprise of the following components:

- Baseline spatial unit. Terms with explicit 3D connotation are used (e.g. "*volumetric space*", "*cubic layer*", "*air space*"), or without explicit 3D content (such as "*parcel*", "*part of land*").
- Location. Definition of 3D real property units describes their location as "*(partly) above, on or below surface*".
- Occupation by a structure. Provisions for the occupation of 3D real property units "*in whole or in part by a building or structure*".
- Delineated boundaries. Stipulations requiring "*delineated dimensions*", "*limited dimensions*", or units "*delimited both horizontally and vertically*" are mainly used, while in the state of Queensland the delimitation of 3D real property boundaries pertains even more specific stipulations such as "*unlimited in height and depth*", "*defined by reference to floors, walls and ceilings*", "*fully limited by bounding surfaces*", or "*restricted by height or depth*".
- Shape definition. Stipulations used allow 3D real property unit to "*consist of space of any shape*".
- Administrative permission. Stipulations requiring that 3D real property units need to be "*shown on strata/air space plan*" or that "*a planning or building permission has been granted*" are used.
- Ownership status. Reference to the distinct ownership status of 3D real property units can also be traced in the definitions of 3D real property of several jurisdictions, using stipulations such as "*designed for separate ownership*", or "*subdivided as different ownership*".

Definitions used in each jurisdiction do not employ all of the above mentioned components, while differences are traced even among countries which belong to the same legal family. Reference to a baseline spatial unit is made in all types of legal stipulations, as does delineation of boundaries. Civil Law-based jurisdictions of Sweden and Norway also include occupation by a structure (Sweden) and ownership status (Norway). Within Common Law-based jurisdictions, two different approaches can be identified. Canadian provinces emphasise on the baseline spatial unit of 3D spatial entities, which has inherent three-dimensional characteristics (volumetric

space, or volumetric parcel), and to the relation of 3D spatial entities by a building or a structure. Administrative permission and location are also referred to, in limited number of Canadian provinces' legislation. On the other hand, Australian states and jurisdictions with legal influence by Australian legislation regarding stratification of real property (such as Singapore, Malaysia and New Zealand), define 3D real property units employing to their stipulations reference to the baseline spatial unit (with three-dimensional connotation or not), to boundary delineation and to the location of 3D real property units. In several jurisdictions, provision for the shape and the ownership status of 3D real property units may also be included. In the state of Queensland, legislation provides for different types of 3D real property units which are defined only by reference to their baseline spatial unit and to the delimitation of their boundaries (which can be achieved through a variety of different options).

8.4.4 Relation between 3D real property and surface property

Relation between 3D real property and surface parcel property does not only refer to the ground, above or below which, a 3D real property unit is formed, but to the whole volume remaining after the "excision" of the 3D parcel as well. Therefore, such relation cannot be described as a "parcel to volume" relation (2D to 3D), but as a "volume to volume" relation (3D to 3D).

Different approaches can be identified, with different aims. Others focus on protecting the unobstructed exploitation of the surface parcel from 3D property above or below it, while others aim to facilitate the effective use of stratified real property units by potential limitations deriving from rights on the surface parcel. Followed approaches can be distinguished in (i) no specific regulations (general requirements regulating traditional land parcels apply)[115], (ii) partial regulation (by establishing implied easements that regulate the relation between specific types of property units for specific aspects, e.g. support or passage[116]), and (iii) specialised regulations[117]. Establishment of specialised provisions allows the detailed regulation of the different aspects of 3D and traditional real property units relation, but requires adjustment of technical and administrative procedures, as well as it introduces ambiguities until such provisions are fully comprehensible by all interested parties. On the other hand, application of general requirements, aims to incorporate 3D real property units to existing legal framework, as well as to promote individual agreements between the involved stakeholders. However, the former implicates that general regulations applying to traditional parcels need to be interpreted proportionately (therefore, no uniform approach can be achieved, while such interpretation is not always feasible), while in the latter case, agreements that are not in accordance with the numerus clausus principle can be made, or stratified exploitation of real property cannot proceed, if an agreement between individual stakeholders cannot be achieved. Provisions for implied easements form a middle ground, aiming to ensure some fundamental relations between surface and 3D real property units, such as support, access and passage of services. However, it is evident that implied easements may apply only in case that constructions are involved, thus they cannot be used to

[115] Traced in Sweden and in the examined Canadian provinces.
[116] Traced in the states of Queensland, Victoria and New South Wales in Australia, New Zealand and Singapore.
[117] Traced in Malaysian legislation.

regulate the relation between non-material legal spaces (in which different relations between surface and stratified real properties need to be established)[118].

8.4.5 Distinction between 3D objects and other real property rights

Since limited real property rights and, in several cases, special real property rights and special real property objects are used for real property stratification purposes, they need to be distinct from 3D real property units, as they apply to different fields and they provide different legal powers and limitations to their right holders. Such distinction is explicit only within the Swedish framework, where 3D real property units can only be used only when all other property types are not suitable to the intended exploitation of land. Examination focused on the following requirements (which stratified real property units need to fulfil):

- Stratification on multiple levels.
- Application of real property rights.
- Use for specific purposes.
- Application of specific conditions.
- Necessary relation to a physical construction or object.
- Necessary relation to a surface parcel.
- Application to impose PLRs.

Although each limited real property right fulfils different combinations of the above mentioned requirements, significant limitations on the use of such rights for real property stratification purposes derive from their intrinsic characteristics.

The most significant disadvantage of the majority of limited real property rights is that they merely separate ownership of the surface parcel, from that of the space above and/or below it. Therefore, stratification on multiple levels, which is the fundamental aim of 3D subdivision of real property, cannot be achieved. Composite ownership concepts, as well as special real property rights and objects may address such requirement, but are subject to other limitations, such as their application only to specific purposes. Composite ownership objects are also required to be related to a physical object, while their application is subject to specific conditions (e.g. common ownership of the land parcel and building's common parts, as well as membership to an owners' association). This, limits the field of application of composite ownership concepts to buildings, excluding potential application to cross parcel infrastructures, or to non-tangible legal spaces (such as PLRs).

Property rights determine the way that real property is owned and used. Considering overlapping real property units as individual real property objects, then such objects need to be subject to limited real property rights, so that the legal powers as well as restrictions and responsibilities of right holders are assigned. Given that limited real property rights are in many cases used for real property stratification, they cannot be further subject to limited real property rights. This means that stratified real

[118] For example, prevention of soil or groundwater contamination, imposes restrictions on the effluent and waste of the surface parcel, based on soil characteristics.

property units, formed based on limited real property rights, do not ascribe to their owner the full range of legal powers, as applying to traditional land parcel ownership. In cases of rights of superficies or of emphyteusis, constructions above or below the land surface are subject to limited real property rights. However, both such rights are subject to conditions regarding their use, and cannot be used to in case of intangible legal spaces. Similar limitations apply to composite ownership concepts and special real property rights and objects, which also constitute stratified real property units, subject to limited real property rights.

Limitations on stratification also derive from requirements for specific purpose or content, for a limited real property right to be employed, in compliance with the numerus clausus principle. Such purpose limitations can be traced in almost all types of limited real property rights and mainly refer to access of individuals, access, maintenance and repairing of networks and utilities, structural support of constructions, and use types. Consequently, stratification capacities through limited real property rights are restricted to those in accord with corresponding requirements of each legal instrument on purpose or content.

Another limitation of real property stratification through limited real property rights, is that stratified property needs to be related to a physical object (for example an apartment, in case of composite ownership types). Therefore, restrictions or legal spaces with no physical counterpart cannot be formed within the limited real property rights' concept.

Establishment of limited real property rights is land parcel-based. Since legislation does not stipulate geometrical requirements of land parcels, neither does it set minimum or maximum restrictions on land parcel area (except of urban planning cases), it may be regarded that such limitation does not significantly affect stratification of real property. However, in such case stratified real property units cannot exceed the boundaries of the surface parcel. Consequently, cross boundary objects need to be subdivided in multiple parts, based on the planar boundaries of surface parcels. Further limitations apply, regarding the formation of non-parcel based interests, e.g. PLRs, especially when multiple, overlapping interests are imposed on areas where more than one parcels exist.
3D real property legislation accommodates such limitations, as it allows formation of real property units above or below the land's surface that are independent from the boundaries of the surface parcel. Limitations regarding the planar extent of stratified real property units can only be traced in the state of Queensland, where it is required that stratified real property units reflect the base parcel geometry, and in Israel, which constraints planar extent of spatial parcels to the limits of a spatial block.

Increasing number of PLRs on real property is among the reasons urging towards stratification of real property. PLRs mainly refer to land use restrictions, which are not only limited to the land's surface, but may also include volumes of space not related to physical constructions. This characteristic, constitutes the main limitation faced by limited real property rights in stratification of real property. Servitudes (or easements) are the only legal instrument that can be used to denote a spatial entity where specific use restrictions, or specific use rights, are imposed on the servient and the dominant parcels respectively. Even in such case, the content of servitudes is limited by the numerus clausus principle, which prescribes specific servitude

types. The concept of conservation easements that applies to several jurisdictions of Common Law could be regarded as an instrument that allows application of PLRs. However, conservation easements are not imposed by the state, but operate within the context of private agreements among individual parties. All other types of limited real property rights cannot serve PLR purposes given their inherent characteristics (they focus on separating surface parcel ownership from exploitation rights of under or above ground space).

8.4.6 3D Public Law Restrictions

Although the impact of PLRs restricting real property exploitation on real property management is acknowledged, their growing number, as well as their vertical expansion leads to the need of their integration within cadastral systems, so that the full extent of RRRs that apply to land is identified. PLRs are imposed by a number of legal statutes, which refer to different aspects of public benefit's protection. Despite the three-dimensional character of PLRs (either in explicit 3D, non-geometrical or implied 3D terms), establishment of 3D PLRs is inhibited by:

- Spatial parameters (such as their delineation in horizontal plane, or their definition by reference to non-geometrical or implied 3D attributes).
- Emphasis on physical characteristics instead of PLRs (this means that registration refers to the existence of objects that are of interest, or of the values of an examined attribute within a region, not on incidental legal restrictions).
- The lack of 3D cadastral framework (as despite the existence of explicit volumetric restrictions, no volumetric subdivision or expropriation implementing aforementioned PLRs may apply).

In terms of imposing PLRs, 3D real property units in Civil Law (or Civil Law-based) and Common Law (or Common Law-based) jurisdictions differ. The former relate 3D real property to construction projects and do not allow for creation of "empty" volumes of space. Although such provision aims to avoid the use of stratified ownership for land speculation purposes, it also inhibits volumetric excision or encumbrance of land for 3D PLR purposes. On the other hand, Common Law jurisdictions allow for the use of stratified real property units for all different types of RRRs, thus facilitating implementation of land-related policies and setting the, legal, background for 3D land management for PLR purposes. Implementation of 3D PLR registration can also be supported by available technological tools for 3D analysis and representation of environmental characteristics (which reflect the environmental requirements set out in legislation), thus conforming 3D defined legal requirements to the traditional 2D-based real property and cadastre framework.

8.5 Evaluation and potential legal amendments

The fifth research objective of this thesis was the "*evaluation of existing concepts and the proposal of legal amendments that facilitate real property stratification*". It is noted that this evaluation does not mean to single out a "best" legal approach for 3D real property stratification. This would be impracticable, since no operational full 3D Cadastre system can be traced globally, neither has a uniform set of requirements been set regarding real property stratification. All concepts of real property stratification operate within different legal environment and reflect the different legal values and practice of each jurisdiction. Identification of the fundamental similarities

and differences, the advantages and the disadvantages of each approach, brings to light potential limitations and sets the direction for those jurisdictions that intend to amend their legal framework enabling real property stratification.

Chapter 7, identifies the advantages and the malfunctions of existing legal instruments used, which constitute the input for potential amendments to facilitate real property stratification.

As regarding to the definition of land and of real property, definitions integrating all physical and artificial objects lying on, above and below land's surface, operate restrictively on real property stratification, as long as they are not accompanied by legal instruments allowing volumetric subdivision of real property. This is evident in Civil Law jurisdictions, where land owners are assigned total, immediate and absolute power on land objects (restricted vertically by legal statute or third parties' rights), but they cannot subdivide it vertically, if not under concept of the "numerus clausus"-based limited real property rights. This issue is addressed within Common Law jurisdictions, where the "inclusive" character of real property definition, operates in favour of subdivision of real property in volumes.

The extent of real property in height and depth is in most cases implied, in relation to the interests of the landowner in land, or in objecting to its exploitation by third parties in height or depth. Given the variety and the variability of Public Law Restrictions with 3D connotation that are imposed on land, there can be no uniform stipulation on the vertical extent of ownership; therefore, existing stipulations allow for case specific provisions, based on the local conditions and the specifications of potential development projects in each region. Setting of upper and lower boundaries of real property ownership also relates to the debate on the nature of ownership[119] and its protection deriving from constitutional stipulations. Civil Law jurisdictions restrict ownership rights through limited real property rights, while in Common Law, the concept of the "bundle of rights" is used to distinguish the different incidents of ownership, which are realised through estates' concepts.

Combined with the concept of immovable real property, is the concept of land parcel and its equivalents on 3D space, 3D real property units. Land parcels are the fundamental units of cadastral systems, showing the planar boundaries within which, individuals' property rights are exercised. Therefore, they are fully compliant with the Roman principles on the extent of real property ownership. However, land parcel concept is deficient when it comes to rights that apply on multiple height levels, and extend to more than one surface parcels. To address these cases, limited real property rights are employed, especially within Civil Law jurisdictions, which, however, face a number of limitations (as presented in chapter 6). A different approach is followed by jurisdictions of Common Law (and the Civil Law-based jurisdictions of China, Sweden and Norway), where 3D real property units have been introduced in the real property regulatory framework. Although legal provisions on 3D real property units share similar influences, each national, state, or provisional legal framework has its unique, 3D real property characteristics. Although 3D real property units are meant to extend the concept of land parcel in 3D space, in order to address cases of complex, overlapping cases of real property rights, 3D real

[119] Whether restrictions are externally imposed on the "unlimited" powers provided by the right of ownership, or whether restrictions are inherent to the right of ownership, or whether restrictions merely restrict the right to exercise specific powers deriving from real property ownership.

property is established as a separate real property entity, which can be used to subdivide delimited spatial volumes from traditional land parcels. Each jurisdiction provides for different types of 3D real property units, under different terminology, of different content and for specific use types. Most jurisdictions have opted for one type of 3D real property units, which is characterised by the spatial delimitation of its boundaries, (partly) above or (partly) below of the land's surface. Civil Law jurisdictions necessarily relate stratified real property units to a construction, while Common Law jurisdictions do not set such limitation, thus allowing the use of 3D real property units to impose all types of RRRs on land. Horizontal delimitation of 3D real property units (within or extending out of surface parcel boundaries) is significant, especially when vertically subdividing real property, as it affects real property formation for cross-boundary infrastructures. Although requirements for 3D property subdivision within the limits of the surface parcel apply in relatively few jurisdictions, in most cases stratified real property units do not need to be restricted within surface parcel boundaries. Provisions regarding the establishment of 3D real property units stipulate the unique ownership status of such units, so that their character as individual real property objects is ensured, thus assigning to their holders all legal powers that derive from the right of ownership.

Stratification of real property does not only refer to constructions, but also includes RRRs which are not necessarily related to man-made physical volumes. Restrictions imposed by statutes of Public Law is a common case of this type of RRRs. Among the existing types of real property rights, only servitudes (easements) can be used to impose restrictions, not in need of necessary relation to a construction, also extending in height and depth. However, servitudes are restricted by the numerus clausus principle, thus only specific types of servitudes can be established, most of them referring to Private Law. Public Law servitudes mainly refer to servitudes of passage for infrastructures and networks. Common Law, provides also for conservation easements that are imposed on land for conservation purposes. Despite the broad range of restrictions provided within the conservation easements concept, such legal instrument is based on private agreements among individual parties, and does not extend on state-imposed PLRs. Besides, conservation easements impose on burdened land parcels, specific types of restrictions that are, in most cases, not of three-dimensional character. Within the context of Common Law, also the legal instrument of restricted easements is provided that allows for restrictions that extend to a delimited volume of space. However, since restricted easement concepts operate within Common Law jurisdictions with statutory 3D real property units, it is clear that such legal instrument cannot be used within a legal context that is not conformant with real property stratification. Stratified real property units serve the purposes of 3D PLRs, given both their three-dimensional character and their dissociation from physical structures (with the exception of Sweden and Norway, where 3D real property is necessarily related to a construction). However, delimitation of PLRs in 3D space, constitutes a complex task that does not only fall into the scope of 3D Cadastre, but also requires detailed analysis of the various components each PLR is based on, in order to be "translated" in 3D spatial units.

8.6 Further research

It is, most likely, clear from the above analysis, the impact of legislation to the stratification of real property and 3D Land Administration. This thesis investigated a variety of legal implications regarding real property stratification, also bringing out several issues that would be required to be explored in future research.

Compatibility between property law stipulations and constitutional requirements on the protection of property, needs to be ensured. Stratification of real property by setting upper height or lowest depth ownership limits, with the rest of the space owned by the state, would constitute, in many jurisdictions, deprivation of real property, which would entrain compensatory expropriation.

Another issue would be the addressing of the "controversy" of Civil Law in allocating land owners absolute, total and immediate power on land, but restricting them from subdividing it to volumes of space, despite the fact that there is no explicit such restriction by statute.

Stratified real property units are designated as individual property units, which are subject to limited real property right. However, it is of interest to examine which types of limited real property rights would be conformant with stratified real property units, and how such rights could be implemented on 3D spatial objects. For example, how could emphyteusis or rights of superficies be imposed on a 3D real property unit? Would this require that several types of limited real property rights should be forbidden by statute to be imposed on stratified real property units?

Regulation of 3D real property units needs also to be investigated. This involves measures regarding the avoidance of using 3D real property for speculation (which is addressed in Civil Law 3D real property legislation by relating 3D real property necessarily to a construction, but also introduces other limitations regarding 3D PLRs), as well as the definition of minimum/maximum 3D real property volumes. This means that law should define if a "minimum" volume (fulfilling specific minimum exploitation) is required to remain after subdividing individual volumes from the surface parcel, and after which no further volumetric subdivision is allowed. Within similar concept, what would happen in case of potential changes in societal needs or land policies inducing additional expansion in height or depth? Would this added space belong to the surface parcel owner? This also relates to the "translation" of descriptive legal stipulations to height, depth or volumetric values. The same issue needs to be addressed also regarding 3D PLRs. Descriptive, qualitative, or non-geometric parameters need to be rendered in terms of height, depth or volume to accurately reflect land-related policies and to show the full legal situation that applies to a land parcel.

Finally, all types of legal modifications on the conceptual character of real property, towards stratification, affect technical requirements for real property registration, administrative procedures and cadastral survey requirements. Therefore, changes to legal framework need to be accompanied by the concomitant amendments in administrative and cadastral framework.

9 REFERENCES

Abramovitch, Yehuda. 1953. “THE MAXIM ‘CUJUS EST SOLUM EJUS USQUE AD COELUM’ AS APPLIED IN AVIATION.” McGill Law Journal 8(4): 247–69.

ACIL ALLEN Consulting. 2017. 3D QLD ROAD MAP PRELIMINARY FINDINGS.

Agallopoulou, Penelope. 2005. Basic Concepts of Greek Civil Law. ed. Youlika Masry Kotsovou. Ant. N. Sakkoulas/Staempfli/Bruylan.

AGS-AER. (2018, October). Activities. Retrieved from 3D Geological framework: https://ags.aer.ca

Ahmad, Yahaya. 2006. “The Scope and Definitions of Heritage: From Tangible to Intangible.” International Journal of Heritage Studies 12(3): 292–300.

Ahr, Steven W., Lee C. Nordt, and Randall J. Schaetzl. 2017. “Lithologic Discontinuities in Soils.” In The International Encyclopedia OfGeography, eds. Douglas Richardson et al. John Wiley & Sons, Ltd, 1–8.

Aien, Ali et al. 2013. “Towards Integration of 3D Legal and Physical Objects in Cadastral Data Models.” Land Use Policy 35: 140–54. http://dx.doi.org/10.1016/j.landusepol.2013.05.014.

Aien, Ali, Abbas Rajabifard, Mohsen Kalantari, and Davood Shojaei. 2015. “Integrating Legal and Physical Dimensions of Urban Environments.” ISPRS International Journal of Geo-Information 4(3): 1442–79. http://www.mdpi.com/2220-9964/4/3/1442/.

Akkermans, Bram, and William Swadling. 2012. “Types of Property Rights: Immovables and Movables.” In Cases, Materials and Text on Property Law, eds. Sjef van Erp and Bram Akkermans. Hart Publishing, 211.

Akkermans, Bram. 2008. “The Principle of Numerus Clausus in European Property Law.” Maastricht University.

Akkermans, Bram. 2017. “The Numerus Clausus of Property Rights.” In Comparative Property Law, eds. Michele Graziadei and Lionel Smith. Edward Elgar Publishing, 100–120.

Alberta Land Surveyors Association. 2011. “Strata and Condominium Surveys.” Strata and Condominium Surveys: 1–5. https://www.alsa.ab.ca/Portals/0/PDF/Member_Resources/Reference_Material/Other/201103Condominiums.pdf?ver=2012-09-06-183700-000.

Alberta Land Titles. 2002. Procedures Manual.

Amirebrahimi, Sam. 2012. “BIM for Facilitation of Land Administration Systems in Australia.” In A National Infrastructure for Managing Land Information, eds. Abbas Rajabifard, Ian Williamson, and Mohsen Kalantari. The University of Melbourne, 95–99.

Andreasson, Kristin. 2006. “Legal Coordinated Cadastres – Theoretical Concepts and the Case of Singapore.” In XXIII FIG Congress, 1–13.

Andreone, Francesco. 2011. “50 Years of Strata Title in Australia.” (May).

Apostolopoulos, K., Gkeli, M., Petrelli, P., Potsiou, C. and Ioannidis, C. 2018. “A new model for cadastral surveying using crowdsourcing.” Survey Review, 50(359): 122-133, DOI: 10.1080/00396265.2016.1253522

Arensman, Douglas B., and Mehmet E. Ozbek. 2012. “Building Information Modeling and Potential Legal Issues.” International Journal of Construction Education and Research 8(2): 146–56.

Arvanitis, Apostolos. 2000. Κτηματολόγιο [Cadastre]. Thessaloniki, Greece: Ziti Publications.

Arvanitis, Apostolos. 2014. Εγχειρίδιο Κτηματογράφησης [Cadastral Survey Handbook]. Thessaloniki, Greece.

Atazadeh, Behnam et al. 2016. “Harnessing BIM for 3D Digital Management of Stratified Ownership Rights in Buildings.” In FIG Working Week 2016: Recovery from Disaster, Christchurch, New Zealand, 7968.

Atazadeh, Behnam, Mohsen Kalantari, Abbas Rajabifard, and Serene Ho. 2017. “Modelling Building Ownership Boundaries within BIM Environment : A Case Study in Victoria, Australia.” CEUS 61: 24–38. http://dx.doi.org/10.1016/j.compenvurbsys.2016.09.001.

Atazadeh, Behnam, Mohsen Kalantari, Abbas Rajabifard, Serene Ho, and Tuan Ngo. 2017. “Building Information Modelling for High-Rise Land Administration.” Transactions in GIS 21(1): 91–113.

Atazadeh, Behnam, Mohsen Kalantari, Abbas Rajabifard, Serene Ho, and Tom Champion. 2017. “Extending a BIM-Based Data Model to Support 3D Digital Management of Complex Ownership Spaces.” International Journal of Geographical Information Science 8816(November): 499–522.

Atazadeh, Behnam; Rajabifard, Abbas. 2017. “Assessing Performance of Three BIM-Based Views of Buildings for Communication and Management of Vertically Stratified Legal Interests.” Journal, International Modelling, Building Information (July).

Atkins, Judy, Ann Hillyer, and Arlene Kwasniak. 2004. Report No. Conservation Easements, Covenants and Servitudes in Canada: A Legal Review. Ottawa, Ontario.

Australian Heritage Commission. 2009. “Protecting Local Heritage Places A National Guide for Local Government and the Community.” : 91.

Azhar, Salman, Malik Khalfan, and Tayyab Maqsood. 2012. “Building Information Modelling (BIM): Now and Beyond.” Australasian Journal of Construction Economics and Building 12(4): 15–28. http://epress.lib.uts.edu.au/journals/index.php/AJCEB/article/view/3032.

Azhar, Salman. 2011. “Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry.” 11(Bazjanac 2006): 241–52.

Baird, M. 1998. “The Role of Evaluation.” In Public Sector Performance – The Critical Role of Evaluation, Selected Proceedings from a World Bank Seminar, ed. Keith Mackay. Washington D.C., 7–12.

Bandeira, Pablo, Jose María Sumpsi, and Cesar Falconi. 2008. “Evaluating Land Administration Systems: A Comparative Method with an Application to Peru and Honduras.” : 29.

Banut, Ramona. 2011. “Overview Working Sessions.” In 2nd International Workshop on 3D Cadastres, 2011, 1–10.

Barbieri, Maurice. 2015. “The Cadastre of Public-Law Restrictions on Landownership in Switzerland.” In Utility Cadastre Seminar, Zagreb, Croatia.

Barnes, Grenville. 2002. “Lessons Learned : An Evaluation of Cadastral Initiatives in Latin America over the Past Two Decades.” In FIG XXII International Congress, Washington, D.C. USA, 1–11.

Baron, Jane B. 2014. “Rescuing the Bundle-of-Rights Metaphor in Property Law.” University of Cincinnati Law Review 82(1): 57–101.

Barratt, Benjamin et al. 2018. A Dynamic Three-Dimensional Air Pollution Exposure Model for Hong Kong. Boston, Massachusetts.

Bartel, Sebastian, and Gerold Janssen. 2016. “Underground Spatial Planning – Perspectives and Current Research in Germany.” Tunnelling and Underground Space Technology incorporating Trenchless Technology Research 55: 112–17. http://dx.doi.org/10.1016/j.tust.2015.11.023.

Bengtsson, Bo. 1992. “Not the Middle Way But Both Ways — Cooperative Housing in Sweden.” Scandinavian Housing and Planning Research 9(2): 87–104.

Bennett, R M A, J A Wallace, and I P A Williamson. 2006. “MANAGING RIGHTS, RESTRICTIONS AND RESPONSIBILITIES AFFECTING LAND.” In Combined 5th Trans Tasman Survey Conference & 2nd Queensland Spatial Industry Conference 2006, Cairns, Tasmania, 1–12.

Bennett, Rohan. 2007. “Property Rights, Restrictions and Responsibilities : Their Nature, Design and Management.” The University of Melbourne.

Biljecki, F. 2017. “Level of Detail in 3D City Models.” Delft University of technology.

Biljecki, Filip et al. 2015. “Applications of 3D City Models: State of the Art Review.” ISPRS International Journal of Geo-Information 4(4): 2842–89. http://www.mdpi.com/2220-9964/4/4/2842.

Billen, R., and S. Zlatanova. 2003. “3D Spatial Relationships Model: A Useful Concept for 3D Cadastre?” Computers Environment and Urban Systems 27(4): 411–25.

BIM Industry Working Group. 2011. A Report for the Government Construction Client Group. http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf.

Binimelis, Rose, Wanda Born, Iliana Monterroso, and Rodríguez-Labajos. 2008. “Socio-Economic Impact and Assessment of Biological Invasions.” In Ecological Studies, eds. M.M Caldwell et al.

Bobylev, Nikolai. 2016. “Underground Space as an Urban Indicator : Measuring Use of Subsurface.” Tunnelling and Underground Space Technology incorporating

Trenchless Technology Research 55: 40–51. http://dx.doi.org/10.1016/j.tust.2015.10.024.

Bogaerts, T., and J. Zevenbergen. 2001. “Cadastral Systems- Alternatives.” Computers, Environment and Urban Systems 25(4–5): 325–37.

Boozer, Anna Lucille. 2013. “Apartment Buildings.” In The Encyclopedia of AncientHistory, eds. R. Bagnall et al. Blackwell Publishing Ltd., 515–16.

Boubrima, Ahmed, Walid Bechkit, Hervé Rivano, and Lionel Soulhac. 2016. “Cost-Precision Tradeoffs in 3D Air Pollution Mapping Using WSN.” In UNET 2016 - 2nd International Symposium on Ubiquitous Networking, Casablanca, Morocco.

Bourdillion, N., R. Braithwaite, D. Hopkins, and R. France. 1995. “Archaeological and Other Material and Cultural Assets.” In Methods of Environmental Impact Assessment, eds. P. Morris and R. Therivel. UCL Press, 380.

Braithwaite, Rosemary, David Hopkins, and Philip Grover. 2005. “Archaeological and Other Material and Cultural Assets.” In Methods of Environmental Impact Assessment, eds. Peter Morris and Riki Therivel. Spon Press, 122–44.

Branco, João Pedro, F. Meijer, and H. Visscher. 2010. “Technical Building Regulations in EU Countries: A Comparison of Their Organization and Formulation.” CIB World Congress: 12.

British Columbia. (2016). Housing and tenancy: Strata Housing. Retrieved from Understanding stratas: https://www2.gov.bc.ca/gov/content/housing-tenancy/strata-housing/understanding-stratas/kinds-of-stratas

Bronick, C.J., and R. Lal. 2004. “Soil Structure and Management: A Review.” Geoderma 124: 3–22.

Brown, Carlton A. 2011. “The Millimeter Legal Coordinated Cadastre.”

Bryde, David, Martí Broquetas, and Jürgen Marc Volm. 2013. “The Project Benefits of Building Information Modelling (BIM).” International Journal of Project Management 31(7): 971–80. http://dx.doi.org/10.1016/j.ijproman.2012.12.001.

Bureau of Archaeological Research Division of Historical Resources. Coastal Management Conservation Easements: Protecting Florida’s Archaeological Sites. https://dos.myflorida.com/media/30910/easement.pdf.

Bureau of Rural Sciences. 2005. “Socio-Economic Impact Assessment Toolkit.”

Butler, D. 2004. “Noise Management: Sound and Vision.” Nature 427(6974): 480–82.

Bydłosz, Jarosław. 2012. “The Cadastre in Poland – The Current Status and Possibilities of Transformation into 3D One.” In FIG Working Week 2012, Rome, Italy, 1–9.

Bydlosz, Jaroslaw. 2013a. “Towards LADM Country Cadastral Profile – Case Poland.” In 5th Land Administration Domain Model Workshop, Kuala Lumpur, Malaysia, 247–60.

Bydlosz, Jaroslaw. 2013b. “TRANSITION OF 2D CADASTRAL OBJECTS INTO 3D ONES – PRELIMINARY PROPOSAL.” In Management of Real Estate Resources, ed. R. Zróbek. Zagreb, Croatia, 85–92.

Cabinet Office, UK. (2011). Building Construction Strategy.

Cadastre and Land registry Knowledge Exchange Network. 2015. Documentation of “Public - Law Restrictions.”

Cafuzzi, D., and E. Crippa. 2005. “Contribution of Vegetation to Slope Stability: An Overview of Experimental Studies Carried Out on Different Types of Plants.” In Geo-Frontiers Congress, Austin, Texas, United States.

Çağdaş, Volkan. 2012. “An Application Domain Extension to Citygml for Immovable Property Taxation: A Turkish Case Study.” International Journal of Applied Earth Observation and Geoinformation 21(1): 545–55.

Caine, Alisa. 2009. “Spatial Rights Legislation in Israel – A 3D Approach.” In FIG Working Week 2009, Eilat, Israel, 1–14.

Caldwell, Lynton K. 1988. “Environmental Impact Analysis (EIA): Origins, Evolution, and Future Directions, Impact Assessment.” Review of Policy Research 8(1): 75–83.

CanBIM. (2014). AEC(CAN) BIM Protocol.

Canter, L. 1996. Environmental Impact Assessment. McGraw and Hill.

Canton de Berne. (2019). Accueil. Retrieved from Cadastre RDPPF: http://www.geo.apps.be.ch/de/oereb-kataster-4.html

Canton of Zurich. (2018, April). GIS Browser. Retrieved from http://maps.zh.ch/

Carson, James E. 1992. “On the Preparation of Environmental Impact Statements in the United States of America.” Atmospheric Environment. Part A. General Topics 26(15): 2759–68.

Carvalho, Filipe, Sara M. Santos, António Mira, and Rui Lourenço. 2017. “Methods to Monitor and Mitigate Wildlife Mortality in Railways.” In Railway Ecology, eds. Luís Borda-de-Água, Rafael Barrientos, Pedro Beja, and Henrique M. Pereira. SpringerOpen, 23–42. https://link.springer.com/content/pdf/10.1007%2F978-3-319-57496-7.pdf.

Cayla, Nathalie, and Simon Martin. 2018. “Digital Geovisualisation Technologies Applied to Geoheritage Management.” In Geoheritage, ed. Emmanuel Reynard. Elsevier Inc., 289–303. http://dx.doi.org/10.1016/B978-0-12-809531-7.00016-2.

Cendero, A., M. Marchetti, M. Panizza, and V. Rivas. 2000. “Geomorphology and Environmental Impact Assessment.” In Geomorphology and Environmental Impact Assessment, eds. M. Marchetti and V. Rivas. A.A Balkema.

Chang, Sze-wei. 2016. “A GIS Model for Analyzing Airspace Obstructions and Safety near Airports.” Journal of Civil Engineering and Architecture 10: 553–62.

Chang, Yun-chien, and Henry E Smith. 2015. “The Numerus Clausus Principle, Property Customs, and the Emergence of New Property Forms.” Iowa Law Review 100: 2275–2308.

Chesnaux, Romain et al. 2011. “Computers & Geosciences Building a Geodatabase for Mapping Hydrogeological Features and 3D Modeling of Groundwater Systems : Application to the Saguenay – Lac-St. -Jean Region, Canada.” Computers & Geosciences 37: 1870–82.

Choon, Tan Liat, and Khadijah Binti Hussin. 2012a. “Issues on 3D Property.” International Journal of Scientific & Engineering Research 3(2): 1–6.

Choon, Tan Liat, and Khadijah Binti Hussin. 2012b. “Towards 3D Property Formation.” International Journal of Scientific & Engineering Research 3(3): 1–8.

Choon, Tan Liat, and Looi Kam Seng. 2014. “Developing Infrastructure Framework to Facilitate the Malaysian Multipurpose 3D Cadastre.” In Kuala Lumpur, Malaysia, 1–21.

Choon, Tan Liat, Nur Amalina Zulkifli, Muhamad Uznir Ujang, and Thoo Ai Chin. 2015. “Malaysian Land Administration Domain Model Country Profile.” Asian Social Science 11(24): 301–14.

City of Helsinki. UNDERGROUND MASTER PLAN OF HELSINKI.

Clarke, Alison, and Paul Köhler. 2005. Property Law Commentary and Materials. Cambridge: Cambridge University Press.

Conejo Fernandez, Carmen. 2003. “Spanish Cadastral Information System - Current Status and I.T. Renovation Strategy.” (July): 233–43.

Cousins, Tessa, and Donna Hornby. 2006. “The Realties of Tenure Diversity in South Africa La Réalité de La Diversité Des Systèmes Fonciers En Afrique Du Sud.” In Les Frontières de La Question Foncière – At the Frontier of Land Issues, Montpellier, 1–16.

Crawford, Colin. 2011. “The Social Function of Property and the Human Capacity to Flourish THE SOCIAL.” Fordham Law Review 80(3): 1089–1134. http://ir.lawnet.fordham.edu/flr/vol80/iss3/5.

Cutting, Robert H, and Lawrence B Cahoon. 2005. “Thinking Outside the Box: Property Rights as a Key to Environmental Protection.” Pace Environmental Law Review 22(1): 55–90. http://heinonline.org/HOL/Page?handle=hein.journals/penv22&id=61&div=&collection=journals%0Afiles/34/22PaceEnvtlLRev55.pdf%0Afiles/33/Page.html.

Czerwinski, A., S. Sandmann, E. Stöcker-Meier, and L. Plümer. 2007. “Sustainable SDI for EU Noise Mapping in NRW – Best Practice for INSPIRE.” International Journal of Spatial Data Infrastructures Research 2(July): 90–111.

Dale, P. F., & McLaughlin, J. D. (1999). Land Administration. Oxford: Oxford University Press.

Dale, Peter, and John McLaughlin. 1999. Land Administration. Oxford: Oxford University Press.

Danese, Maria, Giuseppe Las Casas, and Beniamino Murgante. 2008. “3D Simulations in Environmental Impact Assessment.” Computational Science and Its Applications – ICCSA 2008 5072: 430–43. http://www.springerlink.com/index/10.1007/978-3-540-69839-5.

Danish Enviromental Protection Agency. 2002. “Guidelines on Remediation of Contaminated Sites.” 7(7): 290.

David, Rene, and John E.C. Brierley. 1978. “Major Legal Systems in the World Today.” (415).

de Almeida, José-Paulo Duarte, Claire Ellul, and M.M. Rodrigues de Carvalho. 2013. “TOWARDS A REAL ESTATE REGISTRY 3D MODEL IN PORTUGAL : SOME ILLUSTRATIVE CASE STUDIES.” ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences II: 101–10.

de Soto, Hernando. 2000. The Mystery of Capital. London: Black Swan. http://www.ingentaconnect.com/content/glbj/top50sb/2009/00000001/00000116/art00034.

de Stefano, Vincenzo, Valerio di Pinto, and Carlo Gerundo. 2015. “Naples and Its Parallel City.” In Think Deep : Planning, Development and Use of Underground Space in Cities,.

del Campo, Ainhoa González. 2012. “Gis in Environmental Assessment: A Review of Current Issues and Future Needs.” Journal of Environmental Assessment Policy and Management 14(01): 1250007. http://www.worldscientific.com/doi/abs/10.1142/S146433321250007X.

Delmastro, Chiara, Evasio Lavagno, and Laura Schranz. 2016. “Underground Urbanism : Master Plans and Sectorial Plans.” Tunnelling and Underground Space Technology incorporating Trenchless Technology Research 55: 103–11. http://dx.doi.org/10.1016/j.tust.2016.01.001.

Demsetz, Harold. 1967. “Toward a Theory of Property Rights.” The American Economic Review 57(2): 347–59.

Denmark's Environmental Portal. (2019). About Us. Retrieved from The Danish Environment Portal: One gateway to data about nature and the natural environment in Denmark: http://www.miljoeportal.dk/English/Sider/default.aspx

Department of Mining and Tunnelling. 2004. Study of Minerals Planning Policies in Europe – Extended Summary.

Department of Natural Resources and Mines. 2013. “Registrar of Titles Directions for the Preparation of Plans.”

Department of Planning and Community Development. 2013. DPCD South West Victoria Landscape Assessment Study Regional Overview Report.

Department of Sustainability and Development. 2013. “Acceptable Easement Purposes on New Plans of Subdivision.” : 2.

DEWLP. “Planning Schemes 1.”

Dimopoulou, E., D. Kitsakis, and E. Tsiliakou. 2015. “Investigating Correlation between Legal and Physical Property: Possibilities and Constraints.” Proceedings of SPIE - The International Society for Optical Engineering 9535.

Dimopoulou, Efi, and Elikkos Elia. 2012. “Legal Aspects of 3D Property Rights, Restrictions and Responsibilities in Greece and Cyprus.” 3rd International Workhsop on 3D Cadatres: Development and Practices: 41–60.

Dimopoulou, Efi. 2015. ND Κτηματολόγιο [ND Cadastre]. Hellenic Academic Libraries Link.

Dimopoulou, Efi. Karki, Sudarshan. Roić, Miodrag. de Almeida, José-Paulo Duarte. Griffith-Charles, Charisse. Thompson, Rod. Ying, Shen. Paasch, Jesper. van Oosterom, Peter. 2018. “Initial Registration of 3D Parcels.” In BEST PRACTICES 3D CADASTRES, ed. Peter van Oosterom. Copenhagen, Denmark.

Dinic, Milena, and Petar Mitkovic. 2011. “Planning Regulations in the USA and Their Implications on Urban Design in the Central City Zone.” Facta universitatis - series: Architecture and Civil Engineering 9(2): 289–99. http://www.doiserbia.nb.rs/Article.aspx?ID=0354-46051102289D.

Döner, Fatih. Thompson, Rod.Stoter, Jantien.Lemmen, Christiaan.Ploeger, Hendrik.van Oosterom, Peter.Zlatanova, Sisi. 2010. “4D Cadastres: First Analysis of Legal, Organizational, and Technical Impact—With a Case Study on Utility Networks.” Land Use Policy 27(4): 1068–81. http://linkinghub.elsevier.com/retrieve/pii/S0264837710000207 (October 9, 2012).

Döner, Fatih. Thompson, Rod.Stoter, Jantien.Lemmen, Christiaan.Ploeger, Hendrik.van Oosterom, Peter.Zlatanova, Sisi. 2011. “Solutions for 4D Cadastre – with a Case Study on Utility Networks.” International Journal of Geographical Information Science 25(7): 1173–89. http://www.tandfonline.com/doi/abs/10.1080/13658816.2010.520272 (January 28, 2015).

Donkers, Sjors, Hugo Ledoux, Junqiao Zhao, and Jantien Stoter. 2016. “Automatic Conversion of IFC Datasets to Geometrically and Semantically Correct CityGML LOD3 Buildings.” Transactions in GIS 20(4): 547–69.

Dramstad, Wenche E., and Wendy J. Fjellstad. 2011. “Landscapes: Bridging the Gaps between Science, Policy and People.” Landscape and Urban Planning 100(4): 330–32. http://dx.doi.org/10.1016/j.landurbplan.2011.02.003.

Draye, Anne Mie. 2008. “Legal Protection of Monuments in Their Settings: A Means of Maintaining the Spirit of the Place.” In 16th ICOMOS General Assembly and International Symposium, , 11.

Dsilva, Mcenroe Gifford. 2009. “Department of Mathematics and Computer Science A Feasibility Study on CityGML for Cadastral Purposes.” EINDHOVEN UNIVERSITY OF TECHNOLOGY.

Ducci, Daniela, and Mariangela Sellerino. 2013. “Vulnerability Mapping of Groundwater Contamination Based on 3D Lithostratigraphical Models of Porous Aquifers.” Science of the Total Environment 447: 315–22.

Eames-Mayer, David, and Jason Matthews. 2008. “Easements & Statutory Authorities Nature of Easements.” In ISV, ACSV and SSI Joint Seminar,.

Eastman, Chuck, Paul Teichloz, Rafael Sacks, and Kathleen Liston. 2011. BIM Handbook. Second Edi. John Wiley & Sons, Inc.

Economic Commission for Europe. 2004. Guidelines on Real Property Units and Identifiers. New York and Geneva.

Edirisinghe, Ruwini, and Kerry London. 2015. "Comparative Analysis of International and National Level BIM Standardization Efforts and BIM Adoption." In Proc. of the 32nd CIB W78 Conference, Eindhoven, The Netherlands, 149–58.

Eisenstadt, Melvin M., and Albert E. Utton. 1976. "Solar Rights and Their Effect on Solar Heating and Cooling." Natural Resources Journal 16(2): 363–414.

Ekbäck, Peter. 2011. "Towards a Theory of 3D Property Rights – With an Application to Nordic Legislation." Nordic Journal of Surveying and Real Estate Research 8(1): 65–80.

Ellickson, Robert C. 2011. "Two Cheers for the Bundle-of- Sticks Metaphor, Three Cheers for Merrill and Smith The Merits." ECON JOURNAL WATCH 8(3) 8(3): 215–22.

El-Mekawy, M., and Anders Östman. 2010. "Semantic Mapping: An Ontology Engineering Method for Integrating Building Models in IFC and CITYGML." Proceedings of the 3rd ISDE Digital Earth Summit: 1–11. http://news.digitalearth-isde.org/Bulgaria/pdf/32_El-Mekawy_Sweden_paper.pdf.

El-Mekawy, Mohamed, A. Östman, and Ihab Hijazi. 2012. "An Evaluation of IFC-CityGML Unidirectional Conversion." International Journal of Advanced Computer Science and Applications 3(5): 159–71. http://www.getcited.org/pub/103504239.

El-Mekawy, Mohamed, and Anders Östman. 2012. "Feasibility of Building Information Models for 3D Cadastre in Unified City Models." International Journal of E-Planning Research 1(4): 35–58. http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/ijepr.2012100103.

El-Mekawy, Mohamed, Jesper M. Paasch, and Jenny Paulsson. 2015. "Integration of Legal Aspects in 3D Cadastral Systems." International Journal of E-Planning Research (IJEPR) 4(3): 47–71.

El-Mekawy, Mohamed, Jesper Paasch, and Jenny Paulsson. 2014. "Integration of 3D Cadastre, 3D Property Formation and BIM in Sweden." In 4th International Workshop on 3D Cadastres, eds. P. J. M. van Oosterom and Elfriede M. Fendel. Dubai, United Arab Emirates, 17–34.

Elsom, Derek M. 2005. "Air Quality and Climate." In Methods of Environmental Impact Assessment, eds. John Glasson and Mick Bruton. Spon Press, 145–68.

Enemark, Stig, Keith Clifford Bell, Christiaan Lemmen, and Robin McLaren. 2018. "Fit-For-Purpose Land Administration." (60): 44.

Environmental Protection Authority. 2016. Environmental Factor Guideline Flora and Vegetation.

Environmental Protection Department. (2018, May). Sound and Noise. Retrieved from Noise Mitigation:

https://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m4/mitigation_2.html

Erba, Diego A., and Silvio D. Graciani. 2011. “3D Cadastre in Argentina : Maps and Future Perspectives 3D Cadastre in Argentina : Maps and Future Perspectives.” In 2nd International Workshop on 3D Cadastres, Delft, The Netherlands, 15–30.

Erba, Diego Alfonso, and Mario Andrés Piumetto. 2012. “3D Cadastre in the Federal Countries of Latin America.” In FIG Working Week, Rome, Italy, 1–14.

Erp, Sjef Van, and Bram Akkermans. 2010. “Property Rights : A Comparative View.” In Property Law and Economics, Edward Elgar Publishing, 31–52.

Estonian Land Board Geoportal. (2018, July). Web map server. Retrieved from http://xgis.maaamet.ee/xGIS/XGis?app_id=UU218&user_id=at&bbox=549952.061013112,6590471.28940753,554855.414710513,6593095.31612257&setlegend=SHYBR_ALUS01V=0,SHYBR_ALUS08=1&LANG=2

EU Task Force on Land Tenure. 2004. “Guidelines for Support to Land Policy Design and Land Policy Reform Processes in Developing Countries.” (November). https://ec.europa.eu/europeaid/sites/devco/files/methodology-eu-land-policy-guidelines-200411_en_2.pdf.

European Commission. 1992. “DIRECTIVE 92 /43 / EEC.”

European Commission. 2004. Common Implementation Strategy for the Water Framework Directive (2000 / 60 / EC) Groundwater Body Characterisation.

European Commission. 2014. “DIRECTIVE 2014/52/EU.” : 1–18.

European Commission. 2017. Environmental Impact Assessment of Projects Guidance on the Preparation of the Environmental Impact Assessment Report.

European Federation of Geologists (EFG). 2003. Advice Document to the European Commission on Environmental Impact Assessment Implementation and Practice.

FAA Guide to Low-Flying Aircraft. 2008. 39 https://www.faa.gov/about/office_org/field_offices/fsdo/lgb/local_more/media/FAA_Guide_to_Low-Flying_Aircraft.pdf.

FAA. 2000. “Proposed Construction or Alteration of Objects That May Affect the Navigable Airspace.” : 8.

Farah Zaini, Khadijah Hussin, Siti Radiaton Adawiyah Zakaria. 2014. “LEGAL AND ADMINISTRATIVE ISSUE FOR UNDERGROUND LAND.” In International Real Estate Research Symposium, Kuala Lumpur, Malaysia, 13.

Fausey, N.R. 2005. “Drainage, Surface and Subsurface.” In Encyclopedia of Soils in the Environment, ed. D. Hillel. Elsevier Ltd, 409–13.

Feder, Gershon, and David Feeny. 1991. “Land Tenure and Property Rights: Theory and Implications for Development Policy.” World Bank Development Review 5(1): 135–54. http://documents.worldbank.org/curated/en/1991/01/439939/land-tenure-property-rights-theory-implications-development-policy.

Federal Office of Topography swisstopo. 2015. The Cadastre of Public-Law Restrictions on Landownership (PLR-Cadastre).

Felus, Yaron et al. 2014. “Steps towards 3D Cadastre and ISO 19152 (LADM) in Israel.” In 4th International Conference on Cartography & GIS, eds. Peter van oosterom and Elfriede M. Fendel. Dubai, United Arab Emirates, 391–410.

Ferlan, Miran, Šumrada Radoš, and Hans Mattsson. 2007. “Modelling Property Transactions.” In Real Property Transactions - Procedures, Transaction Costs and Models, eds. Jaap Zevenbergen, Andrew Frank, and Erik Stubkjaer. IOS Press, 27–80.

Feys, Bert. 2006. “A General Introduction to Norwegian Property Law.” Maastricht University.

FIG working group 3D-Cadastres. 2018. “Questionnaire 3D Cadastres.” : 1–16. http://www.gdmc.nl/3DCadastres/participants/3D_Cadastres_questionnaire2018.pdf (May 19, 2018).

FIG Working Group on 3D Cadastre. (2014). Questionnaire 3D Cadastres. International Federation of Surveyors (FIG).

FIG. 1995. FIG PUBLICATION NO. 11 FIG Statement on the Cadastre. Copenhagen, Denmark.
http://www.fig.net/resources/publications/figpub/pub11/figpub11.asp.

Finn, Rachel L, David Wright, Laura Jacques, and Paul De Hert. 2014. Study on Privacy, Data Protection and Ethical Risks in Civil Remotely Piloted Aircraft Systems Operations.

Fitzpatrick, R.W., N. McKenzie, and D.J. Maschmedt. 2001. “Soil Morphological Indicators and Their Importance to Soil Fertility.” In Soil Analysis An Interpretation Manual, eds. K.I. Perevill, L.A Sparrow, and D.J. Reuter. CSIRO Publishing, 369.

Fletcher, J., and R.G. Busnel. 1978. Effects of Noise on Wildlife. Academic Press Inc.

Food and Agriculture Organization of the United Nations (FAO). (n.d.). Retrieved from 6. Soil Texture: http://www.fao.org/tempref/FI/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e06.htm

Foster, Tara J. 1988. “Securing a Right to View : Broadening the Scope of Negative Easements.” Pace Environmental Law Review 6(1): 269–300.

Frankenberg, Günter. 1985. “Critical Comparisons: Re-Thinking Comparative Law.” Harvard International Law Journal 26(2): 411–55. https://www.rewi.hu-berlin.de/de/lf/ls/bae/w/files/ls_compcon/meth_frankenberg_critcomp_harvintlj_85_passwd.pdf.

Fritzsche, K.C., L. Jahrmarkt, and Y. Li. 2018. “Soil Protection Law.” In Handbook of Agri-Food Law in China, Germany, European Union: Food Security, Food Safety, Sustainable Use of Resources in Agriculture., ed. I. Härtel. Springer International Publishing AG, 662.

Fuchs, Bastian. 2017. “BIM – Status of Implementation in Germany Building Information Modelling Status of Implementation in Germany.” In 2017 Annual Conference of the European Society of Construction Law, 1–45.

Georgiades, George. 2016. “ASPECTS OF GREEK CIVIL LAW.” GREEK LAW DIGEST: 80–83.

Georgiadis, Apostolos. 2012. Εγχειρίδιο Εμπραγμάτου Δικαίου [Handbook of Property Law]. 2nd ed. Sakkoulas Publications.

Gillespie, Alexander. 2009. “Defining Internationally Protected Areas.” Journal of International Wildlife Law and Policy 12(4): 229–47.

Givord, Gaetan. 2012. “Cadastre 3D Des Restrictions de Droit Public à La Propriété Foncière.” Conservatoire National des Arts et Métiers.

Gkeli, M., Ioannidis, C., & Potsiou, C. 2017. 3D Modelling Algorithms and Crowdsourcing Techniques. Coordinates Magazine, 13(9), 7–14.

Gkeli, M., Potsiou, C., & Ioannidis, C. 2019. Crowdsourced 3D Cadastral Surveys: Looking towards the Next 10 years. Journal of Geographical Systems, 21(1), 61–87.

Glasson, J., Therivel, R., & Chadwick, A. 1999. Introduction to Environmental Impact Assessment. UCL Press.

Glasson, John. 2005. “Socio-Economic Impacts 1: Overview and Economic Impacts.” In Methods of Environmental Impact Assessment, eds. Peter Morris and Riki Therivel. Spon Press, 20–41.

Glenn, H Patrick. 2007. “The National Legal Tradition.” Electronic Journal of Comparative Law 11(3): 1–15.

Globalaw. 2016. BASICS OF MINING LAW – SELECTED JURISDICTIONS.

Glock, Stéphane. Real Property Law Project - France.

Gogolou, Christina, and Efi Dimopoulou. 2015. “Land Administration Standardization for the Integration of Cultural Heritage in Land Use Policies.” Land Use Policy 49: 617–25. http://dx.doi.org/10.1016/j.landusepol.2015.01.029.

Golay, Dr. Christophe, and Ioana Cismas. 2010. “Legal Opinion : The Right To Property From a Human Rights Perspective.” Human Rights: 32.

Goldschmidt, Leopold A. 1964. Information Report No. 186 - Air Rights. Chicago, Illinois.

Goodey, B. 1995. “Landscape.” In Methods of Environmental Impact Assessment, eds. M. Morris and R. Therivel. London: UCL Press, 78–95.

Government of Victoria. 2011. “Subdivision (Registrar’s Requirements) Regulations.” : 30.

Góźdź, Katarzyna, Wojciech Pachelski, Peter van Oosterom, and Volker Coors. 2014. “The Possibilities of Using CityGML for 3D Representation of Buildings in the Cadastre.” In 4th International Workshop on 3D Cadastres, eds. Peter van Oosterom and Elfriede M. Fendel. Dubai, United Arab Emirates, 339–62.

Grant, D. B. et al. 2018. Upgrading Spatial Cadastres in Australia and New Zealand : Functions, Benefits & Optimal Spatial Uncertainty.

Greater London Authority. 2012. London View Management Framework. https://www.london.gov.uk/priorities/planning/supplementary-planning-guidance/view-management.

Gröger, Gerhard, Thomas H Kolbe, Claus Nagel, and Karl-Heinz Häfele. 2012. Open Geospatial Consortium OGC City Geography Markup Language (CityGML) Encoding Standard. http://www.opengeospatial.org/legal/.

Grøv, E., and Ming Lu. 2011. "DESIGN & BUILD LARGE UNDERGROUND CAVERNS THE IMPORTANCE OF UNDERSTANDING AND UTILIZING IN-SITU ROCK STRESSES." In Proceedings of the Joint HKIE-HKIP Conference on Planning and Development of Underground Space, Hong Kong, 19–35.

Gulliver, Trent F D. 2015. "Developing a 3D Digital Cadastral Survey System for New Zealand." University of Canterbury Christchurch, New Zealand.

Gulliver, Trent, Anselm Haanen, Mark Goodin, and New Zealand. 2016. "A 3D Digital Cadastre for New Zealand by 2021: Leveraging the Current System and Modern Technology." 5th International FIG 3D Cadastre Workshop, 18-20 October 2016, Athens, Greece (October): 473–90.

Guo, Renzhong. Li, Lin. Ying, Shen. Luo, Ping. He, Biao. Jiang, Renrong. 2013. "Developing a 3D Cadastre for the Administration of Urban Land Use: A Case Study of Shenzhen, China." Computers, Environment and Urban Systems 40: 46–55. http://dx.doi.org/10.1016/j.compenvurbsys.2012.07.006.

Guo, Renzhong. Luo, Feng. Zhao, Zhigang. He, Biao. Li, Lin. Luo, Ping. 2014. "The Applications and Practices of 3D Cadastre in Shenzhen." In 4th International Workshop on 3D Cadastres, eds. Peter van Oosterom and Elfriede M. Fendel., 299–312.

Hage, Jaap. 2014. "Comparative Law as Method and the Method of Comparative Law." In The Method and Culture of Comparative Law. Essays in Honour of Mark Van Hoecke, eds. Maurice Adams and Dirk Heirbaut. Hart Publishing, 37–52.

Hełdak, Maria, Jakub Szczepański, and Ciechosław Patrzałek. 2012. "Using the 3D Computer Scanning Method in the Environmental Impact Assessment." Infrastructure and Ecology of rural areas 49–59(1): 49–60.

Henssen, Jo. 1995. "BASIC PRINCIPLES OF THE MAIN CADASTRAL SYSTEMS IN THE WORLD." (May 1995): 5–12.

Hernandez, André. 2003. "Mining Cadastre in Tanzania." In FIG Working Week 2013, Paris, France, 1–13. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Mining+Cadastre+in+Tanzania#0.

Hespanha, J.P. 2012. "Development Methodology for an Integrated Legal Cadastre." Delft University of Technology. http://repository.tudelft.nl/view/ir/uuid:ab61c611-de16-48d6-a4c6-0fe57ffa3e39/.

Historic England. (2018, March). Listing. Retrieved from https://historicengland.org.uk/listing/the-list/map-search?clearresults=True

Ho, Serene, Abbas Rajabifard, Jantien Stoter, and Mohsen Kalantari. 2013. "Legal Barriers to 3D Cadastre Implementation: What Is the Issue?" Land Use Policy 35: 379–87. http://dx.doi.org/10.1016/j.landusepol.2013.06.010.

Ho, Serene. 2014. "Towards 3D-Enabled Urban Land Administration Invisible Constraints and Strategic Choices." The University of Melbourne.

Hodgson, Geoffrey M. 2013. 9 Journal of Institutional Economics Editorial Introduction to 'Ownership' by A. M. Honoré (1961). http://www.journals.cambridge.org/abstract_S174413741200032X.

Hodson, M. 1995. "Soils and Geology." In Methods of Environmental Impact Assessment, eds. Morris M. and R. Therivel. UCL Press, 380.

Hodson, M., C. Stapleton, and R. Emberton. 2001. "Soils, Geology and Geomorphology." In Methods of Environmental Impact Assessment, eds. P. Morris and R. Therivel. Spon Press, 170–96.

Hoecke, Mark Van. 2012. "Methodology of Comparative Legal Research." : 279–301.

Holstein, Lynn. 1996. "Towards Best Practice from World Bank Experience in Land Titling and Registration." In International Conference on Land Tenure and Administration, Orlando Florida, 1–26.

Hong Kong Institute of Building Information Modelling. (2018). Hong Kong Institute of Building Information Modelling. Retrieved from https://www.hkibim.org/

Husa, Jaakko. 2004. "Classification of Legal Families Today - Is It Time for Memorial Hymn?" Revue Internationale de Droit Comparé 56(1): 11–38.

Hussa, Jaako. 2014. "INTERDISCIPLINARY COMPARATIVE LAW—BETWEEN SCYLLA AND CHARYBDIS?" Journal of Comparative Law 9(2): 28–42.

ICAO GIS portal. (2018, March). Retrieved from http://gis.icao.int

ICAO. 2004. "Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information." : 345.

ICAO. 2009. I Aerodromes.

ICAO. 2015. "Manual on Remotely Piloted Aircraft Systems (RPAS)." : 1–166.

ICLG. (2018, April). Mining Laws and Regulations 2019. Retrieved from https://iclg.com/practice-areas/mining-laws-and-regulations#general-chapters

Institute of Geologists of Ireland. 2002. Geology Geology in Environmental Impact Statements.

Intergovernmental Committee for Surveying and Mapping. 2015. Cadastre 2034 Powering Land & Real Property.

International Code Council. 2011. International Building Code 2012.

International Organization for Stadardization (ISO). (2019). Standards catalogue. Retrieved from https://www.iso.org/standards-catalogue/browse-by-ics.html

International Union for the Conservation of Nature. (2018, April). Protected Areas. Retrieved from https://www.iucn.org/theme/protected-areas/about

ITRC (Interstate Technology & Regulatory Council). 2010. Excavation and Disposal of Solid Mining Waste. Washington, D.C. www.itrcweb.org.

Iván, Gyula, and András Osskó. 2015. "Towards 3D Land Registry in Hungary." FIG Working Week (May 2015): 17–21.

Jacobson, Sandra L. 2005. 99 Gen. Tech. Rep. PSW-GTR-191 Mitigation Measures for Highway-Caused Impacts to Birds.

Jadayel, Oussama C, and Rita Y Ibrahim. 2006. "Three-Dimensional Aerial Zoning around a Lebanese Airport." : 1–8.

Jaeger, William K. 2006. "The Effects of Land-Use Regulations on Property Values." Environmental law 36(105): 105–30.

Janečka, K., Karki, S., van Oosterom, P., Zlatanova, S., Kalantari, M., Ghawana, T. 2018. "3D Spatial DBMS for 3D Cadastres." In Best Practices 3D Cadastres, ed. Peter van Oosterom. Copenhagen, Denmark, 133–82.

Janecka, Karel, and Soucek, Petr. 2017. "A Country Profile of the Czech Republic Based on an LADM for the Development of a 3D Cadastre." ISPRS International Journal of Geo-Information 6(143): 1–19.

Jarna, A. et al. 2015. "3-DIMENSIONAL GEOLOGICAL MAPPING AND MODELING ACTIVITIES AT THE GEOLOGICAL SURVEY OF NORWAY." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL-2/W4: 11–16.

Jenni, Lorenz, Andrés Guarín Lopez, Ziegler. Stefan, and Victor Manuel Bajo Pérez. 2017. "DEVELOPMENT AND EMPLOYMENT OF AN LADM IMPLEMENTING TOOLKIT IN COLOMBIA." In 2017 WORLD BANK CONFERENCE ON LAND AND POVERTY, Washington DC, USA, 1–23.

Jensen, Per Anker, and Elvar Ingi Jóhannesson. 2013. "Building Information Modelling in Denmark and Iceland." Engineering, Construction and Architectural Management 20(1): 99–110.

Jensen, Ulf. Real Property Law - National Report Sweden.

Jeong, Dong-Hoon et al. 2012. "Initial Design of an LADM-Based 3D Cadastre –Case Study from Korea." In 3rd International Workshop on 3D Cadastres: Developments and Practices, Shenzhen, China, 159–84.

Johnson, Denise R. 2007. "Reflections on the Bundle of Rights." Vermont Law Review 32: 247–72.

Johnson, Eva Liedholm, and Magnus Ericsson. 2015. "State Ownership and Control of Minerals and Mines in Sweden and Finland." Mineral Economics 28(1–2): 23–36.

Julstad, Barbro, and Agneta Ericsson. 2001. "Property Formation and Three-Dimensional Property Units in Sweden B." In International Workshop, Delft, The Netherlands, 173–90.

Jusuf, Steve Kardinal, Benjamin Mousseau, Gaelle Godfroid, and Vincent Soh Jin Hui. 2017. “Integrated Modeling of CityGML and IFC for City/Neighborhood Development for Urban Microclimate Analysis.” Energy Procedia 122: 145–50. https://doi.org/10.1016/j.egypro.2017.07.329.

Kahalley, Karol L., Kristin A. Nichols, and Robert A. Bassett. 2016. “United States.” In The Mining Law Review, Law Business Research Ltd, 232–42.

Kalantari, M., Rajabifard, A., J. Wallace, and I. Williamson. 2008. “Spatially Referenced Legal Property Objects.” Land Use Policy 25: 173–81.

Kaliampakos, D, and Benardos, A. 2008. “Underground Space Development : Setting Modern Strategies.” WIT Transactions on the Built Environment 102: 1–10.

Kaliampakos, D., Benardos, A. and Mavrikos, A. 2016. “A Review on the Economics of Underground Space Utilization.” Tunnelling and Underground Space Technology 55: 236–44. http://dx.doi.org/10.1016/j.tust.2015.10.022.

Kalogianni, Eftychia, and Dimopoulou, Efi. 2018. “3D Cadastre and LADM – Needs and Expectations towards LADM Revision.” In 7th International FIG Workshop on the Land Administration Domain Model, Zagreb, Croatia, 67–88.

Karabin, Marcin. 2012. “Registration of Untypical 3D Objects in Polish Cadastre–Do We Need 3D Cadastre?” Geodesy and Cartography 61(2): 75–89.

Karabin, Marcin. 2014. “A Concept of a Model Approach to the 3D Cadastre in Poland : Technical and Legal Aspects A Concept of a Model Approach to the 3D Cadastre in Poland : Technical and Legal Aspects.” In 4th International Workshop on 3D Cadastres, eds. Peter van Oosterom and Elfriede M. Fendel. Dubai, United Arab Emirates, 281–98.

Karabin, Marcin., Kitsakis, Dimitrios., Koeva, Mila., Navratil, Gerhard., Paasch, Jesper., Paulsson, Jenny., Vučić, Nikola., Janečka, Karel., Lisec, Anka. 2018. “Layer Approach to Ownership in 3D Cadastre – a Subway Case.” In 6th International FIG 3D Cadastre Workshop, eds. Peter Van Oosterom and Dirk Dubbeling. Delft, The Netherlands, 111–36.

Karki, Sudarshan, Kevin McDougall, and Rod Thompson. 2010. “An Overview of 3D Cadastre from a Physical Land Parcel and a Legal Property Object Perspective.” In FIG Congress 2010: Facing the Challenges – Building the Capacity, , 1–13.

Karki, Sudarshan, Rod Thompson, and Kevin McDougall. 2013. “Development of Validation Rules to Support Digital Lodgement of 3D Cadastral Plans.” Computers, Environment and Urban Systems. http://linkinghub.elsevier.com/retrieve/pii/S0198971512000932 (May 1, 2013).

Karki, Sudarshan. 2013. “3D CADASTRE IMPLEMENTATION ISSUES IN AUSTRALIA.” University of Southern Queensland.

Kast, Fremont E., and James E. Rosenzweig. 1970. Organization and Management: A Systems Approach. 1st ed. New York: McGraw and Hill.

Katz, Larissa. 2008. “Exclusion and Exclusivity in Property Law.” University of Toronto Law Journal 58: 275–315.

Kaufmann, J., and Steudler, D. 1998. Cadastre 2014: A Vision for a Future Cadastral System. http://www.geobc.gov.bc.ca/ilrr/files/documentation/cad2014_eng.pdf%5Cnhttp://www.eurocadaster.org/pdf/kaufmann_cadastre_2014.pdf.

Kaufmann, J., and Steudler, D. 2001. "Cadastre 2014: A Vision for a Future Cadastral System." FIG Commission (July): 43. http://www.geobc.gov.bc.ca/ilrr/files/documentation/cad2014_eng.pdf%5Cnhttp://www.eurocadaster.org/pdf/kaufmann_cadastre_2014.pdf.

Kaufmann, Jürg. 2015. "The Comprehensive Cadastre - The Tool Comprising the Wisdom of the Ages to Master the Challenges of the Modern World." In FIG Working Week 2015, Sofia, Bulgaria.

Kenin, David S. 1962. "Condominium : A Survey of Legal Problems and Proposed Legislation." University of Miami Law Review 17(145): 145–81.

Kerr, William K. 1963. "Condominium--Statutory Implementation." St. John's Law Review 38(1): 1–49.

Kerwer, Dieter. 2005. "Rules That Many Use: Standards and Global Regulation." Governance 18(4): 611–32.

Khoo, Victor H S. 2011. "3D Cadastre in Singapore." 2nd International Workshop on 3D Cadastres (November 2011): 507–20.

Kim, Sangmin, and Joon Heo. 2017. "Development of 3D Underground Cadastral Data Model in Korea: Based on Land Administration Domain Model." Land Use Policy 60: 123–38. http://dx.doi.org/10.1016/j.landusepol.2016.10.020.

Kimsey, Brian. 2010. "Owner' s Roadmap to Building Information Modeling - BIM." : 52.

Kinsella, N Stephan. 1994. "A Civil Law to Common Law Dictionary." Louisiana Law Review 54(5): 1265–1305.

Kishii, Takayuki. 2016. "Utilization of Underground Space in Japan." Tunnelling and Underground Space Technology 55: 320–23. http://dx.doi.org/10.1016/j.tust.2015.12.007.

Kitsakis, D., and E. Dimopoulou. 2014. "3D Cadastres: Legal Approaches and Necessary Reforms." Survey Review 46(338): 322–32. http://www.tandfonline.com/doi/full/10.1179/1752270614Y.0000000119.

Kitsakis, D., and Papageorgaki, I. 2017. "Towards 3D Modelling of Public Law Restrictions in Water Bodies." European Water 60: 395–401.

Kitsakis, D., Apostolou, C. and E. Dimopoulou. 2016. "Three-Dimensional Cadastre Modelling of Customary Real Property Rights." Survey Review: 1–15.

Kitsakis, D., E. Tsiliakou, T. Labropoulos, and E. Dimopoulou. 2017. "Procedural 3D Modelling for Traditional Settlements. The Case Study of Central Zagori." International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 42(2W3): 369–76.

Kitsakis, Dimitrios, Kalantari, Mohsen, Rajabifard, Abbas, Atazadeh, Behnam, Dimopoulou, Efi. 2019. “Exploring the 3rd Dimension within Public Law Restrictions: A Case Study of Victoria, Australia.” Land Use Policy 85: 195–206.

Kitsakis, Dimitrios, and Efi Dimopoulou. 2014. “Contribution of Existing Documentation to 3D Cadastre.” 4 th International FIG 3D Cadastre Workshop (July): 1–17. https://www.researchgate.net/publication/268279614_Contribution_of_Existing_Documentation_to_3D_Cadastre.

Kitsakis, Dimitrios, and Efi Dimopoulou. 2016. “Possibilities of Integrating Public Law Restrictions to 3D Cadastres.” In 5th International FIG 3D Cadastre Workshop, eds. Peter van Oosterom, Efi Dimopoulou, and Elfriede M. Fendel. Athens, Greece, 25–46.

Kitsakis, Dimitrios, and Efi Dimopoulou. 2017. “Addressing Public Law Restrictions within a 3D Cadastral Context.” ISPRS International Journal of Geo-Information 6(7): 182. http://www.mdpi.com/2220-9964/6/7/182.

Kitsakis, Dimitrios, and Efi Dimopoulou. 2018. “Determining the ‘True’ Three - Dimensional Environmental Impact of Public Law Restrictions.” In 6th International FIG 3D Cadastre Workshop, eds. P. J. M. van Oosterom and Elfriede M. Fendel. Delft, The Netherlands, 291–308.

Kitsakis, Dimitrios, Eftychia Kalogianni, Efi Dimopoulou, and Peter van Oosterom. 2018. “Requirements for Standardised Representation of Public Law Restrictions Based on LADM.” In FIG Commission 3 Workshop and Annual Meeting, Naples, Italy, 1–20.

Kitsakis, Dimitrios, Eva Tsiliakou, Tassos Labropoulos, and Efi Dimopoulou. 2017. “Procedural 3D Modelling for Traditional Settlements. The Case Study of Central Zagori.” International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 42(2W3): 369–76.

Kitsakis, Dimitrios, Jesper M. Paasch, Jenny Paulsson, Gerhard Navratil, Nikola Vučić, Marcin Karabin, Andréa Flávia Tenório Carneiro and Mohamed El-Mekawy. 2016. “3D Real Property Legal Concepts and Cadastre : A Comparative Study of Selected Countries to Propose a Way Forward.” In 5th International FIG 3D Cadastre Workshop, eds. Peter van Oosterom, Efi Dimopoulou, and Elfriede M. Fendel. Athens, Greece, 1–24.

Kitsakis, Dimitrios, Jesper Paasch, Jenny Paulsson, Gerhard Navratil, Nikola Vučić, Marcin Karabin, Mohamed El-Mekawy, Mila Koeva, Karel Janečka, Diego Erba, Ramiro Alberdi, Mohsen Kalantari, Zhixuan Yang, Jacynthe Pouliot, Francis Roy, Monica Montero, Adrian Alvarado. 2018. “3D Cadastres Best Practices : Legal Foundations.” In BEST PRACTICES 3D CADASTRES, ed. P. van Oosterom. Copenhagen, Denmark: International Federation of Surveyors (FIG), 1–67.

Kitsakis, Dimitrios, Paasch, Jesper, Paulsson, Jenny, Navratil, Gerhard, Vučić, Nikola, Marcin Karabin, Mohamed El-Mekawy, Mila Koeva, Karel Janečka, Diego Erba, Ramiro Alberdi, Mohsen Kalantari, Zhixuan Yang, Jacynthe Pouliot, Francis Roy, Monica Montero, Adrian Alvarado. 2016. “3D Cadastres Best Practices : Legal Foundations.” : 1–10.

Kitsaras, L. (2001). Οι πρώτες εγγραφές στο Εθνικό Κτηματολόγιο [Initial Registrations in the Hellenic National Cadastre]. Athens: P.N Sakkoulas.

Kjartansdóttir, Ingibjörg Birna Mordue, Stefan, Paweł Nowak, David Philp, and Snæbjörnsson Jónas Thór. 2017. BUILDING INFORMATION MODELLING - BIM. eds. Mariola Książek and Jerzy Rosłon. http://www.ciob.org/sites/default/files/M21 BUILDING INFORMATION MODELLING - BIM.pdf.

Knight, C., and J. Swaddle. 2011. "How and Why Environmental Noise Impacts Animals: An Integrative, Mechanistic Review." Ecology letters 14(10): 1052–61.

Kok, Nils, Paavo Monkkonen, and John M Quigley. 2014. "Land Use Regulations and the Value of Land and Housing: An Intra-Metropolitan Analysis." JOURNAL OF URBAN ECONOMICS 81: 136–48. http://dx.doi.org/10.1016/j.jue.2014.03.004.

Kokko, Kai., Buanes, Arild., Koivurova, Timo., Masloboev, Vladimir., Pettersson, Maria. 2015. "Sustainable Mining, Local Communities and Environmental Regulation." Barents Studies: Peoples, Economics and Politics 2(1): 50–81. http://urn.fi/URN:NBN:fi:ula-201512211410.

Kolbe, Thomas H, and Gerhard Gröger. 2005. "CityGML – A GML3 Application Profile for Virtual 3D City Models 3D City Models." In OGC TC Meeting, New York City.

Kolbe, Thomas H, Claus Nagel, and Alexandra Stadler. 2009. "CityGML – OGC Standard for Photogrammetry ?" In Photogrammetric Week '09, ed. Dieter Fritsch. Heidelberg: Wichmann Verlag, Heidelberg, 265–77.

Kolbe, Thomas H. 2012. "Semantic 3D City Models for Urban Information Fusion and City Lifecycle Management." In Earth Systems Engineering Symposium, Newcastle.

Kravchenko, Svitlana, Tareq M.R. Chowdhury, and Md Jahid Hossain Bhuiyan. 2012. "Principles of International Environmental Law." In Routledge Handbook of International Environmental Law, eds. Katharina Kummer Peiry, Andreas R. Ziegler, and Jorun Baumgartner. Routledge, 11–32.

Küntzel, Rudolf, and Jürg Kaufmann. 2012. "The Swiss Approach of Integrated Land Administration and Land Management" In FIG Working Week 2012, Rome, Italy, 1–9.

Kuus, Priit. 2011. "Utility Networks in Estonian Restrictions Information System."

La Flèche, Erik Richer, ed. 2016. The Mining Law Review. Fifth. Law Business Research Ltd.

Lai, Poh C., Kim Hung Kwong, and Ann S.H. Mak. 2010. "Assessing the Applicability and Effectiveness of 3D Visualisation in Environmental Impact Assessment." Environment and Planning B: Planning and Design 37(2): 221–33.

Lal, Rattan. 1991. "Soil Structure and Sustainability." Journal of Sustainable Agriculture 1(4): 67–92.

Land Victoria. (2019, January). SPEAR. Retrieved from https://www.spear.land.vic.gov.au

Landscape Institute and Institute of Environmental Management & Assessment. 2013. Guidelines for Landscape and Visual Impact Assessment. Routledge.

Larsson, Karolina, Jesper Paasch, and Jenny Paulsson. 2018. “Conversion of 2D Analogue Cadastral Boundary Plans into 3D Digital Information – Problems and Challenges Illustrated by a Swedish Case.” (October): 75–94.

Law, Chi Wing, Chee Kwan Lee, and Kwong Moon Tai. 2004. Visualization of Complex Noise Environment by Virtual Reality Technologies.

Lawrence, D.P. 2003. Impact Assessment: Practical Solutions to Recurrent Problems and Contemporary Challenges. 2nd ed. John Wiley & Sons.

Lee, Bo Mi et al. 2015. “Improvement of the Korean LADM Country Profile to Build a 3D Cadastre Model.” Land Use Policy 49: 660–67. http://dx.doi.org/10.1016/j.landusepol.2015.10.012.

Lee, Ghang, Rafael Sacks, and Charles M. Eastman. 2006. “Specifying Parametric Building Object Behavior (BOB) for a Building Information Modeling System.” Automation in Construction 15(6): 758–76.

Lee, Ghang. 2014. “Towards BIM Guide 2.0 - The Current Status of BIM Guides Development in South Korea.” : 1–15.

Lemmen, Christiaan, and Peter van Oosterom. 2014. “LADM and Its Role in Establishing Cadastral Systems.” In CADASTRE 2014 and Beyond, , 34–38.

Lemmen, Christiaan. 2012. “A Domain Model for Land Administration.” Delft University of Technology.

Li, Lin et al. 2016. “3D Modeling of the Ownership Structure of Condominium Units.” Computers, Environment and Urban Systems 59: 50–63. http://dx.doi.org/10.1016/j.compenvurbsys.2016.05.004.

Liedholm Johnson, Eva. 2010. “Mineral Rights: Legal Systems Governing Exploration and Exploitation.” Royal Institute of Technology (KTH). https://www.kth.se/polopoly_fs/1.131782!/Menu/general/column-content/attachment/FULLTEXT01(2).pdf.

Liedholm, Eva, Jenny Paulsson, and Jesper M Paasch. 2014. “Classification and Co-Ordination of Conflicting Rights for Sustainable Land Use.” Nordic Journal of Surveying and Real Estate Researc 10(2): 61–81.

Lin, Bingxian, Liangchen Zhou, Guonian Lv, and A-xing Zhu. 2017. “3D Geological Modelling Based on 2D Geological Map.” Annals of GIS 23(2): 117–29. https://doi.org/10.1080/19475683.2017.1304450.

Liu, X., Y. Zhu, W. Wang, and F. Liu. 2010. “3D GIS Modeling of Air Pollution Effects.” In 3rd International Congress on Image and Signal Processing, 2714–17.

London maps. (2018). London atmospheric emmissions inventory 2013. Retrieved from https://parallel.co.uk/3D/laei-no2/#14/51.50562/-0.13768/52.8/56

Lu, L., T. Becker, and M.O Löwner. 2017. “3D Complete Traffic Noise Analysis Based on CityGML.” In Advances in 3D Geoinformation. Lecture Notes in Geoinformation and Cartography, ed. A. Abdul-Rahman. Springer, Cham, 265–83.

Ma, Zhiliang, and Yuan Ren. 2017. “Integrated Application of BIM and GIS: An Overview.” Procedia Engineering 196: 1072–79. http://dx.doi.org/10.1016/j.proeng.2017.08.064.

Mabuchi, K., and Y. Sato. 2005. “Climatic Impact of Vegetation Change in the Asian Tropical Region. Part I: Case of the Northern Hemisphere Summer.” Journal of Climate 18: 410–28. https://journals.ametsoc.org/doi/pdf/10.1175/JCLI-3273.1%0A.

Marriott, B. 1997. Environmental Impact Assessment: A Practical Guide. McGraw-Hill.

Martin, Elizabeth, ed. 2003. A Dictionary of Law. Fifth Edit. Oxford University Press.

Masuda, Yukihiro. 2004. “Utilization of Deep Underground Space in Tokyo -Urban Renewal with the City’ s New Backbone Lifeline.”

Mattei, Ugo. 1997. “Three Patterns of Law: Taxonomy and Change in the World’s Legal Systems.” American Journal of Comparative Law 45(1): 5–44. http://repository.uchastings.edu/faculty_scholarship/525.

Mbaya, Sue. 2000. “LAND POLICY : ITS IMPORTANCE AND EMERGING LESSONS FROM SOUTHERN AFRICA.” In Workshop on Land Tenure & Land Use Policy, , 27.

McAdam, Brodie. 2010. “Building Information Modelling: The UK Legal Context Brodie.” International Journal of Law in the Built Environment 2(3): 246–59.

McAuley, Barry, Alan Hore, and Roger West. 2017. Construction IT Alliance (CitA) Limited (2017) BICP Global BIM Study: Lessons for Ireland’s BIM Programme.

McClean, A. J. 1963. “The Common Law Life Estate and the Civil Law Usufruct: A Comparative Study.” International and Comparative Law Quarterly 12(2): 649–67. http://iclq.oxfordjournals.org/cgi/doi/10.1093/iclqaj/12.2.649.

McStotts, Jennifer Cohoon. 2004. “Dwelling Together: Using Cooperative Housing to Abate the Affordable Housing Shortage in Canada and the United States.” Georgia Journal of International and Comparative Law 32(131): 131–65.

Michaels, Ralf. 2009. “Comparative Law by Numbers? Legal Origins Thesis, Doing Business Reports, and the Silence of Traditional Comparative Law.” The American Journal of Comparative Law 57(4): 765–95.

Michaels, Ralf. 2011. “Comparative Law.” In The Oxford Handbook of Comparative Law, eds. M. Reimann and R. Zimmermann. Oxford University Press, 1–7.

Milo, M. 2006. “Property and Real Rights.” In Elgar Encyclopedia of Comparative Law, ed. Jan M Smits. Edward Elgar Publishing Limited, 587–602.

Ministry of Energy and Mines (British Columbia). 2017. “A Guide to Surface and Subsurface Rights and Responsibilities in British Columbia.” : 1–12.

Modelling, T. H. (n.d.). Hong Kong Institute of Building Information Modelling. Retrieved from https://www.hkibim.org/

Mordue, Stefan. 2015. “OPPORTUNITIES AND THREATS: Definition on BIM – ACE.” BIM definitions: 6–7. https://www.ace-

cae.eu/fileadmin/New_Upload/3._Area_2_Practice/BIM/Other_Docs/1_S.Mordue_Definition_of_BIM_01.pdf (May 18, 2018).

Morris, P., and R. Therivel. 1995. Methods of Environmental Impact Assessment. UCL Press.

Morris, P., J. Biggs, and A. Brookes. 2005. “Water.” In Methods of Environmental Impact Assessment, eds. John Glasson and Mick Bruton. Spon Press, 197–242.

Morris, Peter, and R. Emberton. 2005. “Ecology – Overview and Terrestrial Systems.” In Methods of Environmental Impact Assessment, Spon Press, 243–85.

Morris, Peter, and Riki Therivel. 2005. Methods of Environmental Impact Assessment. Second Edi. eds. John Glasson and Mick Bruton. Spon Press. papers2://publication/uuid/DFB6DED2-69C5-4F5F-83C7-556E3B23DC0E%5Cnhttp://www.evtfuto.com/download/Other Links/Methods of Environmental Impact Assessment (2).pdf.

National British Specification (NBS). (2018). BS EN ISO 19650-1:2018. Retrieved from https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=324869

National Institute of Building Sciences buildingSMARTalliance. 2015. National BIM Standard - United States Version 3.

National Parks & Wildlife Service. (2019). Home: Protected sites. Retrieved from Natural Heritage Areas (NHA): https://www.npws.ie/protected-sites/nha

National Roads Authority. 2008. Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes.

National Telecommunications and Information Administration. 2003. 14 50-STATE SURVEY OF RIGHTS-OF-WAY STATUTES. https://www.ntia.doc.gov/legacy/ntiahome/staterow/rowtableexcel.htm.

Navratil, G. 2011. “Cadastral Boundaries: Benefits of Complexity.” Urisa Journal 23(1)(January 2011): 19–27.

Navratil, Gerhard, and Andrew Frank. 2007. “Hierarchies in Subdivision Processes.” In Real Property Transactions - Procedures, Transaction Costs and Models, eds. Jaap Zevenbergen, Andrew Frank, and Erik Stubkjaer. IOS Press, 221–40.

Navratil, Gerhard. 2008. “Legal and Technical Aspects of Decisions on Property Boundaries – The Case of Austria.” 5(1): 7–23.

Navratil, Gerhard. 2012. “Combining 3D Cadastre and Public Law – An Austrian Perspective.” In 3rd International Workshop on 3D Cadastres, Shenzhen, China, 61–72.

NBS. (2017). EU BIM Task Group launches handbook for the strategic implementation of BIM. Retrieved from NBS: https://www.thenbs.com/knowledge/eu-bim-task-group-launches-handbook-for-the-strategic-implementation-of-bim

NBS. 2014. “BIM Levels Explained.” https://www.thenbs.com/knowledge/bim-levels-explained.

Nelken, David. 2004. “Using the Concept of Legal Culture.” Austl. J. Leg. Phil. 29: 1. https://www.law.berkeley.edu/files/Nelken_-_Using_the_Concept_of_Legal_Culture.pdf.

New South Wales Land Registry Services (NSW LRS). (n.d.). About NSW LRS. Retrieved from Land Title Questions: http://www.nswlrs.com.au/about_nswlrs/land_title_questions/whats_tenancy_mean

New South Wales Land Registry Services (NSW LRS). (n.d.). Home: Publications. Retrieved from Glossary: http://www.nswlrs.com.au/publications/glossary

New York City (LPC). (2018, January). Discover New York City landmarks. Retrieved from https://nyclpc.maps.arcgis.com/apps/webappviewer/index.html?id=93a88691cace4067828b1eede432022b

New York State. (2018, February). CRIS. Retrieved from https://cris.parks.ny.gov/Default.aspx

New Zealand Ministry for the Environment. (2018). RMA: National Direction. Retrieved from National environmental standards: http://www.mfe.govt.nz/rma/rma-legislative-tools/national-environmental-standards

Newman, Peter, and Andy Thornley. 1996. Urban Planning in Europe: International Competition, National Systems and Planning Projects.

Ngo, Lawrence K.K., Terence S.W. Tsand, and Chaerles Y.K. Wong. 2014. “3-Dimensional EIA - A Greener Tool to Plan and Design.” IAIA14 Conference Proceedings (April): 1–6.

Nielsen, Vibeke Stærdahl. 2015. “PLR Activities in Denmark.”

Nimmo, J.R. 2013. “Porosity and Pore Size Distribution.” Earth Systems and Environmental Sciences: 9.

Niukkanen, Kirsikka. 2014. “On the Property Rights in Finland.” Aalto University.

Norwegian Environment Agency. (2019). Retrieved from https://www.miljodirektoratet.no/

NSW Law Reform Commission. 1997. 84 Report 84 (1997) - The Right to Support From Adjoining Land.

NSW-LRS. (2019, January). Deposited plans. Retrieved from Stratum boundaries: http://rg-guidelines.nswlrs.com.au/deposited_plans/stratum_boundaries

O’Dell, C., J.R. Grayson, and N. Essaides. 1998. If Only We Knew What We Know: The Transfer of Internal Knowledge and Best Practice. Simon and Schuster.

Ohori, Ken Arroyo et al. 2017. “Towards an Integration of GIS and BIM Data : What Are the Geometric and Topological Issues ?” 12th 3D Geoinfo Conference, ISPRS

Annals of the Pho- togrammetry, Remote Sensing and Spatial Information Sciences IV–4/W5: 1–14.

Oldfield, Jennifer, Peter van Oosterom, Jacob Beetz, and Thomas F. Krijnen. 2017. “Working with Open BIM Standards to Source Legal Spaces for a 3D Cadastre.” ISPRS International Journal of Geo-Information 6(351): 1–19.

Oldfield, Jennifer, Peter Van Oosterom, Wilko Quak, and Jeroen Van Der Veen. 2016. “Can Data from BIMs Be Used as Input for a 3D Cadastre ? Can Data from BIMs Be Used as Input for a 3D Cadastre ?” In 5th International FIG 3D Cadastre Workshop, eds. P. J. M. van Oosterom, Efi Dimopoulou, and Elfriede M. Fendel. Athens, Greece, 199–214.

Onsrud, Helge. 2001. “Making Laws for 3d Cadastre in Norway.” In International Workshop on “3D Cadastres, Delft, The Netherlands, 191–99.

Onsrud, Helge. 2002. “Making Laws for 3D Cadastre in Norway Making Laws for 3D Cadastre in Norway.” FIG XXII International Congress: 1–8.

Onsrud, Helge. 2003. “Making a Cadastre Law for 3D Properties in Norway.” Computers, Environment and Urban Systems 27(4): 375–82.

Ortega, C. 2012. “Effects of Noise Pollution on Birds: A Brief Review of Our Knowledge.” Ornithological Monographs (74): 6–22.

Ortega-Girones, Enrique, Alexandra Pugachevsky, and Gotthard Walser. 2009. “Mineral Rights Cadastre.” World Bank Extractive Industries for Development Series 4: 96.

Owley, Jessica. 2015. “Land Use Policy Cultural Heritage Conservation Easements : Heritage Protection with Property Law Tools.” Land Use Policy 49: 177–82. http://dx.doi.org/10.1016/j.landusepol.2015.07.007.

Paasch, Jesper M. 2005. Modelling Dutch Rights and Restrictions for Real Property Transactions. Stockholm, Sweden.

Paasch, Jesper M. 2007. “Real Property Transactions.” In Real Property Transactions - Procedures, Transaction Costs and Models, eds. Jaap Zevenbergen, Andrew Frank, and Erik Stubkjaer. Delft, The Netherlands: IOS Press, 298.

Paasch, Jesper M. 2011. Classification of Real Property Rights – A Comparative Study of Real Property Rights in Germany, Ireland, the Netherlands and Sweden. Stockholm, Sweden.

Paasch, Jesper M. 2014. “Legal Framework 3D Cadastres Report from Working Sessions I and II.” In 4th International Workshop on 3D Cadastres, Dubai, 1–17.

Paasch, Jesper M., and Jenny Paulsson. 2011. “Terminological Aspects Concerning Three-Dimensional Real Property.” Nordic Journal of Surveying and Real Estate Research 8(1): 65–80.

Paasch, Jesper M., Paulsson, Jenny., Navratil, Gerhard., Vučić, Nikola., Kitsakis, Dimitrios., Karabin, Marcin., El-Mekawy, Mohamed. 2016. “Building a Modern Cadastre: Legal Issues in Describing Real Property In3D.” Geodetski Vestnik 60(2): 256–68.

Paasch, Jesper Mayntz. 2012. “Standardization of Real Property Rights and Public Regulations.” Royal Institute of Technology (KTH).

Paasch, Jesper, and Jenny Paulsson. 2014. “Legal Framework 3D Cadastres Position Paper 1.” (November): 411–16.

Paasch, Jesper. 2012. “Standardization of Real Property Rights and Public Regulations.” Royal Institute of Technology (KTH).

Papaefthymiou, Mary, Tassos Labropoulos, and Panagiotis Zentelis. 2004. “3-D Cadastre in Greece – Legal, Physical and Practical Issues Application on Santorini Island.” : 1–16.

Papageorgiou, Marilena. 2015. “Networking Underground Archaeological and Cultural Sites: The Case of Athens Metro.” In Think Deep : Planning, Development and Use of Underground Space in Cities, eds. Han Admiraal and Narang Suri Shipra., 54–70.

Parisi, Francesco. 2002. “ENTROPY IN PROPERTY.” American Journal of Comparative Law 50(3): 595–632.

Parzych, Piotr, Łukasz Śliwiński, and Jaroslaw Bydlosz. 2013. “3D Cadastre in Polish Conditions.” In SDI & SIM 2013 : International Conference on Spatial Data Infrastructures & Spatial Information Management 2013, eds. Yerach Doytsher, Bashkim Idrizi, and Chryssy Potsiou. Skopje, 13–21.

Patton, Michael Quinn. 2001. “Evaluation, Knowledge Management, Best Practices, and High Quality Lessons Learned.” American Journal of Evaluation 22(3): 329–36. http://journals.sagepub.com/doi/10.1177/109821400102200307.

Paulsson, J. 2008. “3D Property – Types of Rights and Management Factors.” In FIG Working Week 2008, Stockholm, Sweden, 1–10.

Paulsson, Jenny, and Jesper M. Paasch. 2011. “3D Property Research – a Survey of the Occurrence of Legal Topics in Publications 3D Property Research - a Survey of the Occurrence of Legal Topics in Publications.” (November): 1–14.

Paulsson, Jenny. 2007. “3D Property Rights - An Analysis of Key Factors Based on International Experience.” Royal Institute of Technology (KTH).

Paulsson, Jenny. 2011. “Private and Common Responsibilities for the Management of Condominiums.”

Paulsson, Jenny. 2012. “Swedish 3D Property in an International Comparison.” In Shenzhen, China, 23–40.

Pedrinis, Frédéric, and Gilles Gesquière. 2017. “Reconstructing 3D Building Models with the 2D Cadastre for Semantic Enhancement.” In Lecture Notes in Geoinformation and Cartography, ed. Alias Abdul-Rahman. Springer International Publishing, 119–35.

Perakis, Evangelos. 2012. “Η Μερική (Επαν)Εισαγωγή Του Εμπράγματου Δικαιώματος Της Επιφάνειας (ν.3986/2011) [The Partial (Re)Introduction of the Right of Superficies (L.3986/2011)].” Εφαρμογές Αστικού Δικαίου 8(9).

Petrie, Richard. 2014. “Standards Overview.” In Toronto Technical Summit, , 333–55. http://doi.wiley.com/10.1002/9781118820216.ch10.

Pierre, Barbara. 1997. “Classification of Property and Conceptions of Ownership in Civil and Common Law.” Revue générale de droit 28(2): 235–74.

Pieters, Danny. “Functions of Comparative Law and Practical Methodology of Comparing.” : 1–35. https://www.law.kuleuven.be/personal/mstorme/Functions of comparative law and practical methodology of comparing.pdf.

Plan Transition Numérique dans le Bâtiment. (2015). Retrieved from http://www.batiment-numerique.fr/

Ploeger, Hendrik, Aart van Velten, and Jaap Zevenbergen. 2005. Real Property Law and Procedure in the European Union- Report for the Netherlands.

Ploeger, Hendrik, and Hafida Bounjouh. 2017. “The Dutch Urban Ground Lease : A Valuable Tool for Land Policy ?” Land Use Policy 63: 78–85. http://dx.doi.org/10.1016/j.landusepol.2017.01.005.

Ploeger, Hendrik, and Herman de Wolff. 2012. “THE DUTCH URBAN GROUND LEASE: IN FATAL CRISIS OR A BRIGHT FUTURE?” In AESOP 2014: Annual Conference, Utrecht/Delft, The Netherlands, 1–15.

Ploeger, Hendrik, and Jantien Stoter. 2004. “Cadastral Registration of Cross-Boundary Infrastructure Objects.” In FIG Working Week, Athens, Greece, 1–18. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Cadastral+Registration+of+Cross-Boundary+Infrastructure+Objects#0.

Ploeger, Hendrik. 2011. “Legal Framework 3D Cadastres Position Paper 1.” In 2nd International Workshop on 3D Cadastres, Delft, The Netherlands, 545–50.

Poljanšek, Martin. 2017. Environment Design Guide Building Information Modelling (BIM) Standardization. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC109656/jrc109656_bim.standardization.pdf.

Pollakowski, Henry O., and Susan M. Wachter. 1990. “The Effects of Land-Use Constraints on Housing Prices.” Land Economics 66(3): 315–24.

Praduroux, S. (2017). Objects of property rights: old and new. In M. Graziadei, & L. Smith, Comparative Property Law (p. 520). Cheltenham, UK: Edward Elgar Publising.

Praduroux, Sabrina. 2017. “Objects of Property Rights: Old and New.” In Comparative Property Law, ed. L. Graziadei, M.; Smith. Cheltenham, UK, 520.

Qiao, X. et al. 2016. “APPLICATION OF DSM IN OBSTACLE CLEARANCE SURVEYING OF AERODROME.” The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLI: 227–33.

Radel, Krzystof. 2008. “Perpetual Usufruct as a Form of Real Estate Management.” In Real Estate in Czech and Polish Law, eds. Grzegorz Liszewski and Michal Radvan. Białystok, 90–97.

Raffelsiefen, M. Strassburger, T. 2017. “The Protection of Soil: Does the European Union Live Up to Its Own Ambitions?” In International Yearbook of Soil Law and Policy 2016, eds. Ginzky H. et al. Springer International Publishing, 430.

Railway Association of Canada, and Federation of Canadia Municipalities. 2013. “Guidelines for New Development in Proximity to Railway Operations.” : 122. http://www.proximityissues.ca/asset/image/reference/guidelines/2013_05_29_Guidelines_NewDevelopment_E.pdf.

Rajabifard, Abbas., Muyiwa, Agunbiade., Kalantari, Mohsen., Kit Meng, Yip., Atazadeh, Behnam., Badiee, Farshad., Adimin, Dato’ Mohd Noor Bin Isa Mohamad Kamali Bin., Chan, Keat Lim., Aien, Ali., Olfat, Hamed., Shojaei, Davood., Anaraki, Mohsen Rahimipour. 2018. “An LADM-Based Approach for Developing and Implementing a National 3D Cadastre – A Case Study of Malaysia.” In 7th International FIG Workshop on the Land Administration Domain Model, Zagreb, Croatia, 47–66.

Rajabifard, Abbas., Williamson, Ian., Marwick, Brian., Kalantari, Mohsen., Ho, Serene., Shojaei, Davood., Atazadeh, Behnam., Amirebrahimi, Sam., Jamshidi, Alireza. 2014. “3D Cadastre, a Multifaceted Challenge” In FIG Congress 2014, Kuala Lumpur, Malaysia, 17.

Ralli, Tommi, and Katja Weckström. Real Property Law and Procedure in the European Union - National Report Finland.

Raper, R.L., E.B. Schwab, and S.M. Dabney. 2000. “SPATIAL VARIATION OF THE DEPTH OF THE ROOT-RESTRICTING LAYER IN AN UPLAND SOIL OF NORTHERN MISSISSIPPI.” In Second International Conference on Geospatial Information in Agriculture and Forestry, Lake Buena Vista, Florida, 249–56.

Rayfuse, Rosemary. 2016. “Principles of International Environmental Law Applicable to Waste Management.” In Waste Management and the Green Economy - Law and Policy, eds. Katharina Kummer Peiry, Andreas R. Ziegler, and Jorun Baumgartner. Edward Elgar Publishing, 11–32.

Real Property Law - National Report Belgium. 2004.

reddit. (2016). Retrieved from The Interlace Appartments in Singapore: https://www.reddit.com/r/architecture/comments/4cju7w/the_interlace_apartments_in_singapore/

Registrar of Titles and Registrar of Water Allocations. 2009. “Land Title Practice Manual (Queensland).” : 780.

Reinhold, Jahn et al. 2006. Guidelines for Soil Description. Fourth Edi.

Renard, Vincent. 2007. “Property Rights and the ‘ Transfer of Development Rights.’” Town Planning Review 78(1): 41–60.

Reynolds, Elizabeth, and Alexander Reynold. 2015. “Planning for Underground Spaces ‘NY-LON’ Underground.” In Think Deep : Planning, Development and Use of Underground Space in Cities, eds. Han Admiraal and Narang Suri Shipra. 34–54.

Romano, Alessandro. 2016. “Comparative Law : An Essay on the Methodology of Comparative Law.” Chicago-Kent Journal of International and Comparative Law 17(1): 1–17.

Rome, Gregory. 2008. “Civil Law Commentaries.” 1(2): 0–17.

Rönsdorf, Carsten, Debbie Wilson, and Jantien Stoter. 2014. “Integration of Land Administration Domain Model with CityGML for 3D Cadastre.” In 4th International Workshop on 3D Cadastres, eds. Peter van Oosterom and Elfriede M. Fendel. Dubai, United Arab Emirates, 313–22.

Rosen, Gillad. 2016. “Condo-Ism and Urban Renewal: Insights from Toronto and Jerusalem.” In Private Communities and Urban Governance Theoretical and Comparative Perspectives, 77–94.

Rothbard, Murray N. 1982. “Law, Property Rights, and Air Pollution.” Cato Journal 2(1): 55–99.

Rouhette, Georges, and Anne Rouhette-Berton. 2006. “French Civil Code (Translation in English).”

Rutz, Dominik, and Rainer Janssen. 2014. “Socio-Economic Impacts of Biofuels on Land Use Change.” In Socio-Economic Impacts of Bioenergy Production, eds. Dominik Rutz and Rainer Janssen. Springer International Publishing, 81–93.

Sadler, Barry, and Mary McCabe. 2002. “Environmental Impact Assessment Training Resource Manual.” Environmental Impact Assessment Training Resource Manual: 600.
http://www.iaia.org/publicdocuments/EIA/ManualContents/Vol1_EIA_Manual.pdf.

Sandberg, Haim. 2001. “Three-Dimensional Division and Registration of Title to Land: Legal Aspects.” In International Workshop on “3D Cadastres, Delft, The Netherlands, 201–9.

Sandberg, Haim. 2003. “Three-Dimensional Partition and Registration of Subsurface Space.” Israel Law Review 37(1): 119–68.

Schlager, Edella, and Elinor Ostrom. 1992. “Property Rights Regimes and Natural Resources: A Conceptual Analysis.” Land Economics 68(3): 249–62.

Schmid, Christoph U., Christian Hertel, and Hartmut Wicke. 2005. Real Property Law and Procedure in the European Union General Report - Germany. http://www.eui.eu/Documents/DepartmentsCentres/Law/ResearchTeaching/ResearchThemes/EuropeanPrivateLaw/RealPropertyProject/GeneralReport.pdf.

Schoeneberger, P.J., D.A. Wysocki, and E.C. Benham. 2012. Field Book for Describing and Sampling Soils - Version 3. http://lawr.ucdavis.edu/faculty/gpast/hyd151/soilsfieldguide.pdf.

Schwartz, Martin A. 2015. “It’s Up In the Air: Air Rights in Modern Development.” The Florida Bar Journal 89: 42–44.

Science Communication Unit. 2017. Noise Abatement Approaches.

Secretary of State for Transport (UK). 2007. “The Rules of the Air Regulations 2007.” (734). http://www.legislation.gov.uk/uksi/2007/734/pdfs/uksi_20070734_en.pdf.

Sheng, Nan. 2011. “Prediction and 3D Visualization of Environmental Indicators : Noise and Air Pollution.” (December).

Sherry, Cathy. 2009. “The New South Wales Strata and Community Titles Acts A Case Study of Legislatively Created High Rise and Master Planned Communities.” International Journal of Law in the Built Environment 1(2): 130–42.

Sherry, Cathy. 2017. Strata Titles Property Rights. Routledge.

Shojaei, Davood, Abbas Rajabifard, Mohsen Kalantari, and Bishop, Ian. D. 2014. “Design and Development of a Web- Based 3D Cadastral Visualisation Prototype.” International Journal of Digital Earth: 20.

Shojaei, Davood, Hamed Olfat, Abbas Rajabifard, and Mohsen Kalantari. 2018. “Moving Towards a Fully Operational 3D Digital Cadastre : Victoria, Australia.” In 6th International FIG 3D Cadastre Workshop, eds. Peter van Oosterom and Dirk Dubbeling. , 467–82.

Shojaei, Davood., Kalantari, Mohsen., Bishop, Ian D., Rajabifard, Abbas., Aien, Ali. 2013. “Visualization Requirements for 3D Cadastral Systems.” Computers, Environment and Urban Systems 41: 39–54. http://dx.doi.org/10.1016/j.compenvurbsys.2013.04.003.

Shoshani, Uri., Benhamu, Moshe., Goshen, Eri., Denekamp, Saul., Bar, Roy. 2004. “Registration of Cadastral Spatial Rights in Israel – A Research and Development Project.” In FIG Working Week 2004, Athens, Greece, 1–18.

Shoshani, Uri., Benhamu, Moshe., Goshen, Eri., Denekamp, Saul., Bar, Roy. 2005. “A Multi Layers 3D Cadastre in Israel: A Research and Development Project Recommendations.” FIG Working Week and GSDI-8: 1–15. http://www.gsdidocs.org/gsdiconf/GSDI-8/papers/ts_06/ts06_03_shoshani_etal.pdf.

Silbey, Susan. 2010. “Legal Culture and Cultures of Legality.” In Handbook of Cultural Sociology, eds. John Hall, Laura Grindstaff, and Ming-Cheng Lo. Routledge, 470–79.

Silva Lucas, Priscila, Ramon Gomes de Carvalho, and Clara Grilo. 2017. “Railway Disturbances on Wildlife: Types, Effects, and Mitigation Measures.” In Railway Ecology, 81–99.

Sim, R.S., and V. Powell-Smith. 1968. Casebook on Land Law. London: Butterworths.

Singh, Birendra (Bob), Pallavi Roy, Thierry Spiess, and Bala Venkatesh. 2015. “Sustainable Integrated Urban & Energy Planning, the Evolving Electrical Grid and Urban Energy Transition.” : 41. http://bit.ly/2pj84RE.

Singh, Surendra Pal, Kamal Jain, and V. Ravibabu Mandla. 2013. “Virtual 3D City Modeling : Techniques and Applications.” International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL-2/W2: 73–91.

Siouti, G. (2011). Environmental Law. Athens-Thessaloniki: Sakkoulas Publications.

Sivaramanan, Sivakumaran. 2014. “Air Pollution Sources, Pollutants and Mitigation Measures.” : 11.

Smith, Henry E. 2011. “Property Is Not Just a Bundle of Rights Where Does the Bundle Come From ?” ECON JOURNAL WATCH 8(3) 8(3): 279–91.

Smits, Jan M, ed. 2006. Elgar Encyclopedia of Comparative Law (Elgar Original Reference). Edward Elgar Publishing Limited. http://tcpbckup1.yolasite.com/resources/Elgar Encyclopedia of Comparative Law By Jan M Smits.pdf.

Soil Science Division Staff. 2017. Agriculture Handbook No 18 Soil Survey Manual. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054262.

Sophocleous, Marios. 2002. “Interactions between Groundwater and Surface Water: The State of the Science.” Hydrogeology Journal 10(1): 52–67.

Sparkes, Peter. Real Property Law and Procedure in the European Union - National Report England and Wales.

Spyridakis, I.N. 2001a. Real Property Law I. Ant. N. Sakkoulas Publishers.

Spyridakis, I.N. 2001b. Real Property Law II. Ant. N. Sakkoulas Publishers.

Statsbygg. (2011). Statsbygg BIM Manual 1.2.1.

Steinsholt, Håvard. 2010. “Some Aspects of Norwegian Expropriation - Input to Comparative Study of Chosen Expropriation Issues : Germany, Norway and Poland.” In FIG Congress 2010, Sydney, Australia, 11.

Steudler, Daniel, Abbas Rajabifard, and Ian P. Williamson. 2004. “Evaluation of Land Administration Systems.” Land Use Policy 21(4): 371–80.

Stöcker, Claudia et al. 2017. “Review of the Current State of UAV Regulations.” Remote Sensing 9(5): 33–35.

Storme, Matthias E. 2002. “CONTENTS AND PROTECTION OF PROPERTY.” : 120–41. https://www.law.kuleuven.be/personal/mstorme/comprop3.pdf.

Storme, Matthias E. 2004. “PROPERTY LAW IN A COMPARATIVE PERSPECTIVE.” (Spring): 1–50.

Stoter, J., and P. J. M. van Oosterom. 2005. “Technological Aspects of a Full 3D Cadastral Registration.” International Journal of Geographical Information Science 19(6): 669–96. http://www.tandfonline.com/doi/abs/10.1080/13658810500106042 (December 17, 2012).

Stoter, Jantien, and Hendrik Ploeger. 2003. “Registration of 3D Objects Crossing Parcel Boundaries Registration of 3D Objects Crossing Parcel Boundaries.” : 1–16.

Stoter, Jantien, and Martin Salzmann. 2003. “Towards a 3D Cadastre: Where Do Cadastral Needs and Technical Possibilities Meet?” Computers, Environment and Urban Systems 27(4): 395–410.

Stoter, Jantien, and P. J. M. van Oosterom. 2006. 3D Cadastre in an International Context: Legal, Organizational, and Technological Aspects. 1st ed. CRC Press.

Stoter, Jantien, Esben Munk Sørensen, and Lars Bodum. 2004. "3D Registration of Real Property in Denmark." In Proceedings of FIG Working, Athens, Greece, 1–23. http://people.land.aau.dk/~ems/fig-3d/3D_registration.doc.

Stoter, Jantien, Hendrik Ploeger, and Peter van Oosterom. 2012. "3D Cadastre in the Netherlands: Developments and International Applicability." Computers, Environment and Urban Systems. http://linkinghub.elsevier.com/retrieve/pii/S0198971512000841 (April 1, 2013).

Stoter, Jantien, Henk de Kluijver, and Vinaykumar Kurakula. 2008. "3D Noise Mapping in Urban Areas." International Journal of Geographical Information Science 22(8): 907–24.

Stoter, Jantien, Peter Van Oosterom, and Hendrik Ploeger. 2012. "The Phased 3D Cadastre Implementation in the Netherlands." In 3rd International Workshop on 3D Cadastres: Developments and Practices, Delft, The Netherlands, 203–18.

Stoter, Jantien. 2004a. "3D Cadastre."

Stoter, Jantien., Ploeger, Hendrik., Roes, Ruben., Riet, Els Van Der., Biljecki, Filip., Ledoux, Hugo. 2016. "First Registration of Multi-Level Ownership Rights in 3D in the Netherlands." 5th International FIG Workshop on 3D Cadastres (October 2016): 491–504.

Stoter, Jantien., Ploeger, Hendrik., Roes, Ruben., Riet, Els Van Der., Biljecki, Filip., Ledoux, Hugo., Kok, Dirco., Kim, Sangmin. 2017. "Registration of Multi-Level Property Rights in 3D in The Netherlands : Two Cases and Next Steps in Further Implementation." ISPRS International Journal of Geo-Information 6(158): 1–18.

Succar, Bilal. 2010. "Building Information Modelling Maturity Matrix." In Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies, eds. Jason Underwood and Umit Isikdag. IGI Global, 65–103. http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-60566-928-1.ch004.

Sulaiman, S., N. H. N. Mohamad, and S. Idilfitri. 2013. "Contribution of Vegetation in Urban Parks as Habitat for Selective Bird Community." Procedia - Social and Behavioral Sciences 85: 267–81.

Surveyors Registration Board of Victoria. 1994a. Survey Practice Handbook Part 4 - Land Tenure.

Surveyors Registration Board of Victoria. 1994b. Survey Practice Handbook Victoria Part 3 Land Surveying Law and Administration.

Szafarz, Piotr. Real Property Law – National Report Poland.

Takasaki, H., H. Chikahisa, and Y. Yuasa. 2000. "Planning and Mapping of Subsurface Space in Japan." Tunnelling and Underground Space Technology 15(3): 287–301.

Tekavec, Jernej, Anka Lisec, and Miran Ferlan. 2017. "Recent Research on 3D Modelling of Cadastral Data in Slovenia." In AGILE 2017, Wageningen, 10–12.

ten Kate, Jan. 2017. “Predicting Noise Nuisance from Outdoor Music Events in the Built Environment.”

The Government of Hong Kong, Development Bureau. (2018, December 27). Adoption of Building Information Modelling. Development Bureau Technical Circular (Works) No. 18/2018.

The Law Commission. 2008. “Consultation Paper No 186 EASEMENTS, COVENANTS AND PROFITS À PRENDRE.” : 324.

Therivel, Riki, and Mike Breslin. 2005. “Noise.” In Environmental Impact Assessment Training Resource Manual, eds. John Glasson and Mick Bruton. Spon Press, 65–82.

Therivel, Riki. 2005. “Landscape.” In Methods of Environmental Impact Assessment, eds. Peter Morris and Riki Therivel. Spon Press, 125–121.

Thompson, Rodney James, Peter van Oosterom, Sudarshan Karki, and Ben Cowie. 2015. “A Taxonomy of Spatial Units in a Mixed 2D and 3D Cadastral Database.” In FIG Working Week 2015, Sofia, Bulgaria, 20.

Thompson, Stewart, and John Lee. 2005. “Coastal Ecology and Geomorphology.” In Methods of Environmental Impact Assessment, eds. Peter Morris and Riki Therivel. Spon Press, 315–48.

Ting, L, and I P Williamson. 1999. “Cadastral Trends: A Synthesis.” Australian Surveyor 44(1): 46–54. http://www.tandfonline.com/doi/abs/10.1080/00050326.1999.10441903%0Ahttps://www.scopus.com/inward/record.uri?eid=2-s2.0-0032850233&partnerID=40&md5=ab292fef1e9e08395158f7b3aac10753.

Ting, Lisa A. 2002. PhD Thesis “Principles for an Integrated Land Administration System to Support Sustainable Development.” The University of Melbourne. http://www.csdila.unimelb.edu.au/publication/thesis/LisaTing_PhD_Thesis.pdf.

Ting, Lisa, and Ian Williamson. 2001. “Land Administration and Cadastral Trends : The IInpact of the Changing Hlunankind-Land Relationship and Major Global Drivers : The NZ Experience.” Survey Review 281(36): 154–74.

Tiwary, Abhishek, and Jeremy Colls. 2010. Atmospheric Environment Air Pollution: Measurement, Modelling and Mitigation. Third edit. Routledge.

Transport Canada. 2013. “Land Use In The Vicinity of Aerodromes.” : 37. https://www.tc.gc.ca/eng/civilaviation/publications/tp1247-menu-1418.htm.

Triantos, N. 2000. Δουλείες Μεταγραφή Κτηματολόγιο [Easements-Transcritpion-Cadastre]. Nomiki Bibliothiki.

Tsiliakou, Eva, and Efi Dimopoulou. 2011. “Adjusting the 2D Hellenic Cadastre to the Complex 3D World – Possibilities and Constraints Adjusting the 2D Hellenic Cadastre to the Complex 3D World – Possibilities and Constraints.” (November): 115–36.

Tsoumas, V. 2015. Η Χρήση Οδών Και Κοινόχρηστων Χώρων [The Use of Roads and Public Spaces]. Nomiki Bibliothiki.

TU Delft. “Cities/Regions around the World with Open Datasets.” https://3d.bk.tudelft.nl/opendata/opencities/ (May 19, 2018).

Tveiten, Vidar, and Gisle Grepstad. 2015. “ENVIRONMENTAL MANAGEMENT, MONITORING AND MITIGATION DURING CONSTRUCTION.” In Health, Safety and Environment in Norwegian Tunnelling, , 75–78.

Twaroch, C., and G. Navratil. 2016. “Unsichtbare Grundstücksbelastungen [Invisible Encumbrances on Land].” Forum - Zeitschrift des Bundes der Öffentlich bestellten Vermessungsingenieure 42(1): 8–16.

U.S Department of Transportation. (2018, July). Noise. Retrieved from Construction Noise Handbook: https://www.fhwa.dot.gov/ENVIRONMENT/noise/construction_noise/handbook/handbook07.cfm

UN HABITAT. 2003. HANDBOOK ON BEST PRACTICES, SECURITY OF TENURE AND ACCESS TO LAND.

UNEP. 2002. “EIA Training Resource Manual -Topic 6 Impact Analysis.” : 52. https://unep.ch/etb/publications/EIAman/SecETopic6.pdf.

UNEP. 2016. “Guidelines for Framework Legislation for Integrated Waste Management.”

UNESCO. 2017. “Operational Guidelines for the Implementation of the World Heritage Convention.” WHC.17/01: 172. http://whc.unesco.org/en/contacts.

United Nations Environment Programme. 2002. “Social Impact Assessment.” EIA Training Resource Manual: 461–87. https://unep.ch/etu/publications/EIA_2ed/EIA_E_top13_body.PDF.

United Nations. 1992. International Convention on Biological Diversity. https://www.cbd.int/convention/text/.

United Nations. 1996. “THE BOGOR DECLARATION.” : 1–12.

United States Environmental Protection Agency (US EPA). 2008. “Ground Water Contamination.” Getting Up to Speed: 10. https://www.epa.gov/sites/production/files/2015-08/documents/mgwc-gwc1.pdf.

University of Ottawa. (2016). JuriGlobe. Retrieved from http://www.juriglobe.ca/eng

US Geological Survey (USGS). (2018, July). Retrieved from https://water.usgs.gov

Vähäaho, Ilkka. 2012. “UNDERGROUND RESOURCES AND MASTER PLAN IN HELSINKI.” In 13th World Conference of the Associated Research Centers for the Urban Underground Space, Singapore, 31–44. https://www.hel.fi/static/kv/Geo/CasePankki/0-LAND_USE.pdf.

Vähäaho, Ilkka. 2014. “Underground Space Planning in Helsinki.” Journal of Rock Mechanics and Geotechnical Engineering 6(5): 387–98. http://dx.doi.org/10.1016/j.jrmge.2014.05.005.

Vähäaho, Ilkka. 2016. “Development for Urban Underground Space in Helsinki.” Energy Procedia 96: 824–32. http://dx.doi.org/10.1016/j.egypro.2016.09.144.

van Berlo, Léon, and Ruben de Laat. 2011. “Integration of BIM and GIS : The Development of the CityGML GeoBIM Extension.” In Advances in 3D Geo-Information Sciences, eds. T. H. Kolbe, G. König, and C. Nagel. Springer, Berlin, Heidelberg, 1–17.

van der Merwe, C. G. 2002. “A COMPARATIVE STUDY OF THE DISTRIBUTION OF OWNERSHIP RIGHTS IN PROPERTY IN AN APARTMENT OR CONDOMINIUM SCHEME IN COMMON LAW, CIVIL LAW AND MIXED LAW SYSTEMS.” Georgia Journal of International and Comparative Law 31(101): 101–37.

van der Merwe, Cornelius, and D.W. Nedelmann. 1996. “The Swedish Tenant-Ownership Model as an Alternative to Apartment Ownership (Sectional Titles).” The Comparative and International Law Journal of Southern Africa 29(1): 49–60.

van der Merwe, Cornelius, ed. 2015. European Condominium Law (The Common Core of European Private Law). Cambridge University Press.

van der Merwe, Cornelius. 2016. “European Condominium Law: Nine Key Choices.” In ed. Amnon Lehavi.

Van Hoecke, Mark. 2015. “Methodology of Comparative Legal Research.” Law and Method: 279–301. http://www.bjutijdschriften.nl/doi/10.5553/REM/.000010.

van Oosterom, P. J. M., ed. 2018. Best Practices 3D Cadastres - Extended Version. Copenhagen, Denmark.

van Oosterom, Peter, Hendrik Ploeger, and Jantien Stoter. 2006. “Aspects of a 4D Cadastre : A First Exploration Aspects of a 4D Cadastre : A First Exploration.” In XXIII FIG Congress, Munich, Germany, 1–23.

van Oosterom, Peter., Stoter, Jantien., Ploeger, Hendrik., Thompson, Rod., Karki, Sudarshan. 2011. “World-Wide Inventory of the Status of 3D Cadastres in 2010 and Expectations for 2014.” In FIG Working Week 2011, Marrakech, Morocco, 21.

Van Staden, Sonja. 2015. “Ancillary Rights in Servitude Law.” Stellenbosch University.

van Vliet, L.P.W. 2006. “The Boundaries of Property Rights: Netherlands National Report 2006.” Electronic Journal of Comparative Law 11(1): 1–11.

Vandehouwe, Gerard, and Johan Pieters. 2010. “Belgian Land Registry and Land Registration, Present & Future.” https://www.elra.eu/belgian-land-registry-and-land-registration-present-future/ (May 18, 2019).

Vandysheva, Natalia et al. 2011. “Design of the 3D Cadastre Model and Development of the Prototype in the Russian Federation.” Proceedings of the 2nd international workshop on 3D cadastres (November 2011): 355–75.

Varga, Csaba. 2012. Comparative Legal Cultures: On Traditions Classified, Their Rapprochement & Transfer, and the Anarchy of Hyper-Rationalism with Appendix on Legal Ethnography. https://philarchive.org/archive/VARCLCv1.

Vecco, Marilena. 2010. “A Definition of Cultural Heritage : From the Tangible to the Intangible.” Journal of Cultural Heritage 11(3): 321–25. http://dx.doi.org/10.1016/j.culher.2010.01.006.

Velasco, Martín-Varés Amalia. 2015. “Public Restrictions and Spanish Cadastral Valuation.” In Workshop on the Documentation of Public Law Restrictions, Brussels.

Victorian Law Reform Commission. 2010. Easements and Covenants Consultation Paper. Melbourne, Victoria.

Vitikainen, Arvo, and Hiironen. 2012. “Development Scenarios of the 3D Cadastral System in Finland.” In FIG Working Week 2012, Rome, Italy, 1–6.

Vlaanderen. (2018, October). Databank Ondergrond Vlaandered [Flander's Underground Databank]. Retrieved from https://www.dov.vlaanderen.be

Vogel, Ines, Claus Gerhard Bannick, and Holger Böken. 2004. “The German Soil Protection Law and Regulations for the Utilisation of Biowaste.” In I International Conference SOIL AND COMPOST ECO-BIOLOGY, León, Spain, 97–105.

Voss, Winrich. 2010. “Compulsory Purchase in Poland, Norway and Germany - Part Germany.” In XXIV FIG International Congress 2010, Sydney, Australia, 20.

Vrellis, S. (1988). Comparative Law. Athina-Komotini: Ant. N. Sakkoulas.

Vrellis, S. 1988. Sigritiko Dikaio [Comparative Law]. ed. Ant. N. Sakkoulas. Athina-Komotini.

Wallace, Jude. 2007. “Modern Cadastre and Land Administration - The Cadastral Concept and Evolution.”

Wallace, M. I., and K. C. Ng. 2016. “Development and Application of Underground Space Use in Hong Kong.” Tunnelling and Underground Space Technology 55: 257–79.

Warhurst, Alyson, ed. 1999. Mining and the Environment: Case Studies from the Americas.

Wästberg, B., Tornberg J., M. Billger, and K. Haeger-Eugensson, M. Sjöberg. 2013. “How to Visualize the Invisible Simulating Air Pollution Dispersions in a 3D City Model.” In CUPUM 2013 - 13th International Conference on Computers in Urban Planning and Urban ManagementAt: Utrecht, NetherlandsVolume: Proceedings for CUPUM 2013 - 13th International Conference on Computers in Urban Planning and Urban Management,.

Whelan, J., J. Fry, and S. Green. 2010. “Consideration of Landscape in the Framework Documentation during the Evolution of the Rural Environment Protection Scheme (REPS) in the Republic of Ireland.” RERC Working Paper Series 10: 29. www.tnet.teagasc.ie/rerc/.

Whytock, Christopher A. 2009. “Legal Origins, Functionalism, and the Future of Comparative Law.” Brigham Young University Law Review 34(6): 1879–1906.

Wiebe, Keith D, and Ruth Meizen-Dick. 1998. “Property Rights as Policy Tools for Sustainable Development.” Land Use Policy 15(3): 203–15.

Williamson, Ian P. 2001. “Land Administration ‘Best Practice’ Providing the Infraestructure for Land Policy Implementation.” Land Use policy 18 18(4): 297–307. http://www.sciencedirect.com/science/article/pii/S0264837701000217.

Williamson, Ian, and Lisa Ting. 2001. “Land Administration and Cadastral Trends – A Framework for Re- Engineering.” Computers Environment and Urban Systems 25(4–5): 339–66.

Winfield, May. 2015. “Building Information Modelling: The Legal Frontier – Overcoming Legal and Contractual Obstacles.” Society of Construction Law (April): 1–18. www.scl.org.uk.

Winter, Thomas C, Judson W Harvey, O Lehn Franke, and William M Alley. 1998. “Ground Water U. S. Geological Survey Circular 1139.” USGS Publications: 79. http://pubs.usgs.gov/circ/circ1139/%5Cnhttp://books.google.com/books?hl=en&lr=&id=visG1yDeSooC&oi=fnd&pg=PR6&dq=Ground+Water+and+Surface+Water+A+Single+Resource&ots=-IZRIMY1y6&sig=RiCIBwUcoalIulLBwlTm4yHrRuA%5Cnhttp://water.usg.

World Health Organization (WHO). (2018, June). Health and sustainable development. Retrieved from Noise: http://www.who.int/sustainable-development/transport/health-risks/noise/en/

World Health Organization. 1999. Noise Management. https://www.who.int/docstore/peh/noise/Comnoise-5.pdf.

World Intellectual Property Organization (WIPO). 2013. Customary Law, Traditional Knowledge and Intellectual Property: An Outline of the Issues. http://www.wipo.int/export/sites/www/tk/en/resources/pdf/overview_customary_law.pdf.

Xu, Lu. 2015. “The New Real Property Registration Structure in China : Progress with Unanswered Questions.” (March).

Yan, H., and P. Demian. 2008. “Benefits and Barriers of Building Information Modelling.” In 12th International Conference on Computing in Civil and Building Engineering (ICCCBE XII) & 2008 International Conference on Information Technology in Construction (INCITE 2008), Beijing, China.

Ye, C. 2013. “Study of Superficies System of Germany and Japan.” In Proceedings of the 2nd International Conference on Green Communications and Networks, ed. Z. Zhong. Berlin: Springer.

Yiannopoulos, A N. 1968. “Predial Servitudes; General Principles : Louisiana and Comparative Law.” Louisiana Law Review 29(1): 1–45.

Ying, Shen, Renzhong Guo, and Lin Li. 2011. “Design and Development of a 3D Cadastral System Prototype Based on the LADM and 3D Topology.” 2nd International Workshop on 3D Cadastres (November 2011): 167–88.

Ying, Shen, Renzhong Guo, Lin Li, and Biao He. 2012. “Application of 3D GIS to 3D Cadastre in Urban Environment.” In 3rd International Workshop on 3D Cadastres, Shenzhen, China, 253–72.

Ying, Shen., Jin, Fengzan., Guo, Renzhong., Li, Lin., Yang, Jie., Zhou, Yujie. 2014. “The Conversion from CityGML to 3D Property Units.” In 4th International Workshop on 3D Cadastres, eds. Peter van Oosterom and Elfriede M. Fendel. Dubai, United Arab Emirates, 109–22.

Yu, Changbin., Li, Lin., Ying, Shen., He, Biao., Zhao, Zhigang., Wan, Yuan. “Designing a Title Certificate for the Chinese 3D Cadastre.” In 3rd International Workhsop on 3D Cadatres: Development and Practices, Shenzhen, China, 1–22.

Zaini, F., K. Hussin, and M.M. Raid. 2017. “Legal Considerations for Urban Underground Space Development in Malaysia.” Underground Space 2(4): 234–45. http://linkinghub.elsevier.com/retrieve/pii/S2467967417300594.

Zaini, Farah, Khadijah Hussin, Robiah Suratman, and Kamaruzaman Abd Rasid. 2013. “UNDERGROUND LAND OWNERSHIP IN MALAYSIA: A REVIEW.” Jurnal Pentadbiran Tanah 2008(1): 10.

Zevenbergen, Jaap, and Jitske De Jong. 2002. “Public Law Information Regarding Land ; Dutch Proposal for Registration.” In FIG XXII International Congress, Washington, D.C. USA, 1–11.

Zevenbergen, Jaap. 2004. “A Systems Approach to Land Registration and Cadastre.” Nordic Journal of Surveying and Real Estate Research 1: 11–24.

Zevenbergen, Jacob Arie. 2002. “Systems of Land Registration Aspects and Effects.” University of Twente.

Zhang, X., Arayici, Y., Wu, S., Abbott, C., Aouad, G.F.. 2009. “Integrating BIM and GIS for Large Scale (Building) Asset Management : A Critical Review.” In Twelfth International Conference on Civil, Structural and Environmental Engineering Computing., 1–15. http://usir.salford.ac.uk/id/eprint/11418.

Zhang, Xiaoyang. 1999. “Synthesis Of Legal Frameworks Governing Real Estate Investment In The United Kingdom.” Murdoch University Electronic Journal of Law 6(1). http://classic.austlii.edu.au/au/journals/MurUEJL/1999/7.html#leasc.

Zhang, Zhi, Wenwu Tang, Jian Gong, and Ji’e Huan. 2017. “Property Rights of Urban Underground Space in China: A Public Good Perspective.” Land Use Policy 65(April): 224–37. http://dx.doi.org/10.1016/j.landusepol.2017.03.035.

Zhou, Yingxin, and Jian Zhao. 2016. “Assessment and Planning of Underground Space Use in Singapore.” Tunnelling and Underground Space Technology incorporating Trenchless Technology Research 55: 249–56. http://dx.doi.org/10.1016/j.tust.2015.12.018.

Zhuo, Yuefei, Zhimin Ma, Christiaan Lemmen, and Rohan M. Bennett. 2015. “Application of LADM for the Integration of Land and Housing Information in China: The Legal Dimension.” Land Use Policy 49: 634–48. http://dx.doi.org/10.1016/j.landusepol.2015.09.005.

Zulkifli, Nur Amalina, Abdul Rahman Muhammad Imzan Hassan Alias, and Tan Liat Choon. 2017. “Conceptual Modelling of 3D Cadastre and LADM.” In Cadastre: Land Administration Innovations in Geo-Information, eds. Tahsin Yomralioglu and John McLaughlin. , 95–112.

Zulkifli, Nur Amalina, Alias Abdul Rahman, Hasan Jamil, and Teng Chee Hua. 2014. “Towards Malaysian LADM Country Profile for 2D and 3D Cadastral Registration System.” In FIG Congress 2014, Kuala Lumpur, Malaysia, 1–20.

Zuppi, Giovanni Maria. 2008. “The Groundwater Challenge.” In Sustainable Development and Environmental Management: Experiences and Case Studies, eds. Corrado Clini, Ignazio Musu, and Maria Lodovica Gullino. Springer, 49–64.

Zweigert, K., and H. Kötz. 1998. An Introduction to Comparative Law. 3rd ed. Oxford: Oxford University Press.

Βρέλλης, Σ. (1988). Συγκριτικό Δίκαιο. Αθήνα-Κομοτηνή: Νομικές Εκδόσεις Αντ. Ν. Σάκκουλα.

Legal documents

European Commission, Directive 2000/60/EC 2000

European Commission, Directive 2002/49/EC 2002

European Council, European Convention of Landscape 2000

Federal Assembly of the Swiss Confederation, Civil Code

Federal Assembly of the Swiss Confederation, Federal Regulation on Land Registers 2011

Federal Assembly of the Swiss Confederation, Federal Act on Geoinformation 2009 (510.62)

Federal Assembly of the Swiss Confederation, Ordinance on Official Cadastral Surveying 1992 (211.432.2)

Federal Government of The United States, National Environmental Policy Act 1969

Federal Government of The United States, Clean Air Act 1970

Federal Government of the United States, General Mining Law 1872

Federal Government of the United States, Mineral Lands Leasing Act 1920

Federal Government of the United States, Materials Act 1947

Federal Government of the United States, Surface Mining Control and Reclamation Act 1977

Federal Republic of Germany, Civil Code

Federal Republic of Germany, Regulation on the right of Superficies [Erbbau-VO (Erbbaurecht-Verordnung)]

Federal Republic of Germany, Ownership of Apartments and the Right of Permanent Residency (Wohnungseigentumsgesetz, WEG)

Federal Republic of Germany, German Federal Soil Protection Act (BBodSchG, 1998)

Federal Republic of Germany, Federal Mining Act (BBergG) 1980

Government of Alberta, Condominium Property Act 2000 (Chapter C-22)

Government of Alberta, Land Titles Act 2000 Chapter L-4

Government of Alberta, Municipal Government Act 2000 (Chapter M-26)

Government of Alberta, Law of Property Act 2000 (Chapter L-7)

Government of Alberta, Surveys Act 2000 (Chapter S-26)

Government of Argentina, Cadastral National Law (No 26209)

Government of British Columbia, Land Title Act [RSBC 1996] CHAPTER 250

Government of British Columbia, Strata Property Act [SBC 1998] CHAPTER 43

Government of British Columbia, Mineral Tenure Act [RSBC 1996] CHAPTER 292

Government of Canada, Canadian Environmental Assessment Act 1992 (c. 37)

Government of Canada, Constitution Act 1867

Government of Finland, Code of Real Estate (540/1995)

Government of Finland, Mining Act 2011 (621/2011)

Government of Korea, Soil environment conservation Act 1997

Government of Malaysia, National Land Code (Act 56 of 1965)

Government of Malaysia, Strata Titles Act 1985 (Act 318)

Government of Manitoba, The Condominium Act (C.C.S.M. c. C170)

Government of Manitoba, The Real Property Act (C.C.S.M. c. R30)

Government of Manitoba, The Crown Lands Act 2015 (C.C.S.M. c. C340)

Government of Manitoba, Mines and Minerals Act 2018 (C.C.S.M. c. M162)

Government of New Brunswick, Boundaries Confirmation Act 2012 (c. 101)

Government of New Brunswick, Air Space Act (Chapter 109)

Government of New Brunswick, Mining Act 1985 (S.N.B. 1985, c. M-14.1)

Government of New South Wales, Conveyancing Act 1919 (No 6)

Government of New South Wales, Strata Schemes Development Act 2015 (No 51)

Government of New South Wales, Strata Schemes Management Act 2015 (No 50)

Government of New South Wales, Mining Regulations 2016 [2016-498]

Government of New Zealand, Property Law Act 2007 (No 91)

Government of New Zealand, Land Transfer Act 1952 (No 52)

Government of New Zealand, Cadastral Survey Act 2002 (No 12)

Government of New Zealand, Unit Titles Act 2010 (No 22)

Government of New Zealand, Resource Management Act 1991 (No 69)

Government of New Zealand, Crown Minerals Act 1991 (No 70)

Government of Norway, Act on a national register for land information (Cadastre Act) 2017

Government of Norway, Minerals Act 2009 (No 101)

Government of Poland, Civil Code

Government of Quebec, Civil Code 1991

Government of Quebec, Mining Act (chapter M-13.1)

Government of Queensland, Land Act 1994

Government of Queensland, Land Titles Act 1994

Government of Queensland, Property Law Act 1974

Government of Queensland, Body Corporate and Management Act 1997

Government of Queensland, Acquisition of Land Act 1967

Government of Queensland, Acts Interpretation Act 1954

Government of Queensland, Land Valuation Act 2010

Government of Queensland, Mineral Resources Act, 1989

Government of Queensland, Mineral Resources (Sustainable Development) Act, 1990

Government of Singapore, Land Titles Act 1993 (Chapter 157)

Government of Singapore, Sale of Commercial Properties Act 1979 (Chapter 281)

Government of Singapore, Land Acquisition Act 1966 (Chapter 152)

Government of Singapore, State Lands Act 1886 (Chapter 314)

Government of Singapore, Land Titles (Strata) Act 1967 (Chapter 158)

Government of South Africa, Sectional Titles Act (95 of 1986)

Government of Spain, Civil Code

Government of Spain, Mines Act 1973

Government of Sweden, Land Code 1970

Government of Sweden, Real Property Formation Act 1970

Government of Sweden, Environmental Code 2000

Government of Sweden, Minerals Act, 1991

Government of the Czech Republic, Civil Code

Government of the French Republic, Civil Code

Government of the French Republic, Rural and Maritime Fisheries Code

Government of the French Republic, General Local Authorities Code (Code Générale des Collectivités Territoriales)

Government of the French Republic, Code of Construction and Habitation (Code de la Construction et de l' Habitation)

Government of the French Republic, Law 65-557 1965

Government of the Hellenic Republic, Civil Code

Government of the Hellenic Republic, Law 4067/2012

Government of the Hellenic Republic, Law 3986/2011

Government of the Hellenic Republic, Law 3741/1929

Government of the Hellenic Republic, Decree Law 1024/1971

Government of the Hellenic Republic, Decree Law 210/1973

Government of the Hellenic Republic, Technical requirements of cadastral survey, 2013

Government of the Hellenic Republic, Law 2664/1998

Government of the Netherlands, Civil Code

Government of the Netherlands, Cadastre Act 1996

Government of the Netherlands, Soil Protection Act 2013

Government of the Russian Federation, Land Code No. 136-FZ of October 25, 2001

Government of the United Kingdom, Law of Property Act 1925

Government of the United Kingdom, Environmental Protection Act 1990

Government of Victoria, Property Law Act 1958 (No. 6344)

Government of Victoria, Subdivision Act 1988 (No 53)

Government of Victoria, Land Tax Act 2005 (No 88)

Government of Victoria, Land Act 1958 (No 6284)

Government of Victoria, Transfer of Land Act 1958 (No 6399)

Government of Victoria, Mineral Resources (Sustainable Development) Act 1990 (No. 92)

People's Republic of China, Interim Regulations of the People's Republic of China concerning the Assignment and Transfer of the Right to the Use of the State-owned Land in the Urban Area, 1990

People's Republic of China, Property Law of the People's Republic of China (no 62 2007)

State Government of California, Civil Code

State Government of Florida, The Condominium Act 2018 (Chapter 718)

State Government of Louisiana, Civil Code

State Government of Louisiana, Louisiana Condominium Act 1974

State Government of Louisiana, Mineral Code 2006 (Title 31)

State Government of Nevada, Property Rights and Transactions 2010

State Government of New York, Real Property Actions and Proceedings

State Government of North Carolina, North Carolina General Statutes

State Government of South Carolina, South Carolina Code of Laws

The Scottish Government, Tenements (Scotland) Act 2004

United States National Conference of Commissioners on Uniform State laws, Uniform Common Interest Ownership Act 2014

United States National Conference of Commissioners on Uniform State laws, Uniform Condominium Act 1980

Others

Commonwealth of Independent States. (1995). Commonwealth of Independent States Convention on Human Rights and Fundamental Freedoms

European Court of Human Rights, Council of Europe. (1950). European Convention on Human Rights

League of Arab States. (1994). Arab Charter of Human Rights

Organization of African Unity. (2004). African Charter on Human and Peoples' Rights

Organization of American States. (1969). American Convention on Human Rights

United Nations. (1948). Universal Declaration of Human Rights

CURRICULUM VITAE

Dimitrios Kitsakis was born in April 12th 1986, in Ioannina, Region of Epirus in Greece. He graduated from School of Rural and Surveying Engineering of National Technical University of Athens in 2011. The subject of his diploma thesis was the comparative analysis of photogrammeteric methods of point cloud acquisition.

Since 2012, he is working as a freelance surveyor, undertaking preparation of technical studies for private and public sector, topographical surveys, urban planning and cadastral studies. From 2013 to 2019, he has been working as a teaching assistant in the School of Rural and Surveying Engineering of National Technical University of Athens, focusing on Land Administration, cadastral systems, 3D cadastre, 3D modelling and land law.

In 2013, he has started this PhD thesis, which has resulted to a considerable number or publications, in addition to this work.

During 2016, he participated to the "3D campus" project, involving semantic, 3D modelling of National Technical University of Athens' campus, thus building a solid background in geospatial technologies.

In order to enrich his background on land law, he has been attending property law, cadastral law, urban and spatial planning law courses in the Law School of National and Kapodistrian University of Athens.

He has an active role in Commissions 3 and 7 of the International Federation of Surveyors, since 2013.