NATIONAL TECHNICAL UNIVERSITY OF ATHENS

SCHOOL OF RURAL AND SURVEYING ENGIREERING

Indoor Navigation based on IndoorGML

Case Study Rural and Surveying Engineering School, NTUA

--

Master Thesis

Tsangouri Aikaterini

Supervisor :Dimopoulou Efi

Professor of NTUA

Athens,

October 2017

ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor Ms. Efi Dimopoulou Professor of the Rural and Survey Engineering School at National Technical University of Athens. The door to Prof. Dimopoulou office was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

Finally, I must express my very profound gratitude to my parents and to my friends for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Contents

Figure Table

ABSTRACT

Humans spend more of their daily life in indoor space, which becomes more complex due to urbanization and high density of population in a limited territory. In this manner, the navigation in indoor spaces becomes more and more required. Also, the recent progress of mobile devices and indoor positioning technologies could support location-based services in indoor space as well as outdoor space. However, there are many and significant differences between indoor and outdoor spaces and the geospatial technologies that have been developed for outdoors could not be applied for indoors. Indoor Navigation is a relatively new science that is under research. The Open Geospatial Consortium (OGC) in 2014 published a new standard called IndoorGML, which provide a standard data model and XML schema to represent and exchange indoor information, based on cellular space model. The main aim of IndoorGML is to provide interoperability between services and a data model framework for future development from simple indoor navigation services to complicated indoor spatial analysis and big data analysis.

There are two methods to develop IndoorGML model, either from scratch by using an IndoorGML editor or by transforming existing indoor data from CityGML or IFC format in IndoorGML. The case study of this research, concerns the development of the IndoorGML model of the building complex of Rural and Surveying Engineering School of National Technical University of Athens. The model was developed by an Open Java IndoorGML editor (JInedit) and the model's visualization was accomplished in a WebGL Viewer. IndoorGML models could be applied for emergency situations and also in connection with Land Administration Domain Model (LADM) in order to define the rooms' use and the space accessibility depending on person's status of rights.

ΠΕΡΙΛΗΨΗ

Οι άνθρωποι περνούν το μεγαλύτερο μέρος της καθημερινής τους ζωής σε εσωτερικούς χώρους, οι οποίοι γίνονται όλο και περισσότερο περίπλοκοι λόγω της αστικοποίησης και της υψηλής πυκνότητας του πληθυσμού σε περιορισμένη έκταση. Κατά αυτό τον τρόπο, όπως και στους εξωτερικούς χώρους, οι πληροφορίες στον εσωτερικό χώρο είναι σημαντικές για τις υπηρεσίες τοποθεσίας και πλοήγησης. Η πλοήγηση σε εσωτερικούς είναι μεταγενέστερη της πλοήγησης σε εξωτερικούς χώρουςκαι βρίσκεται υπό ανάπτυξη σε αντίθεση με την δεύτερη που είναι αρκετά εξελιγμένη. Οι διαφορές μεταξύ εσωτερικών και εξωτερικών χώρων είναι πολλές και σημαντικές και για το λόγο αυτό δεν μπορούν να εφαρμοστούν οι τεχνολογίες γεωπληροφορικής που αναπτύσσονται για τους εξωτερικούς στους εσωτερικούς χώρους. Η θεμελιώδης διαφορά προέρχεται από το σύστημα χωρικής αναφοράς, το οποίο καθορίζει την ένδειξη της θέσης σε ένα χώρο. Στους εξωτερικούς χώρους, χρησιμοποιούνται συστήματα συντεταγμένων για τον καθορισμό της θέσης, βασισμένα στον Ευκλείδειο χώρο, ενώ στον εσωτερικό χώρο η θέση μπορεί να καθορίζεται από ένα αναγνωριστικό θέσης όπως ο αριθμός του δωματίου. Δεδομένου ότι ο εσωτερικός χώρος δεν μπορεί να θεωρηθεί πλήρως ως Ευκλείδειος χώρος, ο ορισμός της απόστασης μεταξύ δύο σημείων σε εσωτερικούς χώρους διαφέρει από αυτόν στον υπαίθριο χώρο, καθώς θα πρέπει να ληφθούν υπόψιν τα εμπόδια ή οι περιορισμοί του χώρου για τον υπολογισμό των αποστάσεων.

Ένα μοντέλο πλοήγησης σε εσωτερικούς χώρους θα πρέπει κατ’ ελάχιστο να συγκεντρώνει τα ακόλουθα τέσσερα χαρακτηριστικά:

1) Να περιλαμβάνει σημασιολογική πληροφορία: η σημασιολογία σχετίζεται με χρήσιμες πληροφορίες πλοήγησης και υποστηρίζει τις απαιτούμενες γνώσεις διευκολύνοντας την αυτοματοποίηση της παραγωγής του μοντέλου πλοήγησης.

2) Αυτόματη δημιουργία του δικτύου πλοήγησης από την αρχική γεωμετρία: το δίκτυο πλοήγησης θα πρέπει να προέρχεται αυτόματα από οποιαδήποτε 3D απεικόνιση γεωμετρίας ενός κτηρίου. Οι συνεχείς αλλαγές στο εσωτερικό περιβάλλον θα πρέπει να ενημερώνουν αυτόματα το δίκτυοσε πραγματικό χρόνο, ώστε το μοντέλο πλοήγησης να μπορεί να αντιμετωπίσει καταστάσεις έκτακτης ανάγκης.

3) Δυνατότητα δυναμικής δρομολόγησης: το σύστημα εκκένωσης πρέπει να λαμβάνει υπόψη τις αλλαγές του περιβάλλοντος, να αναπροσαρμόζει και να προβλέπει εναλλακτικές διαδρομές σε περίπτωση έκτακτης ανάγκης.

4) Να εφαρμόζει την “door-to-door” κίνηση: η πλοήγηση “door-to-door”εφαρμόζεται στην αναζήτηση διαδρομής καθώς υποστηρίζει μια πιο φυσική κίνηση.

Η αποτελεσματικότητα ενός εσωτερικού συστήματος πλοήγησης εξαρτάται από την ακριβή και ενημερωμένη γεωμετρία, τη σημασιολογία του κτηρίου, τη σωστή εσωτερική θέση, την ευελιξία των διαδρομών πλοήγησης με βάσει τα χαρακτηριστικά και τις ιδιαιτερότητες των ατόμων που πλοηγούνται και από την απόλυτη γνώση των εμποδίων και την προσβασιμότητα στους χώρους του κτηρίου. Προκειμένου να επιτευχθεί η ανάπτυξη ενός καλά δομημένου και αποτελεσματικού

μοντέλου πλοήγησης, οι ερευνητές έχουν καθορίσει ορισμένες βασικές απαιτήσεις που αφορούν όλα τα διαφορετικά στάδια της ανάπτυξης του μοντέλου αυτού.

Όσον αφορά τις απαιτήσεις στην τοπολογία ενός συστήματος εσωτερικής πλοήγησης, πριν από την δημιουργία της τοπολογικής δομής υπάρχουν ορισμένα στοιχεία που θα πρέπει πρώτα να καθοριστούν. Αυτές είναι το ελάχιστο τοπολογικό στοιχείο για μια καλή γραφική αναπαράσταση του κτηρίου, η σύνδεση των σημασιολογικών πληροφοριών στις διαδικασίες παραγωγής τουδικτύου πλοήγησης και ο αλγόριθμος που ταιριάζει περισσότερο στην αυτόματη παραγωγή του γραφήματος πλοήγησης.

Η πλοήγηση σε εσωτερικούς χώρους περιλαμβάνει το σχεδιασμό διαδρομών καθώς και τον εντοπισμό και την παρακολούθηση κινούμενων αντικειμένων ή αντικειμένων μέσα σε εσωτερικούς χώρους. Και οι δύο αυτές πτυχές της εσωτερικής πλοήγησης εξαρτώνται σε μεγάλο βαθμό από τρεις κύριους παράγοντες: τον τρόπο μετακίνησης του κινούμενου αντικειμένου, όπως περπάτημα ή οδήγηση, το πλαίσιο πλοήγησης και την τεχνική εντοπισμού. Η υποστήριξη διαφορετικών πλαισίων πλοήγησης οδηγεί σε πρόβλημα λόγω της πολυπλοκότητας. Συχνά τα μοντέλα πλοήγησης σε εσωτερικούς χώρους μειώνουν αυτήν την πολυπλοκότητα προσαρμόζοντας το πλαίσιο πλοήγησης σε μία συγκεκριμένη διαμόρφωση ή σε ένα περιορισμένο υποσύνολο. Παρόλα αυτά, η υποστήριξη πολλαπλών και διαφορετικών πλαισίων πλοήγησης αποτελεί βασική απαίτηση για ένα πρότυπο μοντέλο εσωτερικής πλοήγησης.

Όσον αφορά τις απαιτήσεις στην μοντελοποίηση του χώρου, ένα πρότυπο σύστημα πλοήγησης σε εσωτερικό χώρο πρέπει να είναι συμπληρωματικό προς υπάρχοντα 3D σημασιολογικά μοντέλα και πρότυπα, όπως είναι το CityGML, το IFC, το X3D ή το ESRI BISDM, προκειμένου να αποφευχθεί η επανάληψη διαδικασιών για την απεικόνιση του εσωτερικού περιβάλλοντος. Κατά αυτό τον τρόπο, ένα πρότυπο μοντέλο πλοήγησης εσωτερικού χώρου θα πρέπει να υποστηρίζει την ιεραρχική ομαδοποίηση των χώρων ώστε να διευκολύνεται ο διαχωρισμός των χώρων βάσει των τοπολογικών και λογικών χαρακτηριστικών και η εφαρμογή αποτελεσματικών αλγορίθμων δρομολόγησης. Τέλος ,ως προς τις απαιτήσεις του πρότυπου μοντέλου εσωτερικής πλοήγησης, αυτό θα πρέπει να σχεδιαστεί με τέτοιο τρόπο ώστε να είναι επεκτάσιμο και να ανταποκρίνεται σε μελλοντικές απαιτήσεις. Το μοντέλο θα πρέπει να περιλαμβάνει έναν μηχανισμό επέκτασης για την ανταλλαγή δεδομένων και την υποστήριξη μιας μελλοντικής ενοποίησης με μοντέλο πλοήγησης σε εξωτερικούς χώρους, προκειμένου να καθοριστεί ένα πρότυπο για την απρόσκοπτη πλοήγηση σε εσωτερικούς και εξωτερικούς χώρους.

Το IndoorGML, το οποίο αποτελεί το βασικό αντικείμενο μελέτης της εν λόγω εργασίας είναι πρότυπο της OGC (Open Spatial Consortium Consortium) για την αναπαράσταση, αποθήκευση και διαχείριση πληροφοριών εσωτερικού χώρου. Χρησιμοποιεί ένα ανοιχτό μοντέλο δεδομένων και ένα σχήμα XML που εφαρμόζεται στη γλώσσα GML (Geographic Markup Language) 3.2.1. Το IndoorGML βασίζεται στο χωρικό μοντέλο κελιού (cellular space model), το οποίο αντιπροσωπεύει έναν δεδομένο εσωτερικό χώρο ως ένα σύνολο μη αλληλεπικαλυπτόμενων κελιών σε εσωτερικούς χώρους.Το κελί αποτελεί τη μοναδιαία οντότητα του χώρου στο πρότυπο του IndoorGML και ο εσωτερικός χώρος μέσω των κελιών περιγράφεται βάσει τεσσάρων βασικών χαρακτηριστικών: 1) γεωμετρία, 2) σημασιολογία, 3) τοπολογία και 4) πολυεπίπεδο χωρικό μοντέλο.

Το πρότυπο IndoorGML στοχεύει στην ικανοποίηση των παρακάτω απαιτήσεων, καθορίζοντας ένα πρότυπο εσωτερικών χωρικών πληροφοριών για τον εντοπισμό σταθερών ή κινητών αντικειμένων σε εσωτερικούς χώρους. Οι απαιτήσεις αυτές είναι :

- χωρική αναπαράσταση ανά κελί: ο εσωτερικός χώρος είναι οργανωμένος σε κελιά, όπου κάθε κελί έχει ένα αναγνωριστικό αριθμό δωματίου (cell id) αντί για συντεταγμένες και παρόλο που τα κελιά έχουν κοινά σύνορα με άλλα δεν επικαλύπτονται
- τοπολογική αναπαράσταση: η συνδεσιμότητα, η γειτνίαση μεταξύ δύο δωματίων ή ενός δωματίου και ενός διαδρόμου είναι εξαιρετικά σημαντική για τις περισσότερες εφαρμογές πληροφοριών εσωτερικού χώρου
- πολλαπλή αναπαράσταση ενός εσωτερικού χώρου: ένας εσωτερικός χώρος μπορεί να ερμηνευτεί με διάφορους τρόπους ανάλογα με το πλαίσιο και τις υπάρχουσες πληροφορίες.

Κατά αυτό τον τρόπο, το IndoorGML είναι σε θέση να υποστηρίξει υπηρεσίες χωρικών πληροφοριών σχετικά με θέσεις σε εσωτερικούς χώρους, περιλαμβάνοντας επίσης και δεδομένα, αντί να αντιπροσωπεύει μόνο τα αρχιτεκτονικά συστατικά των κτηρίων όπως τα πρότυπα CityGML και IFC. Επίσης, το IndoorGML αναπτύχθηκε με τέτοιο τρόπο ώστε να μπορεί να υποστηρίξει εξωτερικές αναφορές και να ενσωματώνεται σε άλλα πρότυπα όπως το CityGML και το IFC. Το IndoorGML παρέχει έναν μηχανισμό αναφοράς ενός αντικειμένου που ορίζεται σε άλλο σύνολο δεδομένων ή βάση δεδομένων μέσω εξωτερικής αναφοράς. Αυτό συμβαίνει στο πλαίσιο της διαλειτουργικότητας, προκειμένου να είναι δυνατή η χρήση και η ανταλλαγή δεδομένων από το ένα πρότυπο στο άλλο. Ακόμη, το πρότυπο στοχεύει στην διασύνδεση του εσωτερικού με τον εξωτερικό χώροκαθώς σε ορισμένες περιπτώσεις είναι απαραίτητο να ενσωματωθούν εσωτερικοί και εξωτερικοί χώροι. Τέτοιες καταστάσεις μπορεί να συμβούν για υπηρεσίες πλοήγησης αυτοκινήτων όταν ένα αυτοκίνητο εισέρχεται από τον εξωτερικό χώρο σε πάρκινγκ στον εσωτερικό χώρο κτηρίου.

Το IndoorGML αποτελείται από ένα βασικό μοντέλο (core module) και ένα επεκτάσιμο(extension module), το μοντέλο πλοήγησης σε εσωτερικούς χώρους. Το βασικό μοντέλο περιλαμβάνει τις βασικές έννοιες του IndoorGML και μπορεί να επεκταθεί για συγκεκριμένο σκοπό εφαρμογών πλοήγησης (π.χ. πεζούς, αναπηρικό καροτσάκι). Το βασικό μοντέλο αποτελείται από την γεωμετρική, την τοπολογική και την σημασιολογική αναπαράσταση. Όσον αφορά την γεωμετρική αναπαράσταση, υπάρχουν τρεις τρόποι για την αναπαράσταση της γεωμετρίας ενός κελιού: με εξωτερική αναφορά χρησιμοποιώντας εξωτερικούς συνδέσμους σε άλλα σύνολα δεδομένων όπως το CityGML ή το IFC, με γεωμετρική αναπαράσταση του κελιού στο IndoorGML ως GM_Solid σε 3D χώρο ή GM_Surface σε 2D χώρο όπως ορίζεται στο ISO 19107, είτε χωρίς καμία γεωμετρία, χωρίς δηλαδή να περιλαμβάνονται γεωμετρικές πληροφορίες στο IndoorGML αρχείο. Όσον αφορά την τοπολογική αναπαράσταση, που αποτελεί το πιο ουσιαστικό στοιχείο των εφαρμογών πλοήγησης για κάθε εφαρμογή πλοήγησης όπως και για το IndoorGML, χρησιμοποιείται η δυαδικότητα Poincaré και πιο συγκεκριμένα το Node-Relation γράφημα (Lee 2004) για την τοπολογική διάταξη του εσωτερικού χώρου και τον ορισμό της τοπολογίας των κελιών μεταξύ τους όπως γειτνίαση και συνδεσιμότητα. Σύμφωνα με τη δυαδικότητα Poincaré, ένα k-διαστάσεων αντικείμενο στον αρχικό χώρο N-διαστάσεων χαρτογραφείται σε αντικείμενο (N-k) διαστάσεων στον δισδιάστατο χώρο. Έτσι στερεά 3D αντικείμενα στον τρισδιάστατο χώρο, π.χ. αίθουσες εντός ενός κτιρίου, χαρτογραφούνται σε κόμβους (0D αντικείμενα) στον δισδιάστατο χώρο. Οι 2D επιφάνειες που μοιράζονται δύο στερεά αντικείμενα μετατρέπονται σε μια ακμή (1D) που συνδέει δύο κόμβους στον δισδιάστατο χώρο. Όσον αφορά την σημασιολογική απεικόνιση, στο IndoorGML, η σημασιολογία χρησιμοποιείται για να ταξινομεί και να αναγνωρίζει κάθε κελί και επίσης για να ορίζει τη συνδεσιμότητα και την γειτνίαση μεταξύ των κελιών. Η ταξινόμηση που παρέχει η σημασιολογία είναι πολύ σημαντική για την πλοήγηση, καθώς μπορεί να υποδηλώνει και να χωρίζει τους χώρουςπλοήγησης όπως τα δωμάτια, τους διαδρόμους και τις πόρτες από τοίχους και εμπόδια. Όσον αφορά το μοντέλο επέκτασης, αυτό περιλαμβάνει την πολλαπλή απεικόνιση του χώρου. Κάθε απεικόνιση θεωρείται ως ένας χώρος με τις δικές του γεωμετρικές και τοπολογικές ιδιότητες. Για παράδειγμα, ένας εσωτερικός χώρος αναπαριστάται τοπολογικά και αποτελείται από δωμάτια, διάδρομους και σκάλες, ενώ επισής μπορεί να αναπαρασταθεί ως χώρος των κελιών που καλύπτονται από WiFi ή από αισθητήρες RFID. Με απλά λόγια, κάθε επίπεδο σημασιολογικής ερμηνείας αντιστοιχεί σε διαφορετική αναπαράσταση του ίδιου εσωτερικού χώρου και κάθε αποσύνθεση σχηματίζει ξεχωριστη απεικόνιση του χώρου. Όσο το βασικό μοντέλο τόσο και η επέκταση καθορίζονται από ένα XML Schema. Σύμφωνα με τις σχέσεις εξάρτησης μεταξύ των μοντέλων, κάθε μοντέλο μπορεί, επιπλέον, να εισάγει ονόματα που σχετίζονται με αυτές στα μοντέλα του IndoorGML.

Το IndoorGML βασίζεται σε δύο εννοιολογικά πλαίσια: το μοντέλο δομημένου χώρου (Structured Space Model) και το μοντέλο πολλαπλών επιπέδων χώρου (Multi-Layered-Space-Model). Το δομημένο μοντέλο χώρου (SSM) ορίζει τη γενική διάταξη της κάθε απεικόνισης του χώρου ανεξάρτητα από το συγκεκριμένο χωρικό μοντέλο που αντιπροσωπεύει. Κάθε χωρική απεικόνιση εξελίσσεται συστηματικά μέσα σε τέσσερα τμήματα. Το μοντέλο του κτηρίου υποδιαιρείται σε τέσσερα τμήματα, τον αρχικό και δισδιάστατο χώρο αφενός και τον γεωμετρικό και τοπολογικό χώρο αφετέρου. Το μοντέλο πολλαπλών επιπέδων χώρου (MLSM) είναι μια επέκταση του δομημένου χωρικού μοντέλου (SSM). Καθώς ο εσωτερικός χώρος αποσυντίθεται σε διαφορετικούς χώρους, κάθε θεματική περιοχή αναπαράστασης σχηματίζει ένα διαφορετικό επίπεδο χωρου στον διδιάστατο χώρο μέσω της αρχιτεκτονικής SSM. Στο IndoorGML, το χωρικό μοντέλο για την πολυεπίπεδη απεικόνιση χώρου, υλοποιείται από την κλάση MultiSpaceLayer. Το MultiLayeredGraph αποτελείται από τις κλάσεις SpaceLayers και InterLayerConnections, ενώ το SpaceLayer αντιπροσωπεύει κάθε χωρικό επίπεδο απεικόνισης(π.χ. το τοπολογικό επίπεδο, επίπεδο χώρου κάλυψης από αισθητήρες κλπ.) Επίσης τα SpaceLayers μπορούν να συνδεθούν μεταξύ τους μέσω της κλάσης InterLayerConnection.

Το IndoorGML είναι το πρώτο πρότυπο που αφορά στην παροχή προτύπων λειτουργίας συστημάτων εσωτερικής πλοήγησης. Καθώς το IndoorGML κερδίζει έδαφος στον τομέα της πλοήγησης σε εσωτερικούς χώρους, η ανάγκη σύνδεσης με άλλα πρότυπα καθίσταται ολοένα και περισσότερο απαραίτητη. Η σύνδεση από άποψη διαλειτουργικότητας αφορά την ανταλλαγή δεδομένων από το ένα πρότυπο στο άλλο και την χρήση των υπαρχόντων τρισδιάστατων μοντέλων σε διαφορετικές εφαρμογές. Έχουν διεξαχθεί αρκετές έρευνες πάνω στο παραπάνω θέμα, μελετώντας τεχνικές για την εκμετάλλευση πληροφοριών από υπάρχοντα 3D σημασιολογικά μοντέλα και την κατασκευή ενός μοντέλου πλοήγησης IndoorGML. Η έρευνα βρίσκεται σε εξέλιξη ενώ μέχρι σήμερα έχει πραγματοποιηθεί σύνδεση με τα CityGML, και IFC πρότυπα, το OSM (OpenStreetMap) και το LADM. Όσον αφορά την σύνδεση του IndoorGML με το OSM, οι Mirvahabi et al.(2015), πρότειναν μια προσέγγιση για την αυτόματη παραγωγή δεδομένων IndoorGML από το αρχείο δεδομένων OSM. Η προτεινόμενη προσέγγιση είναι βασισμένη σε java κώδικα και μετατρέπει αυτόματα το αρχείο δεδομένων OSM στο δομημένο μοντέλο δεδομένων XML του IndoorGML. Η προσέγγιση αυτή εφαρμόστηκε για την παραγωγή του IndoorGML μοντέλου του Σχολείου Γεωπονίας και Γεωεπιστημονικής Μηχανικής στο Πανεπιστήμιο της Τεχεράνης. Όσον αφορά την σύνδεση του IndoorGMLμε το LADM, οι Zlatanova et al., το 2016 ξεκίνησαν μια έρευνα για τη σύνδεση των δύο αυτών προτύπων για να επιτρέψουν τον εντοπισμό του χώρου βάσει δικαιωμάτων ιδιοκτησίας και περιορισμού των ακινήτων. Πρώτα εντόπισαν τις ομοιότητες και τις διαφορές των προτύπων λαμβάνοντας υπόψη δύο επιλογές:1) μια σχέση ισοδυναμίας μεταξύ του LADM LA_SpatialUnit και του κελιού (CellSpace) του IndoorGML μοντέλου για δικαιώματα (Rights,Restrictions,Responsibilities -RRRs), παρόμοια με άλλες ενώσεις κλάσεων LADM και άλλες εξωτερικές κατηγορίες, 2) μια τυπική προσέγγιση για την εξαγωγή ενός επιπέδου του χώρου βάσει LADM μέσα στο IndoorGML. Πιο συγκεκριμένα, η πρώτη προσέγγιση υποδεικνύει τον ορισμό ενός module επέκτασης του IndoorGML για την υποστήριξη του προτύπου LADM εντός του IndoorGML λόγω της ισοδυναμίας του CellSpace του IndoorGML και του LA_SpatialUnit του LADM, ενώ το δεύτερο παρέχει ένα μηχανισμό πρόσβασης σε χαρακτηριστικά από το ένα πρότυπο στο άλλο μέσω εξωτερικής σύνδεσης. Η σύνδεση αυτών των προτύπων θα είναι αποτελεσματική και για τις δύο πλευρές καθώς το IndoorGML μπορεί να αναβαθμιστεί προσθέτοντας πληροφορίες σχετικά με δικαιώματα, ευθύνες και περιορισμούς του χώρου από το LADM και το LADM μπορεί να κληρονομήσει από το IndoorGML τη γεωμετρία. Όσον αφορά την σύνδεση με τα CityGML και IFCπρότυπα, οι Khan et.al το 2014, πρότειναν μια διαδικασία μετασχηματισμού πολλαπλών σταδίων για την αυτόματη παραγωγή δεδομένων IndoorGML από υπάρχοντα εσωτερικά μοντέλα κτηρίων είτε σε IFC είτε σε CityGML LoD4. Η γενική ιδέα της πρότασης αυτής είναι να παράγουν μοντέλα δεδομένων IndoorGML από διαφορετικά υφιστάμενα σημασιολογικά 3D μοντέλα κτηρίων είτε σε IFC είτε σε CityGML LoD4 χρησιμοποιώντας το εργαλείο FME της Safe Software και προσδιορίζοντας τις δομές πλοήγησης σύμφωνα με τους διαφορετικούς τύπους μετακίνησης και τους περιορισμούς του χώρου.

Επιπλέον, το CityGML ως σημασιολογικό 3D μοντέλο, δίνει την δυνατότητα δημιουργίας ενός εκτεταμένου CityGML μοντέλου μέσω του CityGML ADE, το οποίο υποστηρίζει συγκεκριμένες εφαρμογές που βασίζονται στην έννοια του CityGML. Για την κατασκευή του CityGML ADE, υπάρχουν δύο διαφορετικές προσεγγίσεις για την ενσωμάτωση δεδομένων CityGML και δεδομένων εφαρμογής. Η πρώτη μέθοδος πραγματοποιείται με την ενσωμάτωση των αντικειμένων CityGML σε μεγαλύτερα πλαίσια εφαρμογών, συνδέοντας δεδομένα CityGML και δεδομένα εφαρμογής. Δεύτερη μέθοδος είναι η επέκταση του μοντέλου δεδομένων CityGML, καθορίζοντας πρόσθετα χαρακτηριστικά των αντικειμένων και νέες κατηγορίες χαρακτηριστικών για τις συγκεκριμένες εφαρμογές. Η δεύτερη μέθοδος χρησιμοποιείται πιο συχνά καθώς είναι πιο εύκολα εφαρμόσιμη και μπορεί νακαλύψει πολλές εφαρμογές.

Σύμφωνα με τα παραπάνω, οι Kim et al., το 2014, πρότειναν ένα CityGML Indoor ADE για εσωτερικές εφαρμογές διαχείρισης εγκαταστάσεων δημιουργώντας το μοντέλο με τη δεύτερη μέθοδο. Το εν λόγω CityGML Indoor ADE περιλαμβάνει δύο μοντέλα που βασίζονται στη Μοντέλο κτηρίου CityGML, το Μοντέλο των χαρακτηριστικών του εσωτερικού χώρου και το Μοντέλο των χαρακτηριστικών των εγκαταστάσεων του χώρου. Το πρώτο μοντέλο αντιπροσωπεύει τα χαρακτηριστικά του χώρου, όπως αίθουσες ανάγνωσης, αίθουσες συνεδριάσεων και αίθουσες γραφείων, ενώ το δεύτερο μοντέλο περιγράφει χαρακτηριστικά των εσωτερικών εγκαταστάσεων (έπιπλα- η/μ εγκαταστάσεις στον χώρο), όπως εγκαταστάσεις σε περίπτωση καταστροφής, και κινούμενες εγκαταστάσεις. Η έρευνα αυτή διεξήχθη από το Πανεπιστήμιο της Σεούλ και υποστηρίχθηκε από ένα ερευνητικό πρόγραμμα Αρχιτεκτονικής & Αστικής Ανάπτυξης που χρηματοδοτήθηκε από το Υπουργείο Χωροταξίας, Υποδομών και Μεταφορών της κυβέρνησης της Κορέας και εφαρμόστηκε σε υπόγειους σταθμούς μετρό ή δημόσια κτήρια όπου είναι μαζικές μεταφορές των ανθρώπων σε εσωτερικούς χώρους.

Παρόλο που το CityGML μπορεί να χρησιμοποιηθεί για να αναπαραστήσει εσωτερικούς χώρους δεν αποδεικνύεται ιδιαίτερα κατάλληλο μοντέλο δεδομένων για εφαρμογές πλοήγησης σε εσωτερικό χώρο, καθώς αν και μπορεί να υποστηρίξει μέσω του ADE πρόσθετες κλάσεις περιλαμβάνει μόνο την σημασιολογική τους υπόσταση με αποτέλεσμα να μην μπορεί να χρησιμοποιηθεί για εφαρμογές πλοήγησης. Από την άλλη πλευρά, το IndoorGML είναι κατάλληλο για εφαρμογές εσωτερικής πλοήγησης καθώς περιλαμβάνει τη γεωμετρία, την τοπολογία και τη σημασιολογία των κελιών στον εσωτερικό χώρο.

Για την ανάπτυξη IndoorGML μοντέλων κτηρίων από το μηδέν είναι διαθέσιμοι ελάχιστα προγράμματα, καθώς όπως αναφέρθηκε και παραπάνω το πρότυπο αυτό είναι σχετικά καινούργιο και βρίσκεται υπό εξέλιξη. Οι Hwang et al., το 2012, ανέπτυξαν ένα πρόγραμμα για τη δημιουργία και ένα πρόγραμμα θέασης IndoorGML μοντέλων.

Όσον αφορά το πρακτικό κομμάτι της εργασίας αυτής, δημιουργήθηκε το IndoorGML μοντέλο των κτηρίων της Σχολής Αγρονόμων Τοπογράφων Μηχανικών του Εθνικού Μετσόβιου Πολυτεχνείου. Πρόκειται για δύο κτήρια δύο και τριών ορόφων που συνδέονται μεταξύ τους μέσω μιας υπέργειας γέφυρας. Η δημιουργία του IndoorGML μοντέλου πραγματοποιήθηκε μέσω του εργαλείου JInedit, ενός ανοιχτού Javaπρογράμματος, χρησιμοποιώντας ως δεδομένα εισόδου τις κατόψεις των ορόφων των κτηρίων. Στο πρόγραμμα αυτό ο χρήστης προσδιορίζει μέσω ψηφιοποίησης των κατόψεων τα δωμάτια,τους διαδρόμους, τις πόρτες, τα σκαλιά και τους ανελκυστήρες και ορίζει τις συνδέσεις μεταξύ των χώρων αυτών. Το αρχείο αυτό εξήχθη σε IndoorGML μορφή και απεικονίστηκε μέσω του WebGL IndoorGMLViewer.

Κάποιες πιθανές εφαρμογές των IndoorGML μοντέλων θα μπορούσαν να είναι σε καταστάσεις έκτακτης ανάγκης όπως πλημμύρες, φωτιά και σεισμός, βρίσκοντας εναλλακτικές διαδρομές για την ασφαλή απομάκρυνση από το κτήριο. Μια ακόμη ενδιαφέρουσα εφαρμογή του IndoorGML μοντέλου είναι συνδυάζοντάς το με το μοντέλο LADM, για τον καθορισμό των λειτουργιών του κάθε χώρου και το καθορισμό της προσβασιμότητας στους χώρους ανάλογα με την ιδιότητα του χρήστη με βάση τα δικαιώματα, τους περιορισμούς και τις ευθύνες του χώρου.

Περαιτέρω έρευνα του προτύπου θα δώσει λύση στα σημερινά προβλήματα που αντιμετωπίζονται από την χρήση του, ενώ ταυτόχρονα θα επεκτείνει τις δυνατότητες και την συνδεσιμότητά του με άλλα πρότυπα ώστε οι δυνατότητες του να αξιοποιηθούν στο έπακρο.

INTRODUCTION

Nowadays, navigation has become an essential component of human life. Due to the increasing size and complexity of buildings, navigation applications are extended from outdoor to indoor spaces as well. With the progress in indoor spatial data modeling, several spatial information services for indoor spaces have been provided. IndoorGML, is a standard data model and XML-based exchange format for the management of indoor spatial data that was published by OGC. There are two methods for the development of an IndoorGML model. The first one, is to apply an IndoorGML editor and create from scratch indoor navigation data and the second to transform existing indoor spatial data from semantic models such as CityGML or IFC, to IndoorGML format. The first method was implemented for the development of the IndoorGML model of the building of Rural and Surveying Engineering School of National Technical University of Athens.

The thesis is organized as follows :

Chapter 1, illustrates the indoor navigation background, the requirements as well as existing indoor navigation models.

Chapter 2, illustrates the IndoorGML standard. More specifically, the standard's requirements, concepts, framework and the method for subspacing are defined. The IndoorGML connection with other standards such as OpenStreetMap, BIM and LADM are also presented.

Chapter 3, illustrates Indoor Navigation Applications that have been developed so far. More specifically, the indoor Spatial Awareness Initiative and algorithms for path-finding are discussed. The Location Based Service is also introduced along with an application of it, the EU program i-locate.

Chapter 4, illustrates methods for the development of indoor navigation models. More specifically, methods to develop IndoorGML model either from scratch or by transformation from CityGML or IFC models are presented. Also, a method for generating navigation models logic Models from CityGML and a CityGML Indoor ADE are displayed. Finally, IndoorGML and CityGML standards are compared regarding their functions.

Chapter 5, illustrates the case study. The whole process of the development of the IndoorGML model for the building of Rural and Surveying Engineering School of National Technical University of Athens is described and the results are discussed.

Chapter 6, discusses the case studies findings more in general and proposes topics for future research.

1. INDOOR NAVIGATION

The navigation activity is an everyday practice for every human. Personal navigation systems (PNS) have become an up-growing tool for route planning and guidance of individual traffic using cars and other vehicles. The availability of global localization techniques like GPS and the acquisition and provision of the road network for large parts are the main reason for navigation systems development. On the other hand, pedestrian navigation systems are not the as evolved as car navigation systems. In the past years, the increasing size and complexity of buildings, especially public buildings such as airports, shopping malls and hospitals, has extended the human need for navigation to indoor environments as humans are having difficulty in finding their target location. Moreover, indoor navigation could provide escape routes from buildings and fastest routes for rescue personnel to a disaster area in emergency situations.

In the beginning, the studies mainly focused on how to develop an indoor navigation standard that will be appropriate for the most of the occasions, overcoming any constraints and problems can be faced up. Through the years and as research on 3d city modeling growing up, indoor navigation studies directed their attention on how to detach the need for indoor navigation applications data from existing building data models, in terms of interoperability. Interoperability is a desired characteristic of a standard, which allows the exchange of information between different standards, as each standard interface is completely understood from the other and can have access to it without any restrictions.

In order to develop a customized building model suitable for use in indoor navigation, a structured process needs to be established to capture the main requirements for this purpose. Requirements are detected through identified use cases and test cases developed to ensure that a customized or extended building model can be used for indoor navigation scope.

Consequently, the main requirements for the development of an indoor navigation model will be analyzed as well as related work will be presented.

1.1 Indoor Navigation Definition and Background

Indoor Navigation is a specific application for building models and provides multiple additional challenges to general-purpose building models (Brown et al., 2012).These challenges concerns different tasks like localization, route planning and route homing, different types of environment such as airports, hospitals, underground stations, different types of users like people/group with total, limited or no access to specific areas, different types of modes of locomotion like pedestrian on foot or pedestrian in wheelchair and different type of scenarios like emergency situations.

In general, three are the main components of navigation, which are the following:

- determination of the location of a subject or object,
- determination of the best path (often the fastest, the shortest, or the cheapest) from a start to an end location, and

- Guidance along the path which includes monitoring of the difference between the current position and the path and enforcement of appropriate actions to minimize the difference.

According to Li et al., (2008), the general functional requirements for navigation are multidimensional, covering three levels. Level 1 is space level, including microscopic sub-level, mesoscopic sub-level and macroscopic sub-level. Level 2 is information level, containing six sub-levels, namely temporal information, spatial information, content information, data type information, data format information and navigation control information. Level 3 is service level, requiring four sub-levels, namely accuracy, rapidness, adaptability and convenience. Indoor navigation apparently belongs to the first level and microscopic sub-level, which represents space in 3 dimensions.

The two most important required elements for the development of a 3D indoor navigation model are: accurate topological information that is necessary for network analysis and semantic information which is necessary for routing.

More specifically, an indoor navigation model should have at last the four following characteristics:

1) Be semantically rich: semantics are related to useful navigation information and supports the required knowledge to facilitate automation of navigation model generation.
2) Generate automatically the network from original geometry: navigation network should be automatically derived from any 3D geometry representation of a building. Constant indoor environment changes should automatically and in real time update network in order navigation model to be able to face emergency situations.
3) Have dynamic routing capacity: evacuation system should consider the environment changes, re-computing and predict alternatives routes in case of emergency situations.
4) Be aware of door to door movement: door to door navigation is implemented to path-finding as it insists the most natural movement.

1.1.1 Geometric Modeling for Indoor Environments

Every relevant topographic object of building space has a shape, extent, position and appearance that can be measured and modeled. The abstraction of the real world can be described by geographical features and represented in 3D space. Using the concepts of metrics and metric spaces the geometry provides the means for the quantitative description of the spatial characteristics of features.

A metric space is defined as: Let X be a set and d a real value. A mapping $d : X \times X \rightarrow IR$ is called a metric, if for all elements x, y and z from X the following axioms are fulfilled:

- $d(x, y) = 0$; if and only if $y = x$
- $d(x, y) = d(y, x)$
- $d(x, y) + d(y, z) \geq d(x, z)$ (Triangle inequality, for x, y, z in X)
- $d(x, y) \geq 0$

Then, *d* is said to be a *metric* on X; (X, *d*) is called a metric space and *d*(x, y) is referred as the distance between x and y.
The international standard for geographic information, ISO19107, provides conceptual schemas for describing and modeling real objects as features. The included geometry package contains various classes for coordinate geometry. The object's spatial position is defined of the type of coordinate system by mathematical functions which are used for describing the geometry of an object. A subset of the metric space is the well-known Euclidean Space, with the Euclidean distance as a metric. In the general case of the n-dimensional space IR n, the Euclidean distance is defined between two points or vectors by the Euclidean norm of the difference vector between these points.

$$d(x,y) = |x-y| = \|x-y\|_2 = \sqrt{(x_1-y_1)^2 + \text{L} \ + (x_n-y_n)^2} = \sqrt{\sum_{i=1}^{n}(x_i-y_i)^2}$$

The Euclidean Space is used to model real world objects like buildings and their interiors in the field of CAD (Computer Aided Design), computer graphic, IFC (Industry Foundation Classes) or CityGML, by using cartesian coordinates. 3D objects modeled in Boundary Representation (B-rep), e.g. as it is realized in CityGML, are geometrically represented by its boundary surface in IR3. Using geometric primitives, such as vertices, edges, and faces, allows more flexibility for modeling irregular geometric objects. The interior rooms of a building are represented as volumes in Euclidean space by boundary representation.

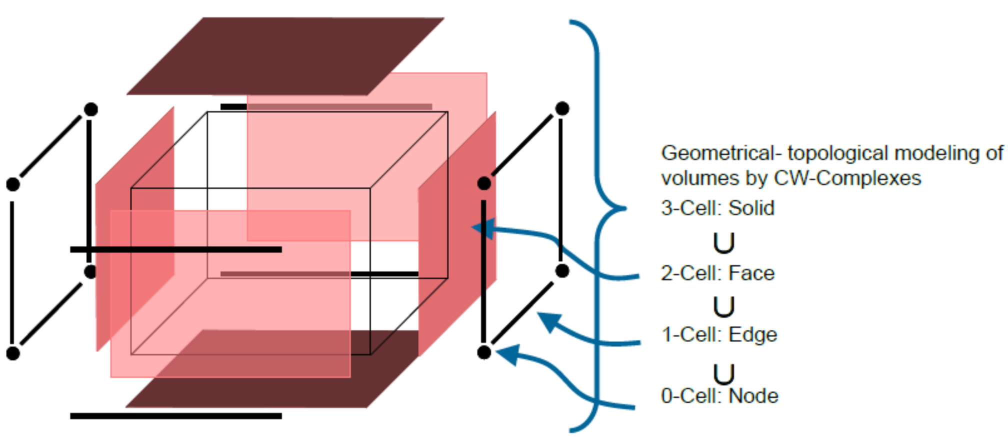


Figure 1.1 : Representation of a 3D-Solid by B-Rep in Geometry and by CW-Complexes in Topology
Source : Requirements and Space-Event Modeling for Indoor Navigation, Nagel et.al, 2010

Since the Euclidean space is a metric space, a natural topology such as neighborhood, interior, outer and boundary is induced. In case of transforming geographic information from one geodetic reference or coordinate system to another, geometry will be changed but topology relationships will be constant to any transformation process.

1.1.2 Topological Modeling of Indoor Environments

Geometric calculations such as point-in-polygon strategies, adjacency and boundary are computationally intensive. Therefore, combinatorial structures, known as topological complexes, are constructed. Computational topology provides information about the connectivity of geometric primitives that can be derived from its corresponding geometry. The introduction of a topology allows a unique interpretation of position relations like "nearby" and "tends to" on quite general structures. A topological space is a set X consisting of subsets T (called open sets) from X, if the following axioms are fulfilled:

- The empty set and the basic set X are open sets.
- The intersection of any finite open sets is an open set.
- The union of any open sets is an open set.

A set X together with a topology T on X is called topological space (X, T).Within a topological space every point x has a filter U (x) of surroundings. A subset U of a topological space (X, T) is called surrounding of the point $x \in X$, if an open set O with $x \in O \subseteq U$ exists. Therefore the concept "Nearby" can be specified mathematically. An open subset $U \subseteq X$ which contains x is called (open) surroundings from x. The open surroundings determine the topology (that is the family O of the open sets): a set is open if it contains surroundings to each of its points.

The topological model is closely related to the representation of spatial relationships among objects in geographic phenomena. The geographic phenomena are mostly geometrically represented in Euclidean space by Cartesian coordinates in IR3 and this metric space induces a natural topology. Therefore, the metric defines topological relationships like adjacency, interior, outer, and boundary between objects, e.g. spaces relating to a building. To describe those topological relations, e.g. closure, interior, boundary, separated, and connected, in conjunction with Euclidean distances, the concept of CW-complexes can be applied. This concept is based on a n-cell classification where n denotes the dimension of the cell. 0-cell represents a vertex, 1-cell a line or edge, 2-cell represents a face and 3-cell is a solid. The cells do not need to have the same size but they will all be of some limited range of sizes according to the used granularity of space.

A conceptual schema for this purpose is defined in the topology package of ISO 19107. The topological system of ISO 19107 is based on algebraic manipulations of multivariate polynomials. The package is defined in a way that geometric problems can be translated from geometric part into algebraic problems in the topology part. Problems can be solved in the topology domain and then translated back.

Topology is the most necessary information for a navigation model as it defines adjacency and connectivity between objects. The most 3D data models such as CityGML or IFC do not employ the topology package of ISO 19107 due to its complexity, but they derive the topological relationships between objects from their geometrical representation. More specifically, these models induce natural topology of objects which are represented in boundary representation (i.e. the result of an intersection of two faces is an edge). CityGML implements topology by using the XML schema of XLinks provided by GML which is simpler than the topology package of ISO 19107. The disadvantage of this process is that topology queries can only be performed in one direction. However, ISO 19107 topology model could be derived from a CityGML dataset.

1.1.3 Semantic Modeling of Indoor Environments

The new applications of 3D city and building models such as urban planning and facility management, disaster management and indoor navigation require additional information about buildings except from geometric and topology information. In particular, the ontological structure includes thematic classes, attributes, and their interrelationships such as specialization and aggregations hierarchies that have to be defined. Semantic modeling indicates the decomposition of objects into parts based on logical criteria and not on geometrical and topological. This thematic categorization of objects will be the basis for addressing, route descriptions and route tracking in indoor navigation model and also delineates the natural spatial reference system of the user for naming of start and end points. Nowadays, the most well-known international building model standards such as CityGML and IFC, provide geometric, topologic and semantic information of buildings and their interior areas.

1.1.4 Subspacing and Sensor space Navigation Model

In semantic 3D building models, the free space within buildings is modeled by non-overlapping room objects. This representation is appropriate to derive a room-to-room connectivity graph. However, Lorentz et.al., 2006 proposed a different decomposition of the semantic room entities, in which the room itself is geometrically fragmented into cells, that are again represent non-overlapping parts of the room. Based on the topological relationships of the resulting cells, a cell-to-cell connectivity graph can be derived by Node-Relation structure and more specifically with the application of duality transformation.

The correct space subdivision and its dual cell-to-cell representation are extremely important for emergency situations. The figure 1.2 illustrates connectivity graphs for the emergency situation of fire, the left figure for rooms and the right for a part of a room. In figure 1.2a) no further partitioning is applied to the topographic room objects and the corridor, whereas in 1.2b) rooms and corridor are subdivided into disjoint cells representing partially accessible passages of the corridor with respect to adjacent doors.

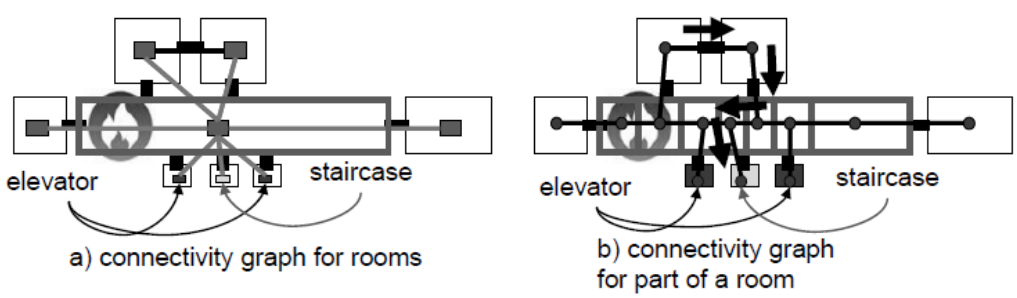


Figure 1.2: Spatial Decomposition of rooms

Source: Requirements and Space-Event Modeling for Indoor Navigation, Nagel et.al, 2010

The task within this fire scenario is to find an evacuation route from the upper left room to the staircase. As a constraint for the modus of navigation, rooms affected by fire, i.e., the left part of the corridor, are marked as non-navigable. Based on the room-to-room connectivity graph, this task cannot be performed since the corridor is only represented by a single vertex in the dual graph and is completely marked as non-navigable. However, the semantic decomposition of the corridor into single cells allows for its dual representation by several vertices. Since only two cells are affected by fire and thus marked as non-navigable, a valid escape route can be computed based on the cell-to-cell connectivity graph. The affected by fire cells are denoted with black arrows in figure b.

Smaller units of topographic space and the corresponding semantic decomposition of room objects could provide all the necessary means for a more accurate indoor route planning. The semantic decomposition of room is not implemented to NRS process, but it is proved to be effective in emergency situation such as the example of fire, as it allows a more detailed planning of escape routes.

Furthermore, the single partitions can be individually addressed by sensor-based positioning and tracking systems to provide a more accurate location of moving subjects or objects. Lorenz et al. 2006 described such a system by integrating a Wi-Fi sensor model using so-called fingerprints. Fingerprints represent measurements of the signal strength of Wi-Fi transmitters at discrete locations within a room. The cell decomposition of the room is performed based on different fingerprint measurements which are modeled as attributes of room cells. This approach on the one hand allows localization within rooms, on the other hand faces substantial disadvantages. Since the partitioning of topographic Euclidean space follows the characteristics of sensor space, there is no separation of the different space concepts any more. Instead of a spatial partitioning of topographic space according to geometrical, semantic or rule-based aspects, the decomposition is decisively influenced by the sensor model, e.g., by the received signal strength of the transmitter or signal source.

Both space representations cannot be modeled individually, as changes to building topology or sensor configuration would both affect the entire structure. Moreover, the integration of another kind of sensors or transmitters, will introduce difficulties and complexity in the modeling process, since the same room cell in topographic space could be covered by various overlapping sensor propagation areas, e.g., based on Wi-Fi signal strength and RFID signal strength.

1.2 Indoor Navigation Requirements

As it was mentioned above, indoor navigation is not as evolved as outdoor navigation and therefore there are many challenges to face. Absolute positioning and localization methods like GPS are usually not available in indoor environments and route planning requires geo information methods. The term navigable space is not only referring to the physical built environment but also to the mode of locomotion of the moving object and the logical navigation constraints such as security zones and opening hours. Spatial reference systems are required both for the localization method and for the end-user.

The efficiency of an indoor navigation system depends on the accurate and updated geometry and semantics of building, the correct indoor positioning, the flexibility of navigation routes concerning human characteristics and specificities and the absolute knowledge of threats and building accessibility. In order to achieve the development of a well-structured and efficient navigation model, researchers have specified some basic requirements that concern all the different stages of the development process.

1.2.1 Topographic Space Requirements

As it is mentioned above, topological elements play a very important role in indoor navigation systems and also the quality of topological information impacts on the indoor navigation model accuracy. Before the establishment of a topological structure of a building for the indoor navigation model, there are some components that should be firstly defined, as the minimum topological element for a good graph representation of a building, the connection of semantic information into the derivation processes of a graph, the algorithm that suits more to the automatically generation of a graph.

Conceptually, the complicated inner spatial relations between 3D entities (such as room) is represented by Node-Relation structure with the support of Poincare Duality theory, which treats a 3D entity as a topological node and the shared face as a topological link (Lee 2001).This strategy is acceptable when every two neighboring entities are logically connected by an entrance, for example, there is a door or window between the two entities. There are one or more numbers associated with each edge or node of a graph, and these numbers might represent distances, costs, reliabilities, times, or other relevant parameters(Evans &Minieka 1992).

The topological relations inside a building are defined by the Node-Relation structure, with the support of semantic modeling. Meijers et al., (2005) presented a semantic model representing 3D structuring of interiors to be used for an intelligent computation of evacuation routes. The model consist of two levels (polygon and section), which take into account the possibilities to move through buildings. In presented approach, the graph considers only end section (only with one entrance/exit), granting polygon and connector section (with more than one entrance exit). The process for semantic modeling for a topological element contains three basic rules: 1) an end section maps always to a node, 2) a granting polygon maps always to an edge, 3) a connector section maps to a graph. However, these classifications should be well-balanced by its application domains. For example, a one-door room can be treated as an end section in normal indoor navigation but it may change as a connector section in emergency indoor navigation, because it is possible for a people escaping out into its neighboring room from a window.

Some more topological requirements for the development of a well-structured and efficient indoor navigation model are reported below. An indoor environment should capture the general semantic information for a specific building and be represented by all spaces belonging to this indoor environment. This is needed in route planning, as all space objects belonging to a specific building should be identified in order to be used in routing algorithms. Also, all spaces that insist an indoor environment should be semantically and geometrically represented in order to define the spatial properties of physical spaces and to be able to get decomposed for different modes of locomotion (e.g. user in a wheelchair). One more topological requirement is that all spaces belonging to an indoor environment should be categorized according to specific pre-defined space types and be able to be decomposed into smaller space parts in order to be defined the start and the end for a route. Moreover, additional semantic attributes should be recorded to all indoor spaces, as routing algorithms often require that additional semantic attributes for their implementation. Concerning leveling, storey within an indoor environment should be represented and associated to all spaces belonging to a specific storey within an indoor environment as well as storage of semantic information for the function, usage and occupants of an indoor space should be defined, in order routing algorithms be able to compute routes for start and end points that are located on different floors. Also, all indoor spaces and sub-indoor space parts should be able to be geocoded, not only for routing finding inside an indoor environment, but much more for the connection of indoor and outdoor space.

Moreover, specialized types of indoor space should be used to differentiate levels of connectivity of indoor spaces and also specialized types of connecting space with specific semantics should be used for vertical and horizontal and fixed, assisted and transfer connecting spaces, e.g for a staircase, the number of stairs and the type of staircase if it is navigable for people with wheelchair.

Concerning the obstacles inside a building, transfer spaces should be separated into both physical (e.g. door or window opening spaces) and virtual opening spaces (e.g. airport security gate) for which specialist attributes can be defined. Virtual opening spaces are required when no physical boundaries exist between indoor and outdoor spaces. A virtual opening could define the potential access points into an indoor environment. Indoor obstacle spaces should be semantically categorized as fixed, movable and dynamic obstacle spaces, with physical attributes representing the spatial extent, supporting weight, persistency, current state and scenario type.

Also, fixed position obstacle spaces will have semantics defining the surface material and specialist semantics defined for interior and external walls, floors, ceilings, stairs, ramps and general fittings. The surface material of a floor surface is required to determine the suitability of a floor surface for use by a wheelchair user. Movable obstacle spaces will have semantics including physical weight and specialist semantics defined for windows, doors, furniture, and construction work. A movable furniture obstacle requires physical weight and bother attributes to determine the ability of movement of this obstacle by different user groups. Finally, door and window semantic information representing the type, the opening mechanism, the sub-parts, the directionality of opening, the current state, the accessibility (users with access, times of access, access type and direction) and usability in scenarios, could be additional information to the routing algorithm for a more accurate and flexible indoor navigation system.

1.2.2 Different Navigation Contexts Requirements

Indoor navigation comprises route planning as well as localization and tracking of moving subjects or objects within interior built environments. Both aspects of indoor navigation depend to a great extent upon the context of navigation which is constituted by three main factors:

- mode of locomotion of the moving subject or object such as walking, driving (e.g. using a wheel chair, mobile robots) which defines and restricts the navigable topographic space.
- context of navigation, which is determined by logical contexts representing pre-knowledge or navigation constraints which result from specific application domains.
- localization technique and the localization infrastructure.

Amongst others, this comprises the methods used for localization and tracking, the positioning and ranges of sensors and transmitters, and the technical characteristics and capabilities of end-user devices. The support of different contexts of navigation leads to a configuration problem with a high degree of combinatorial complexity. Current models for indoor navigation often reduce this complexity by tailoring the context of navigation to either one specific configuration or a limited subset. The interior built environment is partitioned due to one mode of locomotion and the corresponding route planning and addressing criterions and considering a given localization technology and its sensor characteristics. Often a geometric route network for indoor navigation is proposed, which maps the resulting subdivisions of indoor space to a graph structure representing topological connectivity. Further navigation relevant aspects of the fixed navigation configuration are introduced into this graph as a set of homogenous attributes for nodes and edges. While these approaches are well suited for a single configuration, they lack the flexibility to support multiple contexts such as additional modes of locomotion or different localization techniques. Thus, the support for multiple and different navigation contexts is an essential requirement for a general indoor navigation standard.

1.2.3 Modeling of Interior Spaces Requirements

An indoor navigation standard must be complementary to existing 3D semantic building models and standards, such as OGC CityGML, IFC, X3D, or ESRI BISDM, in order to avoid duplicating existing concepts for the representation of interior built environment. Moreover, in terms of interoperability, the reference and the absorption of the original 3D building models in one of above formats should be supported, while indoor navigation standard should not be restricted to 3D models but also be connected to 2D floor plans.

Current standards for semantic building models often employ a hierarchical aggregation concept which allows for the semantic and geometric decomposition of a building into storeys which again are decomposed into rooms and hallways. This aggregation hierarchy and decomposition of features into smaller parts reflects the structural and spatial assembly of the built environment. Beyond the physical built structure, rooms may further be subdivided due to specific aspects of the navigation context such as the mode of locomotion or logical navigation constraints, but may also be induced by limited propagation areas of sensor-based positioning systems. Different topographical and logical decompositions may constitute different subsets of a room and therefore a separation into hierarchical grouped layers is reasonable. Routing algorithms often employ hierarchical strategies. Therefore, an indoor navigation standard should support hierarchical grouping of spaces in order to facilitate a separation of spaces due to topographical (e.g. modes of locomotion) and logical (e.g. security zones) aspects and the implementation of effective routing algorithms.

1.2.4 Extensibility Requirements

Indoor navigation is subject to multiple influencing factors. New technologies for indoor localization are developed, additional modes of locomotion might have to be considered, and any kind of knowledge may be modeled as logical space restricting the navigable space. Therefore, an indoor navigation standard has to be extensible in order to meet future requirements. This comprises an extension mechanism to augment the standard in order to model and exchange data with different standards. But it also addresses a future integration with outdoor navigation in order to define a general framework for seamless navigation in indoor and outdoor spaces.

1.3Existing Indoor Navigation Models

There are several indoor models that have been found in current literature. These models require a detailed topographic space model including both semantics and constraints, in order to meet the requirements mentioned in the above sub-section. In consequence, existing indoor navigation models are featured in detail, reporting their advantages and disadvantages by their implementation occasionally.

1.3.1 The Node-Relation-Structure (NRS)

The Node-Relation-Structure (NRS) was proposed by Lee and constitutes a data model for representing spatial relationships between 3D spatial entities in built-environments such as buildings by resolving complex geometric computational problems differently from current topological models representing local neighborhood relations. These relationships, i.e., adjacency and connectivity relations, are directly derived from 3D geometry and topology of the interior entities. The NRS represents the spatial relations by two data models. One is a combinatorial data model (CDM), which is a logical data model to represent topological relations of 3D objects, while the other is a geometric network model (GNM) to implement spatial accesses in the NRS using searching path algorithms. The geometric network model for the NRS is constructed by converting the combinatorial data model representing the connectivity relationships between 3D entities.

The CDM is conceptualized by three basic elements, which are: a)Poincaré Duality, b) graph theory and c) multi-scale data representation.

Poincaré Duality is implemented to the structure of NGR In order to simplify the complex spatial relationships between 3D entities, which transforms '3D to 2D relations' in primal space to '0D to 1D relations' in dual space. Because the CDM consists of 0-cells and 1-cells, the model is utilized by graph theory. Using graph methods, the sub-graph of the NRS is consolidated to a high-level node, which is called a Master_node for hierarchical data representations.

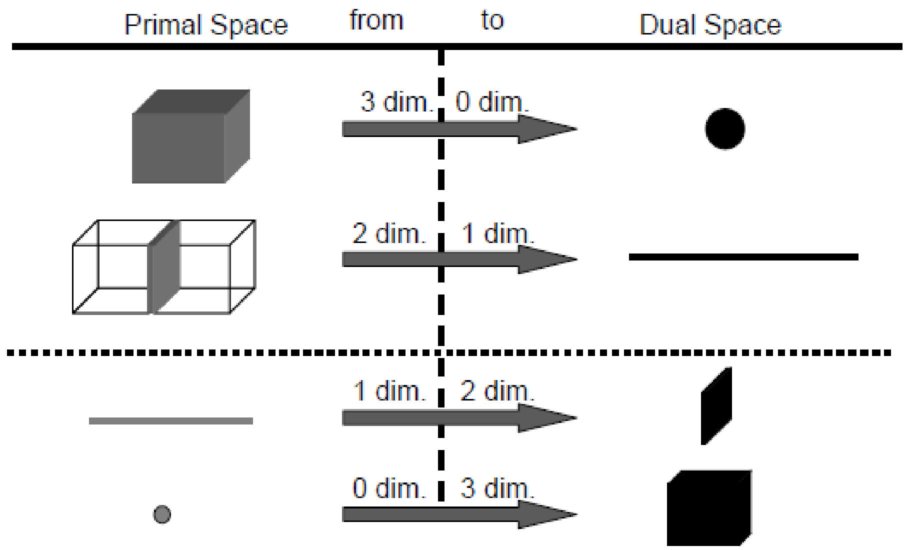


Figure 1.3 : Poincare Duality Principles

Source: Requirements and Space-Event Modeling for Indoor Navigation, Nagel et.al, 2010

In order to achieve a multi-level data representation, 3D spatial queries are implemented in the NRS based upon shortest path operations. Also, the combinatorial network model represents the connectivity relations should be transformed into the geometric network model. The most important point in this process is to identify linear features from a simple polygon by using Medial Axis Transformation.

Using the straight medial axis transformation, the hallway is transformed into the linear features. Each node representing 3D spatial units is projected and connected onto the medial axis if there is a connectivity relation. The time required for the projection of each node onto the linear features is O(nm), where n is the number of nodes and m is the number of edges in the medial axis. Using the reconstructed geometric network model, therefore the complex topologic relations among 3D spatial objects are analyzed.

The NRS system is designed as a module to be a major component of 3D GISs in the Visual Basic development environment for implementing the NRS. The NRS system consists of two major modules, which are Data Generation Module (DGM) and 3D NRS Implementation Module (3D-NRSIM).Finally, NRS system is used for the analysis of the complex connectivity relationships among 3D objects in built-environments through several routing algorithms, in an efficient way.

Since the resulting combinatorial model only represents topological relations, it does not contain metric information. However, metric information is needed for 3D spatial queries in the NRS in order to compute the shortest path operations. In this way, a complementary geometric network model is derived in Euclidean space by applying mathematical skeletonization algorithms and centroid calculations to the3D spatial objects. A geometric and topological network model could be established based on both graph representation. This model could be also used for 3d complex spatial queries.

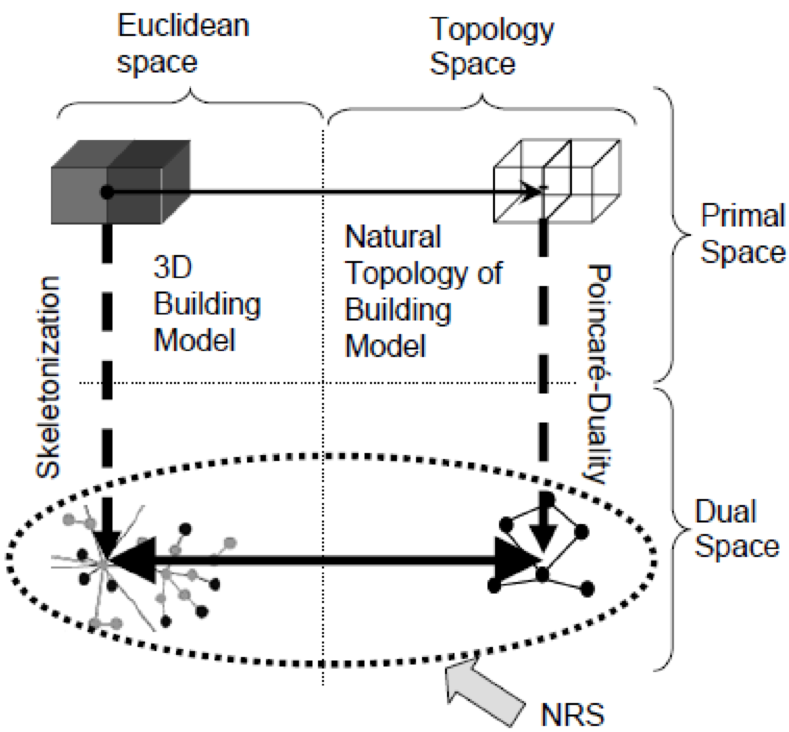


Figure 1.4 : Schematically representation of Lee 's approach

Source: Requirements and Space-Event Modeling for Indoor Navigation, Nagel et.al, 2010

The above figure illustrates the approach of Lee for topological and geometric representation for the implementation to an indoor navigation system. More specifically, this approach separates distinctly the primal space from the dual space on the one hand, and geometry and topology on the other hand.

To conclude, the NRS data model supports the implementation of indoor navigation systems, e.g. in the context of emergency response, since the complete indoor environment of a building is described by a graph with an embedding in IR3. This graph represents not only topological adjacency and connectivity relationships between spatial objects but also metric information for the computation of shortest path.

1.3.2OntoNav

The OntoNav system was introduced by Anagnostopoulos et al., (2003) and describes a semantic indoor navigation system. It proposes an indoor navigation ontology which provides semantic descriptions of the constituent elements of navigation paths such as obstacles, exits, and passages.

Furthermore, specific user capabilities/limitations are modeled allowing for a user-centric navigation paradigm and the application of reasoning functionality.

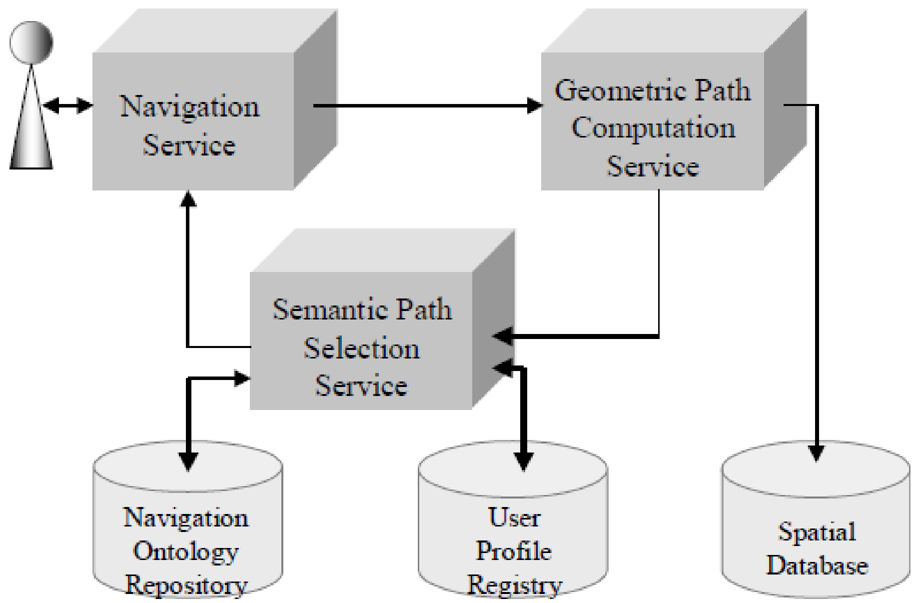


Figure 1.5 : OntoNav Architecture
Source: Anagnostopoulos et.al OntoNav: A Semantic Indoor Navigation System,2003

The above figure illustrates the system's architecture and its basic components are the following:

- **Navigation Service (NAV):** is the main interface between the user and the system. It receives users' requests for navigation and responds with the requested path (if any), in a form tailored to each user's special characteristics (perceptual, physical and other preferences). The Navigation Service aggregates the Geometric Path Computation Service (GEO) and the Semantic Path Selection Service (SEM) and can also be interfaced, depending on the deployment configuration, with other systems such as user authentication or directory services and ontology repositories.
- **Geometric Path Computation Service (GEO):** is the responsible service for the computation of all the geometrical paths from a user's current location to a specified destination (Point of Interest, POI). Therefore, it utilizes a spatial database, where the building's ground plans are stored. Navigation paths are computed by a traditional graph-traversal algorithm on a graph representation of stored geometry. The paths that are computed by the searching algorithm then are sent to the SEM Service for further filtering based on the user characteristics and routing preferences.

- **Semantic Path Selection Service (SEM):** is the main service providing functionality of system and is responsible for the selection of the *best traversable* navigation path among those established by the GEO service. The selected path is the one that corresponds to all the capabilities and preferences of the user and it is, thus, selected based on predefined rules and on a user profile registry, which contains these user capabilities/preferences. This task is achieved with the aid of a navigation ontology which enables the required reasoning: path selection according to the physical capabilities and routing preferences of the user, and selection of the proper navigation guidelines (anchors), according to the physical and perceptual capabilities of the user.

Concerning the semantic model of the proposed navigation scheme, which is based on semantic descriptions of the constituent elements of navigation paths, it should enable reasoning functionality. An Indoor Navigation Ontology (INO) was established, which suits both the path searching and the presentation tasks of a navigation system. Figure 1.6 depicts a core part of this ontology.

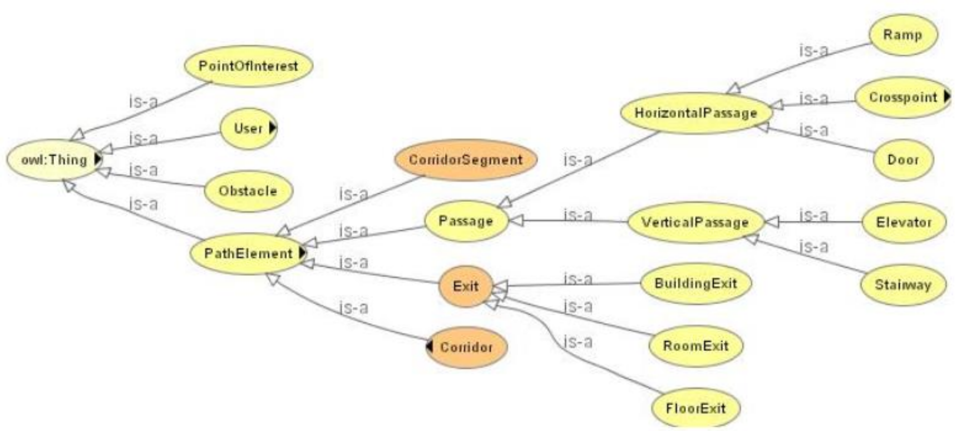


Figure 1.6 : Indoor Navigation Ontology
Source : Anagnostopoulus et.al, OntoNav: A Semantic Indoor Navigation System,2003

The main components of the established ontology are following :

- **User**: this concept represents the users of the navigation service, which have specific physical and perceptual capabilities/constraints. A (incomplete) classification of users is: blind, physically handicapped, children, elderly people and "normal" users. Additionally, a user could be classified according to her navigational status (e.g., deviated from a path, lost etc.).
- **PointOfInterest**: any physical or virtual location or object, which may be of interest to a user (e.g., room, printer).

- **Passage**: any spatial element that is part of a path and has specific accessibility properties. Passages are categorized to *horizontal* (connecting corridors in the same floor) and *vertical* (connecting corridors in different floors). The main types of vertical passages are elevators and stairs, while the main types of horizontal passages are wheelchair ramps, doors, and crosspoints.
- **Exit**: an exit or entrance of an indoor region. Such region may be the whole building, a floor, or a room.
- **Obstacle**: anything that prevents the passage of the user. That definition includes a) physical objects whose dimensions (width and height) block a corridor or passage, b) certain properties of exits or passages (e.g., closed door, non-operating elevator), and c) other non-permanent conditions which prevent the passage of the user (e.g., security policies, a deluge of people in a space that makes difficult the passage of blind people, etc). The latter type of obstacles is very important as it enables the definition of dynamic and non-physical obstacles.
- **CorridorSegment**: the concept of a corridor segment is a construct devised to facilitate modeling and it is derived by the geographic graph of paths. A CorridorSegment connects exits and/or passages.
- **Corridor**: a corridor is comprised of corridor segments, which connect two crosspoints or a vertical passage and a crosspoint. A corridor can contain points of interest (POI) and obstacles.
- **Anchor**: any passage, exit or POI included in a path that can aid the presentation of the navigation plan. Anchors cannot be movable objects. Examples of anchors are: crosspoints, doors, stairs and ramps. Thus anchors are mainly structural elements of buildings. However, non-structural POIs could also be used as anchors, e.g. a coffee machine.
- **Path**: a sequence of interleaved corridors, exits and passages, which is capable of getting a user from its current location to a destination location. A *walkable path* is a special path, which can be used by any "normal" user. Apparently the set of walkable paths in an indoor environment is the superset of all other path-sets, which are accessible by specific user classes. The geometric model (graph) of this system represents this superset (walkable paths). A path usually contains several POIs, anchors and obstacles. The subset of them, which will be used for the final user navigation, is defined depending on the user perceptual capabilities.

The combination of the above elements indicates a reasoning process and finally concludes to the selection of the best-suited navigation plan for the user. This process comprises several reasoning and computational tasks which are the following:

1) Task A: determination of the navigation starting point (S') and ending point (E').
S is the current location of the user and E the respective location of the requested POI. These locations are, in general, not represented as nodes in the graph and S and E can be rooms, corridors or passages, while all these types of locations may have more than one exits or passages directly connected to them. A transformation from a point-to-point to a set-to-set navigation problem is implemented for all the combinations of elements of sets S' and E'. These

elements/nodes may not be the actual user or POI locations but are, in general, good approximations of them. Moreover, this approach enables the addition/removal of POIs without affecting the path graph topology.

2) Task B: discovery of all the possible walkable paths that can lead the user from its current location S' to the target Point of Interest (location E').

This process determines (with traditional graph traversal algorithms) all the paths that a user can traverse for each combination of the S' and E' elements. If the set cardinalities are |S'|=s and |E'|=e, the complexity of the search algorithm will be *O(se).* The output of this iterative computational task is a (possibly empty) set of walkable paths. For each walkable path its end-to-end length is also computed.

3)Task C: semantic-driven selection of the Best Traversable Path (BTP**)**.

This reasoning task is a two-phase procedure. During the first phase, reasoning is performed on the instances of the navigation ontology using the *physical navigation rules* and the *routing preferences*.

4)Task D: selection of the anchors across the best traversable path.

Anchors are the elements of the path that are best suited for the presentation of the navigation guidelines. During this process, all the anchors of the selected path are detected and are, then, matched against the perceptual navigation rules and the physical navigation rules. The navigation rules are the ones that define the number and the location of the anchors that should be used in each particular navigation case.

1.3.3 Indoor Navigation in OWS-6

The "Outdoor and Indoor 3D Routing Services Engineering Report" specified in OWS-6 (OGC Web Services, Phase 6) proposed a service-based framework for indoor navigation utilizing 3D building data encoded in CityGML for route planning and the OGC WMS interface for position and route communication.

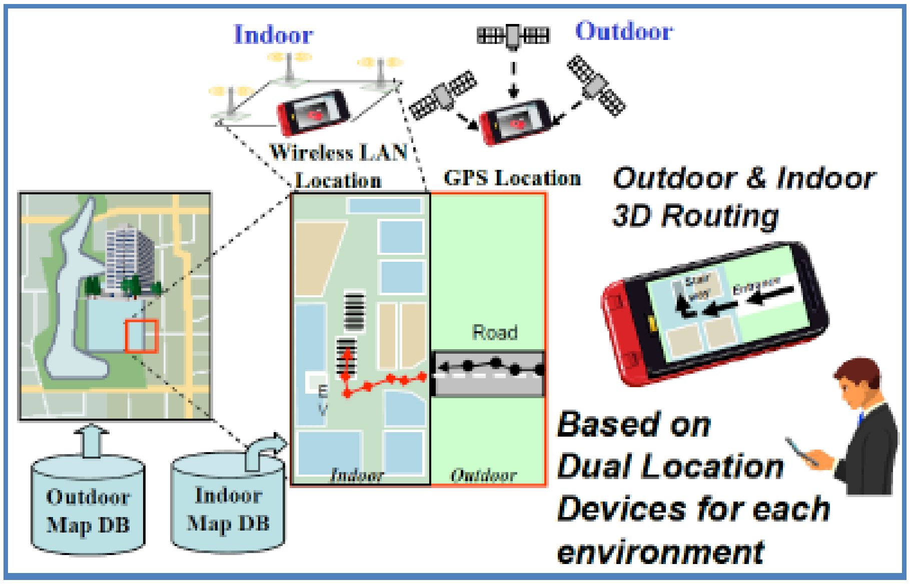


Figure 1.7 : Overview of the OWS-6 Outdoor and Indoor Routing Services architecture

Source :Requirements and Space-Event Modeling for Indoor Navigation, Nagel et.al, 2010

This navigation model is a network topology model which can be derived from 3D building models given in CityGML. Also, it facilitates route planning in indoor areas and subdivides rooms into cells in order to derive the topological graph structure. Each cell is corresponded to a node in the topological graph. Further nodes are introduced at points where two adjacent cells touch and edges denote topological adjacency between the nodes. As illustrated in Figure 1.8,the resulting cell-adjacency graph also has an embedded geometric space.

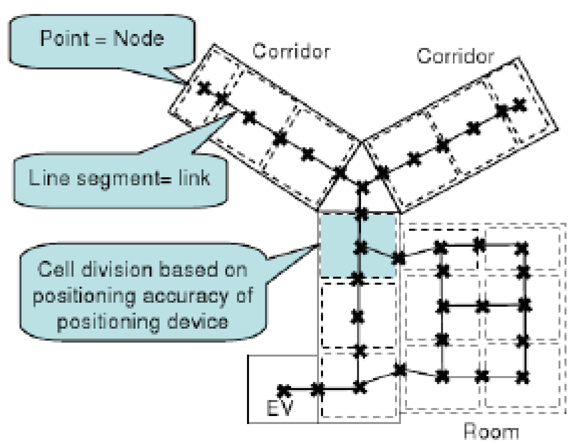


Figure 1.8: Derivation of network topology by the center points of each cell

Source: Requirements and Space-Event Modeling for Indoor Navigation, Nagel et.al, 2010

The partitioning of topographic space into smaller cells is mainly based on the positioning accuracy of the localization infrastructure and the corresponding capabilities of the end-user device. The derivation of the network topology model from building topography is defined in a semi-automatic way and the result is a fixed but non-deterministic graph facilitating routing in a specific navigation context with a predefined and fixed type of locomotion and localization method.

However, the indoor navigation approach proposed in OWS-6 addressed some of the challenges and requirements of indoor navigation models, it faced problems concerning the usage of a fixed localization method as well as the lacking support for additional modes of locomotion and further space concepts like logical spaces including navigation constraints. All the above deficiencies of this navigation model have been considered in the development of the Multilayered Space-Event Model which is also proposed by OGC.

1.3.4 Multi-Layered Space Event Model

The Multi-Layered-Space-Event Model (MLSEM) is a framework defined by Becker et al.(2009a), which defines not only a method to abstract or form graph geometries from primal space (3d objects representing in topographic space) but also a link between those graphs with other graph models. These graphs models could represent different attendant thematic spaces of indoor environment for use in indoor applications. IndoorGML, the new OGC standard for indoor navigation is based on MLSEM concepts, as it is mentioned in detail to the next chapter.

The main characteristic of this approach is the fact that it allows for the decomposition of a specific space into smaller units according to respective semantics, without influencing other space representations. Furthermore, it indicates the connection between layers, i.e., space models, in a well-defined way and derives a valid and unique joint state embracing all linked layers at a given point in time. Based on joint states, e.g., between topographic space and sensor space, the proposed multilayer modeling approach can be utilized to enable localization and route planning strategies. In this framework, alternative space models are represented as separate layers.

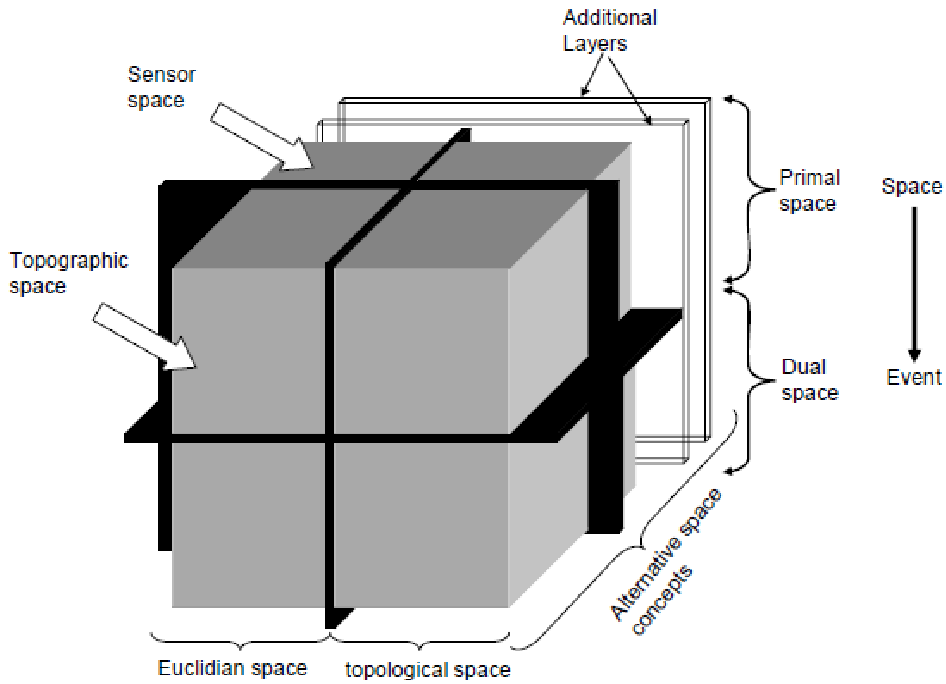


Figure 1.9 : Multilayered combination of alternative space concepts

Source: Becker et.al, A Multilayered Space-Event Model for Navigation in Indoor,2008

The above figure illustrates an example of the proposed modeling framework, with the front layer representing the topographic space, and the back layer the sensor space. Each layer can further be divided into four segments (indicated by black cutting planes). The vertical division corresponds to space representations within Euclidean space respective topology, while the horizontal division indicates primal and dual space. As a result, each space model is given by four distinct space representations.

The separation of layers is not the same for different space models with different partitioning schemas. For example, in topographic space geo-objects such as buildings may be represented using semantic 3D building models, and also semantic decompositions into, e.g., rooms, walls, doors, etc. can be applied within these model. However, the notion of sensor space substantially differs from topographic space. The sensor space is rather decomposed according to signal characteristics such as propagation and signal coverage areas. Besides topographic and sensor space, further alternative concepts of space can be incorporated into the framework by adding additional layers. The number of layers is unbounded. For example, different definitions for space (e.g., movement space, activity space, visual space etc.) can be encountered and can also be used to describe a built environment.

However, the notion of space and its semantic decomposition again differs from topographic or sensor space. Since each layer provides a valid and consistent representation of space, the common framework itself is to be seen as a valid multi layered space representation, which can be used as a whole to describe, for example, the indoor environment of buildings.

For each layer, topological relationships such as connectivity and adjacency relations between 3D spatial objects are represented within topology space. Topology is represented in primal space by the equivalent 3D geometry in Euclidean space, after applying a duality transformation. This transformation is based on Poincaré duality, and the 3D cells in primal topology space are mapped onto nodes (0D) in dual space, while topological relationships between 3D cells are transformed to edges (1D) linking pairs of nodes in dual space. The developed dual graph is a Node- Relation Graph which could also be seen as a state transition diagram.

The active state is represented by a node within the dual graph and denotes the spatial area where the guided subject or object is currently in. Once the subject or object moves into a topologically connected area, another node within the dual graph and thus a new active state is reached. The edge connecting both nodes represents the event of this state transition. Therefore, events are related to the movement of subjects or objects through the explicit topological representation of space. Accordingly, this modeling approach is a space-event model. Under the assumption that the space is subdivided into disjoint areas, exactly one node within the NRS respectively the state transition diagram can be active.

As concerns the representation of topographic space for indoor navigation, it is consisted by the interior environment of buildings and its semantic decomposition into building elements like rooms and doors in order to enable route planning.

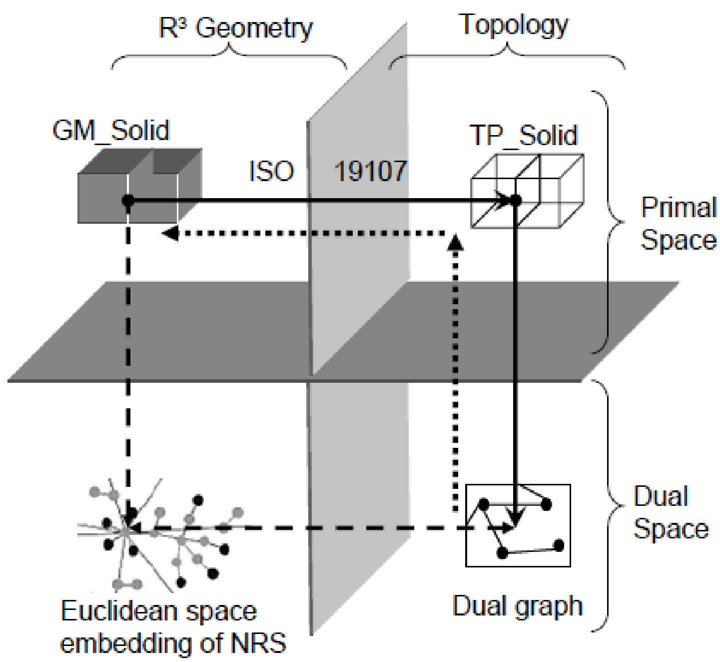


Figure 1.10: Topographic Space

Source: Becker et.al, A Multilayered Space-Event Model for Navigation in Indoor,2008

According to the general space concept of layers, the topographic space can be described by four distinct representations as it is shown in Figure 1.10. The upper left element illustrates the non-overlapping 3D geometry representation of built environment in Euclidean space. This geometry information can be directly derived from IFC and CityGML building models. The upper right element represents the induced natural topology of the 3D spatial objects according to ISO 19107. Since disjoint partitioning of Euclidean space is assumed, the relation between both upper elements can be expressed with the "Realization" association between geometric and topological objects defined by ISO 19107. Accordingly, associated objects in either space must share a common dimension and are related by 1:1 relation.

While the upper part represents the primal Euclidean respectively topology space, their dual representations are depicted by both lower elements. For the lower right part, topology is represented as dual graph based on the NRS model and is derived from topology in primal space by Poincaré duality transformation. The NRS does not contain metric information which is, however, necessary in terms of spatial 3D queries such as shortest path calculation. In order to integrate metrics, one possible solution could be the usage of the methods "representative Point()" and "centroid()" defined for GM_Objects in ISO 19107. For 3D solids, these methods return a point geometry representing the centroid of the volumetric object. This point representation could be stored attributively within the NRS.
Since nodes of the NRS are directly related to TP_Solids in primal topology space, which, in turn, are directly related to GM_Solids in primal Euclidean space, as it is depicted by dotted arrows in figure 1.11, this metric information can be uniquely derived. Furthermore, weights representing, for example, distances between rooms can be assign to the edges of the NRS. These weights could be derived from primal Euclidean space accordingly. The lower left element of the topographic layer finally represents the Euclidean space embedding of the NRS. The dual transformation of Euclidean space results in a geometric network model. This dual graph representation is derived by mathematical functions such as skeletonization processes. The figure below Illustrates an example of the partitioning of building interior into rooms and its representation in dual space.

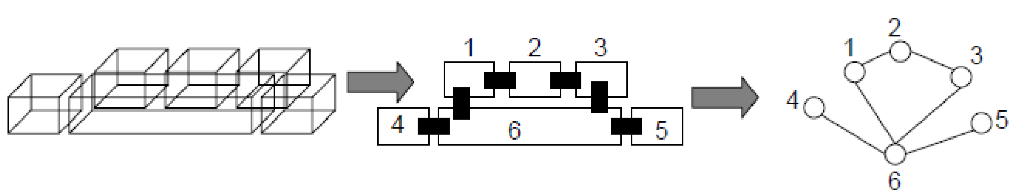


Figure 1.11: Partitioning of indoor space and its representation in dual space

Source: Becker et.al, A Multilayered Space-Event Model for Navigation in Indoor,2008

The concept of space-event modeling allows for consistent specification and interpretation of various space concepts. This ensures equivalent interpretations of sensor space and topographic space. When arranging sensors within a building (e.g., Wi-Fi), transmission ranges may overlap, which requires their decomposition into disjoint regions in order to define unambiguous states. As a state one can define the range or different signal strength areas. The event can be understood as an entry into a sensor area or as the crossing of a certain threshold value.

Like in the topographic layer, the granularity of partitioning affects the accuracy of positioning. Accordingly, the decomposition of space in smaller cells, gains in precision for the navigation applications. Areas with no sensor coverage are defined by an additional state, which called "void". This state is used when the navigating subject or object leaves the range of a sensor without other sensors around, e.g., when leaving the building.

A navigating subject or object can only belong to one cell at a time and thus always only one state may be active. For different space layers with different partitioning, each layer contains such a state transition graph with exactly one active state. The overall state is then given by the joint state of all space models, but only certain combinations of states between different layers are valid. These combinations are expressed by additional edges between the nodes of different layers. These edges are called joint-state edges. The overall structure then constitutes an N-partite graph, where all the nodes from all N layers are included but are separated into N partitions which are connected by the joint-state edges. Furthermore, the graph also contains the state transition (or cell adjacency) edges. The figure below illustrates an example of layer combination. The dashed lines represent state transitions / cell adjacencies within the layers and the continuous lines joint-state edges between different layers.

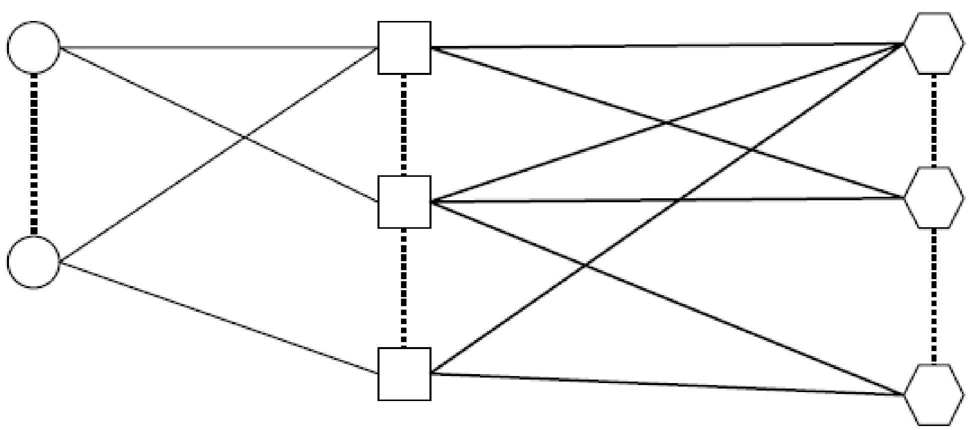


Figure 1.12 : Layer Combination

Source: Becker et.al, A Multilayered Space-Event Model for Navigation in Indoor,2008

The figure below depicts a tripartite graph containing nodes from three layers. Nodes of different layers are connected by joint-state edges. Only one state in each partition can be active and active states must be connected to each other by joint-state edges. The dashed edges represent cell adjacencies within each layer.
The joint-state edges can be automatically derived by pair wise intersection of the respective geometries between different layers. If two cells from different space models do not overlap or

are contained within each other there will be no valid joint-state in which these nodes are active at the same time.

Moreover, except of the combination of nodes of the NRS between different layers, connections between layers of the other three quadrants can also be useful. For example, the connection of the geometries in primal space allows a common 3D visualization within Euclidean space. If geometry is represented according to ISO 19107 in IR^3 the spaces are represented as GM_Solid objects which can be visualized together in one 3D scene. (Figure 1.13)

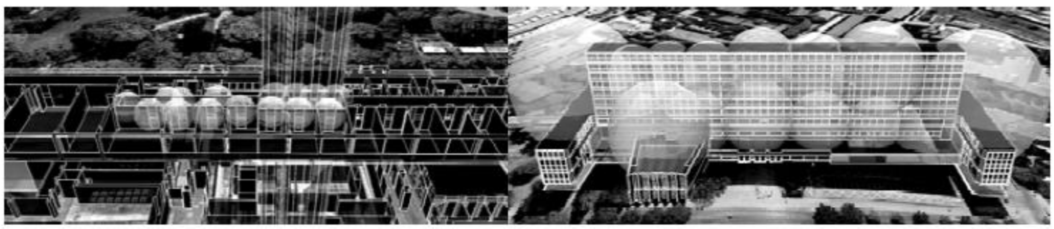


Figure 1.13 :Examples for combined visualizations (left: RFID; right: Wi-Fi).

Source: Becker et. al, A Multilayered Space-Event Model for Navigation in Indoor,2008

The edge between the two NRS denotes the joint-state connection, combining both graphs to the N-partite graph which defines the valid states of the entire model. The existence of this joint-state connection not only allows the determination of relative positions with respect to a sensor, but also the absolute position determination within the sensor and topographic space. The uncertainty about the absolute position in Euclidean space can be restricted to the intersection volume of all 3D cell geometries associated with the active nodes in the joint-state. In addition, the N-partite graph allows also for assessment of localization infrastructure and estimation of location uncertainty with a given building decomposition in topographic space and a given sensor / transmitter configuration in sensor space.

2.IndoorGML

IndoorGML is an OGC (Open Spatial Consortium Consortium) standard for the representation, storage and management of indoor spatial information. It uses an open data model and an XML schema applied in OGC Geographic Markup Language (GML) 3.2.1.IndoorGML is relying on cellular space model, which represents a given indoor space with a set of non-overlapping cells(the main IndoorGML basic space unit) in indoor space. The indoor cellular space is described in IndoorGML standard by four basic features: 1) geometry, 2) semantics, 3) topology and 4) multi-layered space model. In consequence, the background and the requirements as well as the basic features of IndoorGML standard will be presented in detail.

2.1Background and requirements

Indoor space differs a lot from outdoor space and this is mainly due to the complexity of indoor space. The requirements of indoor spatial information varies according two types of applications: 1) management of building components and indoor facilities and2) the usage of indoor space. The first type focuses on building components such as roofs and walls, while the second type focuses on usage and localization of features (stationary or mobile) in indoor space .Many standards that have been released could be implemented efficiently for the first application but are not appropriate for the second application. Such standards are CityGML, an OGC standard for 3D city model as an extension of GML that consists core, appearance and thematic module, and IFC (ISO/TCI184/SC84 2013)an International BuildingSmart and ISO model for recording each construction components of a building.

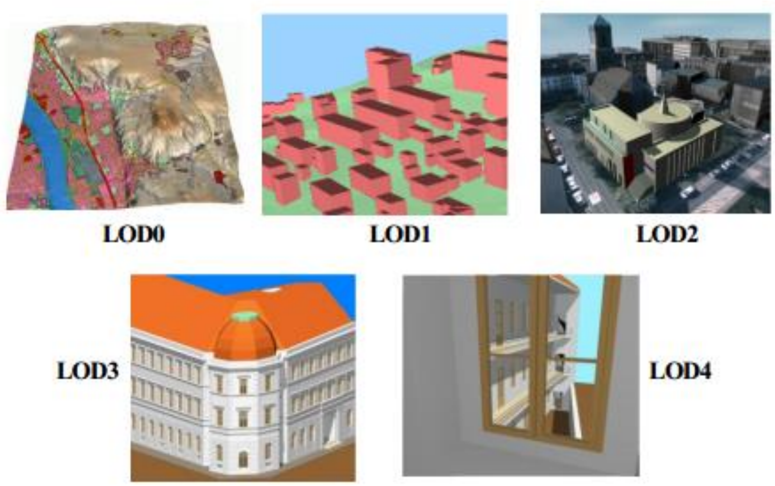


Figure 2.1: CityGML Building model in 5 different LoDs

Source: Kolbe T., Representing and Exchanging 3D City Models with CityGML, 2009

CityGML provides five level of detail (LoDs) for the building model and the last level LoD4 includes the interior spatial objects of the building model (figure 2.1). On the other hand, IFC develops a building model with a construction engineering viewpoint, focuses on texture or material of each interior spatial object. Despite the differences between IFC and CityGML models, both aims to represent indoor and outdoor building components, however they cannot meet the requirements from applications of indoor spatial information. These requirements concerns:

- Cellular spatial representation : indoor space is organized in cells, where each cell has an identifier (namely *c.*ID) such room number rather than coordinates and cells that have common boundary with others never overlap.
- Topology representation : the connectivity, adjacency between two rooms or a room and a corridor is extremely important for the most applications of indoor spatial information
- Multiple representation of a single indoor space: a single indoor space can be interpreted in different ways depending on context and existing information.

The IndoorGML standard aims to meet the above requirements and define a framework of indoor spatial information in order to locate stationary or mobile features in indoor space. More specifically, this framework provides spatial information services referring to positions in indoor space and including also data, instead of representing building architectural components as the above mentioned standards (CityGML, IFC). The two main functions of IndoorGML standard are to represent the properties of indoor space and to provide spatial reference of features in indoor space. IndoorGML was developed in such a way to meet the above mentioned requirements from applications of indoor spatial information and also some more which are:

- Externalreference: since IndoorGML has been established in order to compensate the weakness of CityGML and IFC, it is highly recommended to be able to integrate with CityGML and IFC. IndoorGML should provide a mechanism to reference an object which is defined in another data set or database via external reference. This is happens in terms of interoperability, in order to be able to use and exchange data from one standard to the other.
- Interface between indoor and outdoor: even if IndoorGML has been developed for representation of indoor objects, in some situations it is necessary to integrate indoor and outdoor spaces. Such situations may happen for car navigation services when a car moving from outside to a parking lot in a building.

2.2 IndoorGML Concepts

IndoorGML consists of a core module and an extension module, the indoor navigation module. Core model includes the basic concepts of IndoorGML and it can be extended for a specific purpose of navigation applications (e.g. pedestrians, wheel-chair, and robot). The three basic concepts of IndoorGML and the one concerning the extension module are analyzed below.

2.2.1 Geometric representation

The geometric representation of a 2D or 3D feature in indoor space, it is not of major priority of IndoorGML standard, as they are distinctly defined by ISO19107inCityGML and IFC. Even though, in terms of completeness, geometry of a 2D or 3D object could be optional defined according to ISO19107for an IndoorGML model. According to this, there are three options for the representation of geometry of a cell, the minimum organizational or structural unit of indoor space in IndoorGML :

1)External Reference : the IndoorGML document contains external links (namely c.xlink, where c is a cell in IndoorGML) to objects defined in other data sets such as CityGML or IFC, instead of representing explicitly the geometry of cells in IndoorGML. The referenced objects include the geometric information in external data set and it should be 1:1 or n:1 mappings from cells in IndoorGML in order to be corresponded in other dataset,

2)Geometry in IndoorGML : Geometric representation of cell (namely c.geom, where c is a cell in IndoorGML) can be included within the IndoorGML file by GM_Solid in 3D space and GM_Surface in 2D space as defined in ISO 19107, while solid with holes or surface with holes can also be descripted by the standard,

3) No Geometry: No geometric information is included in IndoorGML document.

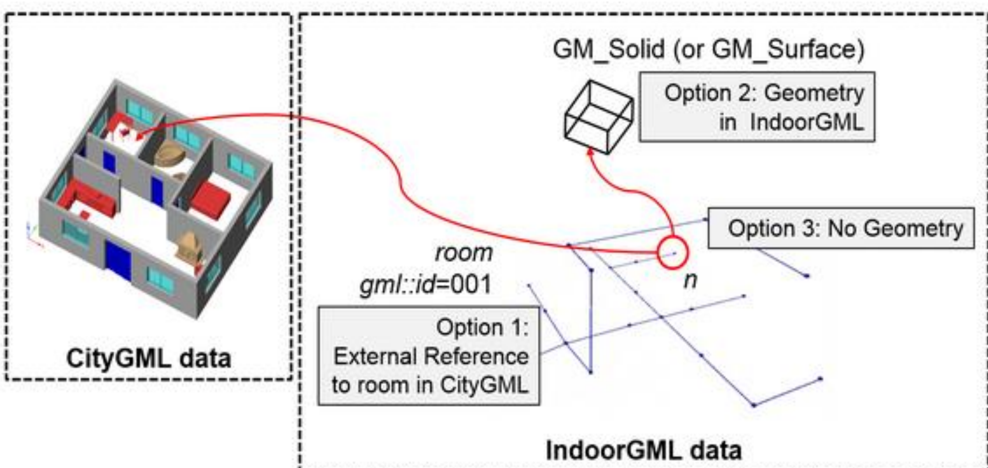


Figure 2.2 : Geometrical Representation of IndoorGML

Source: Lee et al., OGC® IndoorGML, 2015

2.2.2 Topological representation

Topology is the most essential component for every navigation application and for IndoorGML as well. Poincaré Duality and more especially the Node-Relation Graph (NRG) (Lee 2004), represents topological layout of indoor space and reveals the topology of cells in IndoorGML, like adjacency and connectivity, among indoor objects.

In more detail, the NRG allows abstracting, simplifying, and representing topological relationships among 3D spaces in indoor environments, such as rooms within a building. It has no need of geometrical properties and it is implemented as a graph, where adjacency and connectivity relationships between cells are represented. The Poincaré Duality (Munkres 1984) provides a theoretical background for mapping indoor space to NRG representing topological relationships. It simplifies the complex spatial relationships between 3D by a combinatorial (or logical) topological network model.

According to Poincaré Duality, a *k*-dimensional object in *N*-dimensional primal space is mapped to (*N*-k) dimensional object in dual space. Thus solid 3D objects in 3D primal space, e.g., rooms within a building, are mapped to nodes (0D object) in dual space. 2D surfaces shared by two solid objects is transformed into an edge (1D) linking two nodes in dual space.

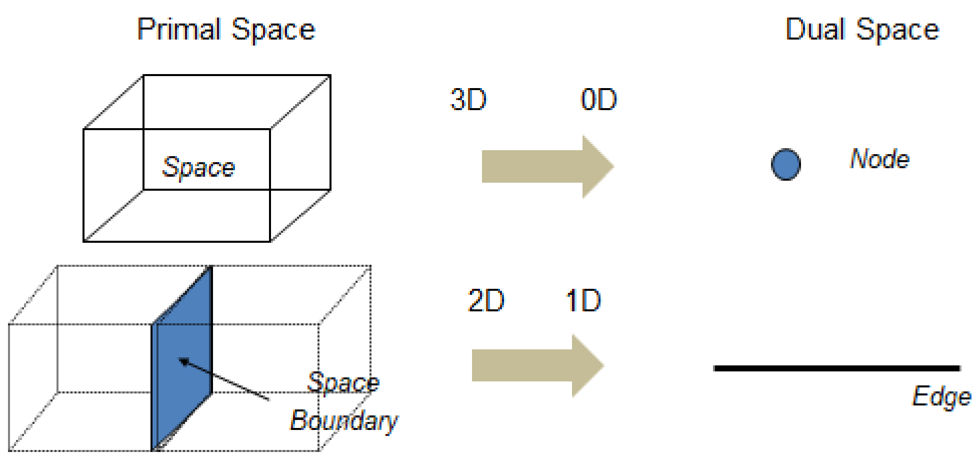


Figure 2.3: Node-relation Graph in IndoorGML

Source: Lee et al., OGC® IndoorGML, 2015

Also, from the topographic indoor space can be derived the adjacency graph and then the connectivity graph which should correspond to the type of edges of adjacency graph. If the edge indicates a boundary of door, then two ending nodes of this edge are connected, otherwise they are disconnected. Moreover, more attributes on edge could be defined for further information such as directions and types of doors (Ki-Joune Li).

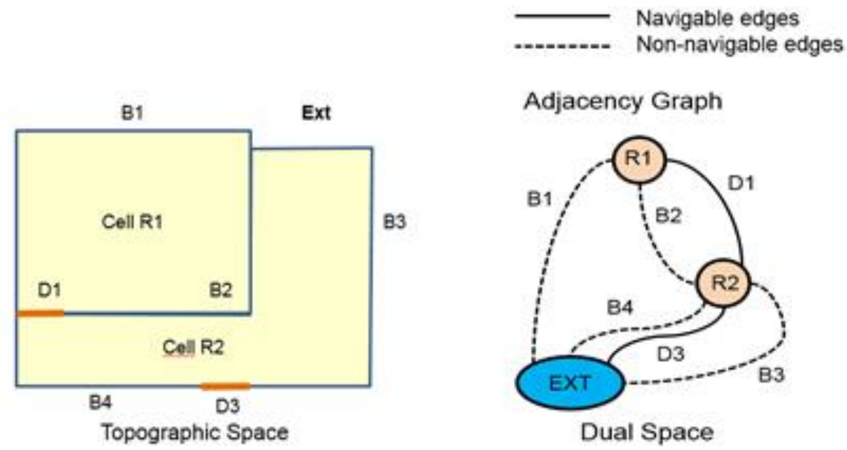


Figure 2.4 : Topographic Space and Adjacency graph

Source: Lee et al., OGC® IndoorGML, 2015

As it is depicted on the above figure, there are three cell spaces including exterior, cellr1, r2. Cell R1 is surrounded with B1, B2, and D1. In dual space, R1 is a node, while B1, B2 and D1 are represented as edge. Passing through d1 is possible, so d1 is a navigable edge, however passing through B2 is not, so b2 is a non-navigable edge.

There are two alternatives for the representation of the graph from primal space into IndoorGML. The first one includes the geometries of node and edge as point and curve respectively and this kind of graph is called geometric graph. The second alternative represents the graph without any geometrical properties and it is called logical graph. The most indoor navigation applications implement the geometrical graph, as they have to compute the routing distance.

2.2.3Semantic representation

Semantic is an important characteristic of cells, as each cell has its usage and function in a particular indoor space. In IndoorGML, semantics is used in order to classify and identify every cell and also underlines the connectivity and adjacency between cells. The classification that semantics provides is of great importance for navigation, as it can indicate and separate navigable cells such as rooms, corridors and doors from non-navigable cells as walls and obstacles.

2.2.4 Multi-Layered Representation

In IndoorGML a single indoor space, as mentioned above, it can be represented by different overlaying interpretations. Each interpretation is considered as a cellular space layer with its own geometric and topological properties. For example, an indoor space is represented as a topological cellular composed of rooms, corridors, and stairs, while it is also represented as different cellular spaces with WiFi coverage cells and RFID sensor coverage cells respectively as the following figure. In plain terms, each semantic interpretation layer corresponds to a different decomposition of the same indoor space and every decomposition forms a separate layer of cellular space.

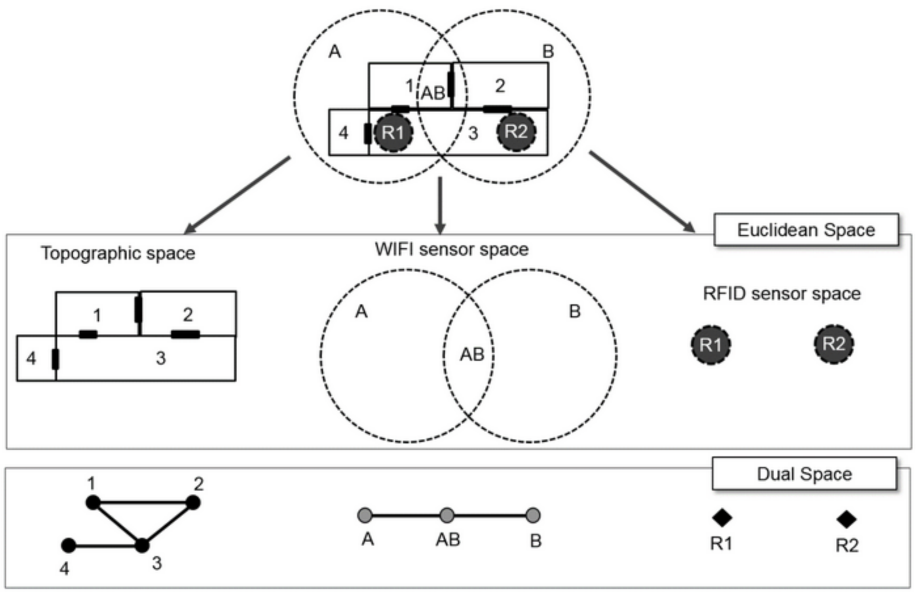


Figure 2.5: Multi-layered Representation in IndoorGML

Source: Lee et. al., OGC® IndoorGML, 2015

2.2.5 Definition of IndoorGML Modules

Each IndoorGML module, core and extension, is specified by an XML Schema definition file and is defined within an individual and globally unique XML target namespace. According to dependency relationships among modules, each module may, in addition, import namespaces associated to such related IndoorGML modules. The IndoorGML core module defines the basic concepts and component of the IndoorGML data model. While the aspects explained in section 2 except semantic modeling are reflected into the core module, extension modules comprise the semantic modeling aspect of IndoorGML. Based on the IndoorGML core module, the extension module contains a logically separate thematic component of the IndoorGML data model. IndoorGML introduces the first thematic extension module, called *IndoorNavigation* module.

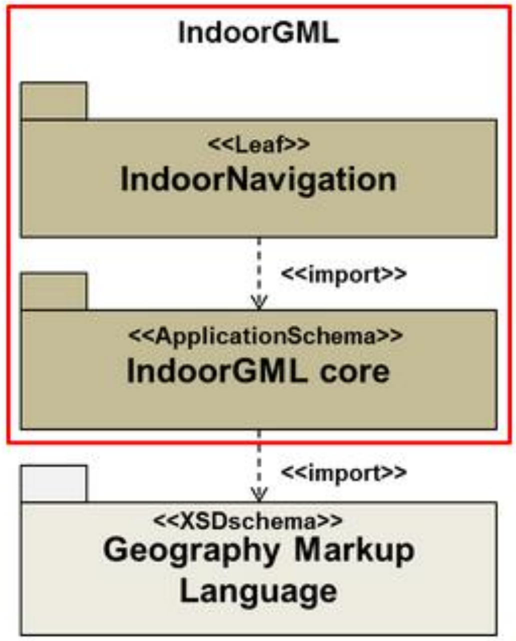


Figure 2.6 : Modular Structure of IndoorGML

Source: Lee et al., OGC® IndoorGML, 2015

The dependency relationships among IndoorGML's modules are illustrated in Figure 2.6 using an UML package diagram. Each module is represented by a package. The package name corresponds to the module name. A dash arrow in the figure indicates that the schema at the tail of the arrow depends upon the schema at the head of the arrow. For IndoorGML modules, a dependency occurs where one schema <import> other schema and accordingly the corresponding XML namespace. In the following sections the modules are described in detail.

2.3 IndoorGML Frameworks

IndoorGML is based on two conceptual frameworks the *Structured Space Model (SSM)* and *Multi-Layered Space Model* (MLSM). Both frameworks will be introduced in detail below.

2.3.1 Structured Space Model

The Structured Space Model (SSM) defines the general layout of each space layer independent from the specific space model which it represents. Each space layer evolved systematically within four segments. The building model is subdivided into four segments, primal and dual space on the one hand and geometry and topology space on the other hand, as illustrated in figure 2.7.

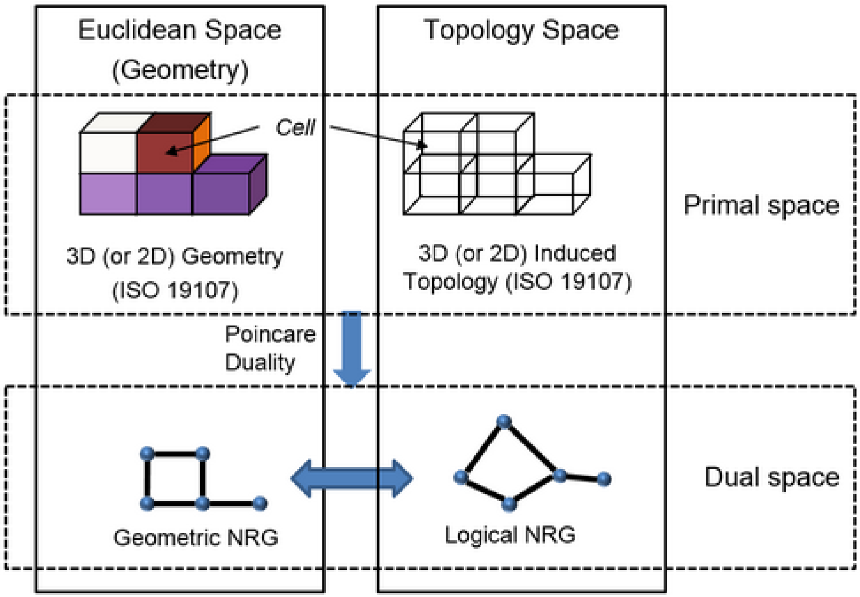


Figure 2.7 :

Structured Space Model subdivision in 4 segments

Source: Lee et al., OGC® IndoorGML, 2015

The development of geometric and topology space is according to rules of ISO 19107 for modeling geometrical features of real world phenomena. However, the ISO standard does not include nor the transition from primal to dual space, neither the topological relationships such as adjacency and connectivity by means of the topology in ISO 19107 but by explicit associations within the IndoorGML data model.

In the Structured Space Model, topological relationships between 3D (or 2D) spatial objects are represented within topology space. More specifically, the 3D cells in primal space are mapped to nodes (0D) in dual space and the adjacency relationships between 3D cells are transformed to edges (1D) linking pairs of nodes in dual space, after implementing a duality transformation. Moreover, the node of NRG is called state and the edge of NRG is called transition. The active state is represented by a node within the NRG and denotes the spatial area where the guided object is currently located. Once the object moves into a topologically connected area, another node within the NRG and thus a new active state is reached. The edge connecting both nodes represents the event of this state transition. As mentioned above in topological representation, there are two types of NRG graphs. Logical NRG, which represents topological relationships among 3D spatial objects in topological space and geometric NRG, which embeds the Euclidean IR3 space.

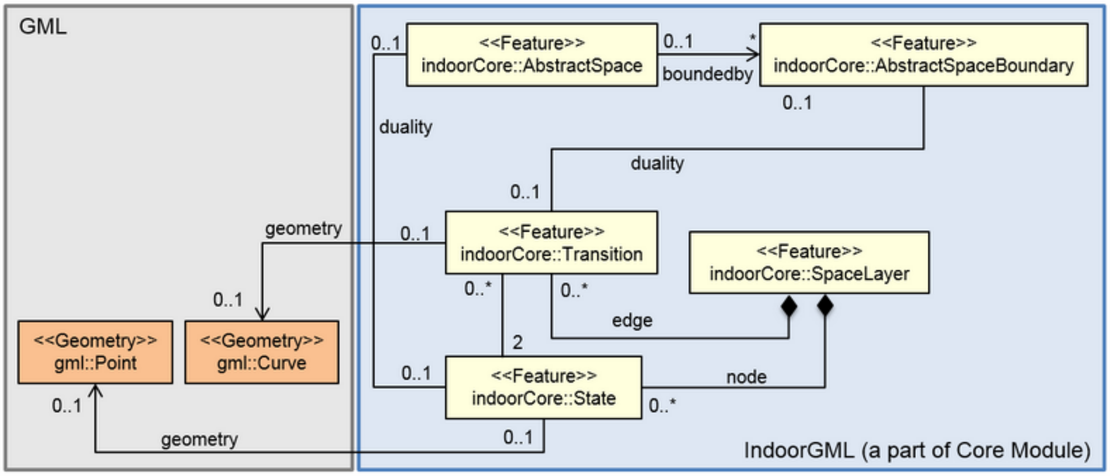


Figure 2.8 : SSM UML diagram

Source: Lee et al., OGC® IndoorGML, 2015

The UML diagram depicted in the above Figure underlines the structure of the data model for the Structured Space Model. The SpaceLayer is an interpretation and a decomposition layer and it is composed of States and Transitions which represent nodes and edges of NRG for dual space, respectively. The NRG and state-transition diagram for each layer are realized by SpaceLayer.

The NRG is implemented in IndoorGML model as part of the Structured Space Model. In dual space, the logical NRG in the lower right part of structured space model as seen in the previous figure represents topological relationships among spaces in topological space, which is described as the cardinality of State and Transition to *Geometry* classes is 0 in this figure. When the cardinality is 1 in the figure, the topological model is implemented by coordinate space embedding of NRG (Geometric NRG), which is in the lower left part of structured space model as seen in Figure 2.8 The current version of IndoorGML supports logical NRG and geometric NRG for dual space.

2.3.2 Multi-Layered Space Model

The *Multi-Layered Space Model* (MLSM) is an extension of Structured Space Model (SSM). As indoor space is decomposed into different cellular spaces, each thematic interpretation area forms a different space layer in dual space through SSM architecture. The representation of multiple space layers of the same indoor space is called Multi-Layered Space Model.

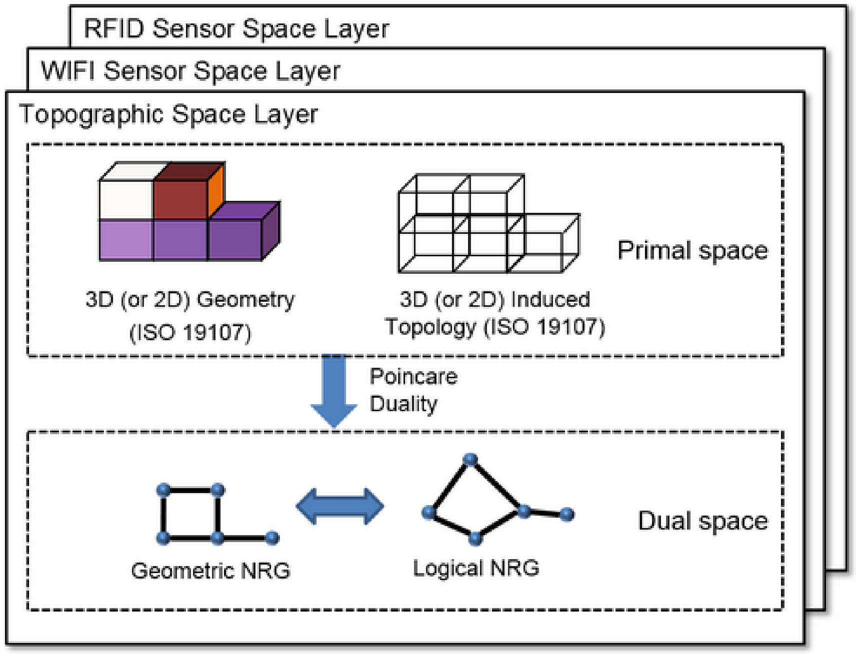


Figure 2.9 : Multiple Space Model

Source : Li, IndoorGML-A standard for Indoor Spatial Modeling, 2016

As discussed above, a same indoor space can be represented differently depending on application requirements. Indoor space is decomposed in layers and each layer-decomposition results in a separate NRG. The figure below depicts an example of a multi-layered space model.

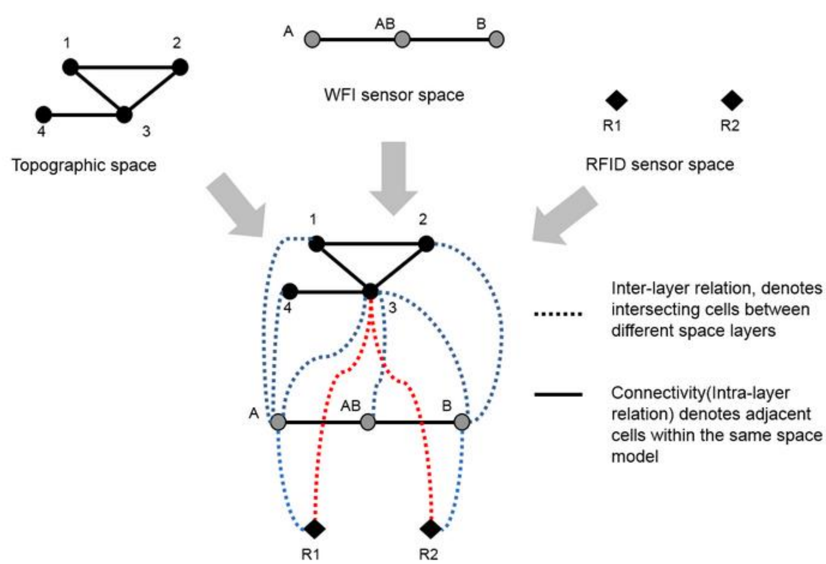


Figure 2.10 : A Multi-Layered Space Model example

Source : Li, IndoorGML-A standard for Indoor Spatial Modeling, 2016

As shown in the figure, the layers for topographic space layer, WIFI sensor space layer, and RFID sensor space constitute independent structured spaces and each layer results in separate NRGs.Inter-layer relations connects the layers of the multi-layered space model. In a topographic layer, the nodes represent the possible states of a navigating object and correspond to cells with volumetric extent in primal space (e.g. rooms) while the edges represent state transitions, i.e., the movement of an object from one space to another. They correspond to connectivity relations between the cells in primal space (e.g., neighbored rooms connected with a door). In the sensor space, NRG has a slightly different structure. The nodes represent again the cells with volumetric extend (e.g. the entire coverage space of a WIFI transmitter), while the edges represent the transition from one space to another based on the neighboring WIFI coverage spaces. Since the layers cover the same real world space, the separated dual graphs can be combined into a multi-layered graph.

In IndoorGML, the space model for multi-layered space representation, called *multi-layered space model*, is implemented by MultiSpaceLayer class. MultiLayeredGraph consists of SpaceLayers and InterLayerConnections, while SpaceLayer represents each space layer (e.g. topographic space layer, sensor space layer, etc.) and it forms a NRG composed of objects from State and Transition. The inter-layer relationships are implemented by InterLayerConnection class. Some relationship instances between two cells of different space layers from InterLayerConnection class are {(1,A,Within), (4,A,Within), (3,A,Cross), (3,AB,Cross), (3,B,Cross), (2,B, Within), (A,R1,Contains), (B,R2,Contains), (3,R1,Contains),(3,R2,Contains)}. As shown in the figure below, the MultiSpaceLayer is an aggregation of SpaceLayer and InterLayerConnection.

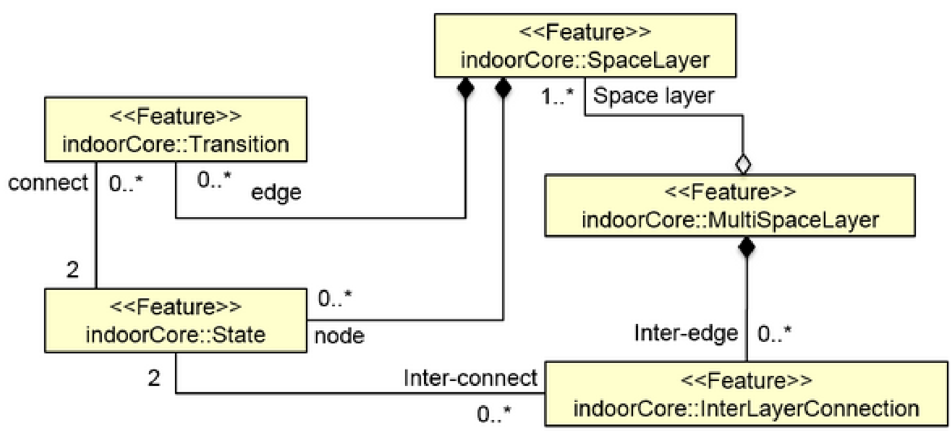


Figure 2.11: UML diagram for MLSM

Source : Li, IndoorGML-A standard for Indoor Spatial Modeling, 2016

2.4Subspacing

Subspacing is a very important part for the development of an indoor space model. Subspacing is the decomposition of indoor space in hierarchical structures and features and more specifically, the definition of cells. A feature such as corridor or hall could be divided to accurately represent the geometric properties of indoor space based on the connectivity relationships among space objects.

The whole concept for subspacing is explained below with the help of figure 2.12 In the case of corridor of Figure 2.12-(a), node *n*6 in the NRG representing a corridor within the indoor space (Figure 2.12-(a), Figure 2.12-(b)) is considered as a consolidated *Master Node*, which is transformed to a sub-graph preserving connectivity relationship among the compartmentalized spaces of the corridor (Figure 2.12-(c)). It means that node *n6* in the original NRG is converted into *n*6-1 and *n*6-2 and edge *e*1 in Figure 2.12-(c)) in the transformed NRG, which is a sub-graph representing a 2d space.

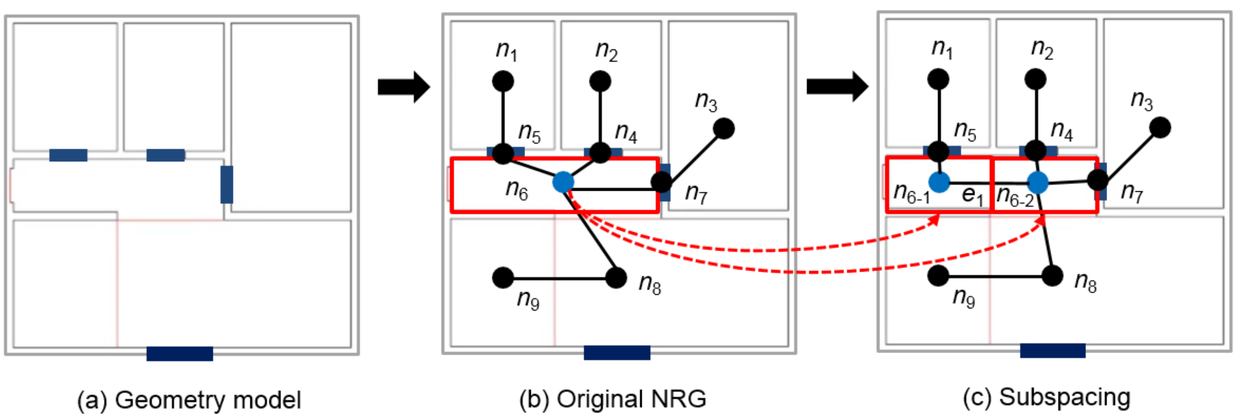
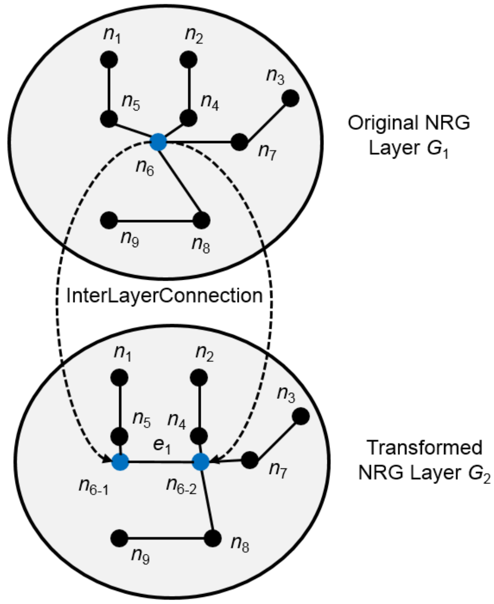


Figure 2.12 :Subspacing

Source: Lee et al., OGC® IndoorGML, 2015

IndoorGML standard supports subspacing for the establishment of a indoor space model. Figure 2.12 depicts how the hierarchical structure of indoor space is transformed by means of multi-layered space model. The NRG *G*1 is the original graph layer with node *n*6, while NRG*G*2 graph is the transformed graph layer with partitioned nodes *n*6-1 and *n*6-2. Then the hierarchical structure is represented by means of inter-layer connection of the multi-layered space model.



$\{(G_1.n_k, G_2.n_k, \text{equal}) \mid k \neq 6\}$: Defalut *InterLayerConnection*
$\{(G_1.n_6, G_2.n_{6\text{-}1}, \text{contains}), (G_1.n_k, G_2.n_k, \text{contains})\}$: *InterLayerConnection* for subspacing

Figure 2.13: Hierarchical Structure in IndoorGML

Source: Lee et al., OGC® IndoorGML, 2015

2.5 Connection with other Standards

The OGC standard IndoorGML (Lee et al., 2004) is the first standard dedicated to provide a framework for operating indoor navigation systems. As IndoorGML gains ground in the field of indoor navigation, the need to be connected with other standards becomes more and more required. Connection in terms of interoperability is referring to exchange data from one standard to the other and to use existing 3D models in different applications. A lot of research has been carried out on the above topic, investigating techniques to distract information from existing 3D semantic models and build the IndoorGML navigation model. Research is still ongoing, connecting IndoorGML with well-know and used standards such as CityGML, IFC, OpenStreetMap (OSM) and Land Administration Domain Model (LADM). The approaches and the outcomes of the studies are following.

2.5.1 IndoorGML and OSM

In recent years, navigation has become essential in human‘s everyday life and also essential in many other fields like disaster management, traffic management and urban planning. Moreover, the increasing complexity of urban environment with the construction of big public buildings such as hospitals, shopping malls and airports has introduced the need to navigate in indoor environments. Indoor navigation applications need the same data model for navigation analysis and exchange of information to each other (Li et al., 2010). IndoorGML standard seems to provide the appropriate data model and XML schema of indoor spatial information. However, collecting indoor spatial data by professional and commercial suppliers is usually high cost and time consuming, in contrast with Volunteered Geographic Information (VGI) projects such as OSM that provide the cheapest source of geospatial data. This is the main reason that VGI has become popular in the last few years to the geo-information professionals.

In the past years, much research has been carried out focusing on indoor navigation problems that caused by the employment of VGI data and automatic extraction of IndoorGML data from OSM data. Goetz et al., (2012) proposed the automatic generation simulation-related data based on IndoorOSM, a tagging schema for indoor mapping under OSM methodologies, in order to perform multi-agent evacuation simulations. Mortari in his master thesis (2013), introduced an automated extraction of improved geometrical network model from CityGML for indoor navigation, by using JOSM editor for generating most of the input files to the algorithm he proposed. Herrera et al., (2014) employed IndoorOSM data and hardware component of Smartphone to provide a hybrid indoor localization approach. However, none approach managed to develop an automated extraction IndoorGML data from OSM data.

In VGI projects, people participate without the need to specialized knowledge. Also, self-improvement, self-promotion and creation dynamic, and cost effective spatial information infrastructure are the benefits of VGI according to Goodchild (2007).
OSM is one of the most popular VGI projects, which creates and distributes free geographic data for the world. Everyone can be part of OSM with any level of expertise and create, edit or improve spatial data in OSM. Geometric data collected by GPS receivers or individual knowledge of people is shared in the form of node, way, and relation in OSM databases, while semantic data is recorded in the form of key-value pairs and linked to geometric data.
In the last years, has been created many extensions for OSM such as indoor mapping, 3d mapping, geocoding and routing services. IndoorGML insists an OSM extension, established at the end of 2011. IndoorOSM actually is a tagging schema for indoor mapping according to OSM principles. IndoorOSM represents floors, rooms, corridors, doors and POIs of indoor environments in 2d geometries with additional semantic or metric indoor information.

Mirvahabi et al. (2015) proposed an approach for automatic generation of IndoorGML data core file from OSM data file. The proposed approach is java-based and converts automatically OSM data file to the XML structured core data model of IndoorGML. The approach was implemented for the building of school of Surveying and Geospatial Engineering at the University of Tehran and the methodology steps are illustrated in the figure below.

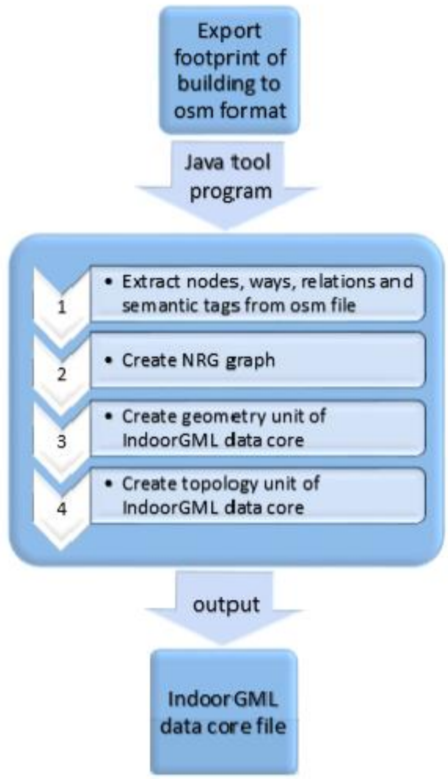


Figure 2.14 : Methodology steps

Source: Mirvahabi and Abbaspour, Automatic Extraction of IndoorGML Core Model from OpenStreetMap, 2015

JOSM editor was used in order to enter building footprint and floors as relation in OSM. Moreover, semantic information such as part ID, room, name, building level and openings location for each building part are also recorded by JOSM Editor. Then, footprint of mentioned building was exported to .osm file. This file contains a data model consisted by node, way, relations and semantic tags of the building. In the first step, geometric and semantic data is extracted from the .osm file. In the second step, the extracted data is used for the establishment of NRG graph and in the next steps geometric and topology unit of IndoorGML data core are created. The output file is in XML format and consists of two units: geometry and topology unit and can be used alongside the navigation data model for navigation application of indoor space. This approach can also be used for several buildings and combined with outdoor data model.

2.5.2 IndoorGML and LADM

The subdivision of a space in IndoorGML is not an easy task as sometimes spaces have not well-defined physical borders (such as walls, ceiling and floors) to identify a function, use or right on the space. IndoorGML model allows multiple space subdivisions per building, which can be derived from the building's topography, the function of space, the security restrictions, or according to the coverage of sensors (wifi or RFID) or the legal (LADM RRRs) status of spaces. Restrictions, rights and responsibilities on a part of a floor or a building can influence the accessibility and can significantly change the set of cells that can be used to derive a network (Zlatanova et al. 2016). In many public building, restricted or security areas are rarely identified with physics limits and are difficult to be imprinted to the model.

Land Administration Domain Model is the only standard to describe exclusively the space rights and the ownership status. In more detail, LADM is a FIG and ISO based standard (ISO19152:2012), which describes the process of determining, recording and disseminating information about the relationship between people and land or space. The basic classes of LADM model are: 1) parties, people and organizations, 2) RRR (rights responsibilities and restrictions) that concerns ownership rights, 3) spatial units (parcels, the legal space of buildings and utility networks) and 4) spatial sources and spatial representations (geometry and topology). The spatial units are abstract spaces and represent geometrically and topologically the rights and the administrative units. Also, spatial units can be overlapped with topographic features and not be bounded.

The two standards, IndoorGML and LADM, have been developed for different purposes, indoor navigation and land administration accordingly, and thus have many differences but also similarities. 3D legal spaces often need reference to objects in order to be understandable. They can have their own independent geometry and topology, but rarely is modeled as it is not well-defined. On the other hand, IndoorGML contains 3D topographic information, which can be identical or not to the architectural structure of a building. In this way, IndoorGML can be used for the definition of LADM’s legal space.

Zlatanova et al.2016, launched a research to link the two standard to allow space identification on the basis of ownership, right and restriction on properties, after detecting their similarities and differences and taking into consideration two options:
1) ‘equivalence’ association between LADM LA_SpatialUnit and IndoorGML abstract space for rights(RRRs), similar to other associations of LADM classes and other external classes,
2) formal approach for deriving a LADM space layer within IndoorGML context.

More specifically, the first approach indicates to define an extension module of IndoorGML for supporting the LADM standard within IndoorGML due to the equivalence of CellSpace of IndoorGML and LA_SpatialUnit of LADM, while the second provides a mechanism to access features from the one standard to the other via external link.
The linking of these standards will be effective for both sides as IndoorGML can be upgraded by adding information on rights, responsibilities and restrictions from LADM to the space cells and LADM can inherit from IndoorGML the geometry. Further research, will show which approach is the most appropriate and how to structure data in order every condition to be covered.

2.5.3 IndoorGML and BIM

Building Information Modeling (BIM) emphasizes the building representation in 3D geometric and indoor semantic information and also contains high geometrical details and riches in the attribute information. In such a way, BIM could be a spatial data source for indoor Spatial Data Infrastructure (indoor-SDI) and further for IndoorGML, the OGC standard for indoor spatial information. Teo and Yu (2017), proposed direct conversion schemes to extract indoor building information from BIM to OGC IndoorGML.

Industry Foundation Classes (IFC) is an open data format for openBIM. IFC data format is adopted in this study as most BIM model can be converted to IFC as an exchange data. The topological conversion is a major process of generating and mapping nodes and edges from IFC to IndoorGML. In this step, we extract 3D indoor network model from IFC for IndoorGML conversion. An indoor network is a data model which is converted from IFC model automatically.

The three major steps for the conversion of BIM/IFC to IndoorGML dual space model are the following: 1)data preprocessing, 2)topological conversion, and 3)modeling IndoorGML model. The above figure illustrates the workflow of the proposed scheme.

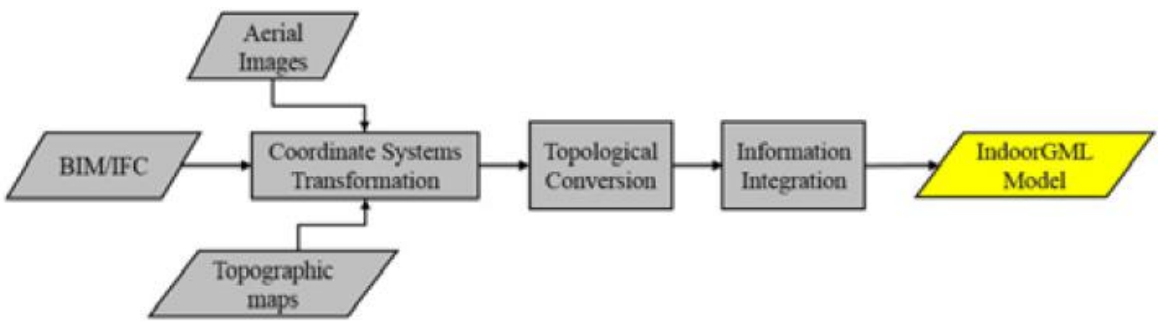


Figure 2.15 : Conversion process from IFC to IndoorGML

Source : Teo and Yu ,The Extraction of Indoor Building Information from BIM to OGC IndoorGML,2017

After the coordinate system transformation from the relative coordinate system of BIM to mapping frame in IndoorGML, follows the topological conversion where the nodes and the edges are generated. There are many methods for the generation of nodes. For simple and closed space or building objects, nodes can be generated by automatic calculation. It is a method to generate a node in the centroid by calculating the shape of the space or object. Also, edge generation is an automatic process. Basing on the opening element, users identify rooms sharing the same one so that the corresponding nodes can be connected.

The last process is the integration of the generated nodes and edges to the IndoorGML dual space model. This process is further separated into two steps: mapping information into IndoorGML and establishing the linkage between related node and edge.

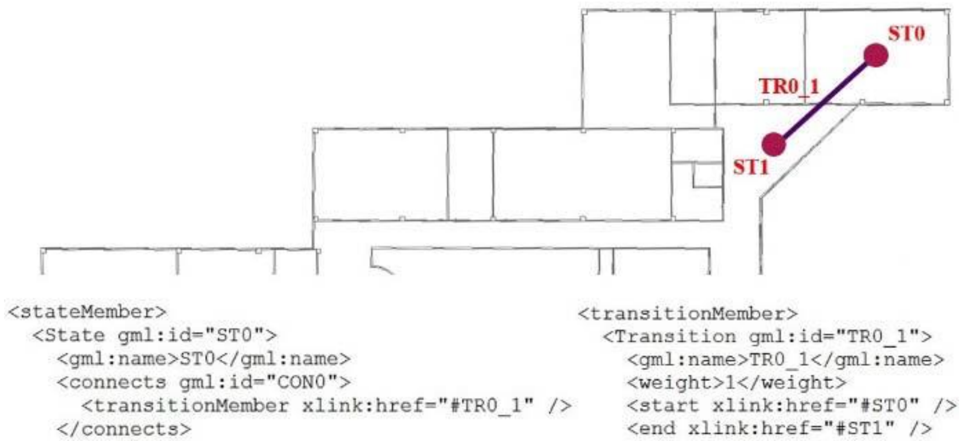


Figure 2.16: Integration Nodes and Edges to the IndoorGML Model

Source : Teo and Yu, The Extraction of Indoor Building Information from BIM to OGC IndoorGML,2017

The above proposed method was tested to the BIM model of Taipei Main Station, Taipei City. The BIM model was developed based on 2D CAD graphs, 3D CAD models and field surveying by the Autodesk Revit 2014 software and then converted to IFC format. The building consists of seven floors above ground and two basements.

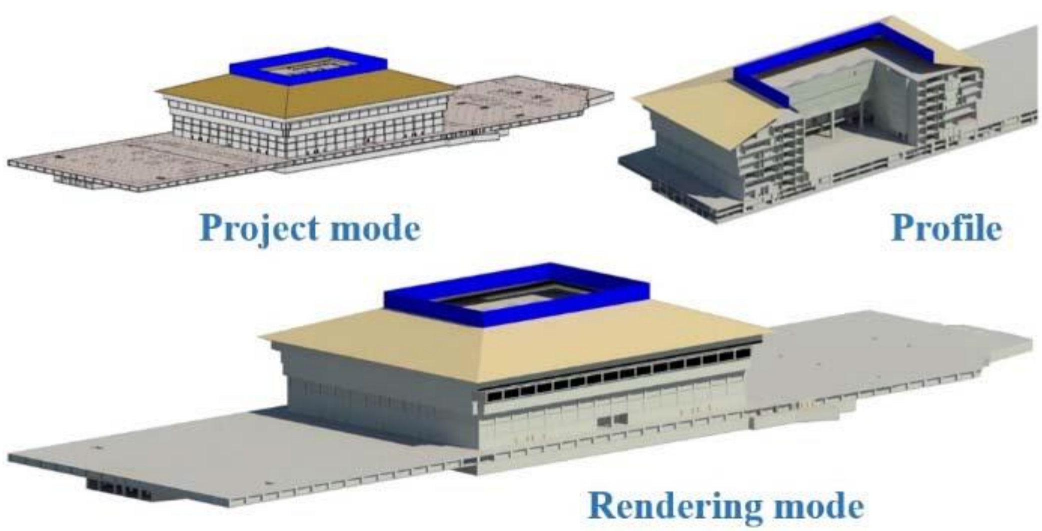


Figure 2.17: Tapei Main Station BIM model

Source :Teo and Yu ,The Extraction of Indoor Building Information from BIM to OGC IndoorGML,2017

The FME software was used for the extraction of indoor building entities of IFC and then they developed a program to calculate the nodes, extract the edges, and connect the nodes and edges automatically. Rooms that were converted to nodes were further divided into corridors, elevator rooms, general rooms, and staircases according to the function and usage. All the nodes, corridors, doors and general rooms were used for generating horizontal routes of each floor, while elevator rooms and staircases were used for vertical routes. Last step of conversion, is the transformation of nodes and edges with their information into XML Schema and finally the generation of the IndoorGML model.

For the visualization of the generated IndoorGML model, they used MATLAB. The whole model in IndoorGML is illustrated in Figure 2.18, where nodes (States) are represented with blue triangles and edges (Transitions) with red lines.

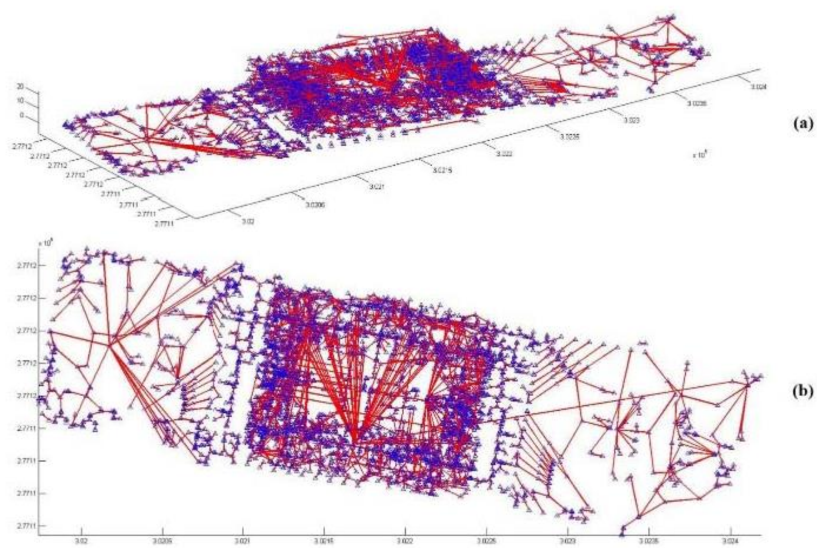


Figure 2.18: IndoorGML model of Taipei Main Station, (a) 3D model, (b) plan view

Source: Teo and Yu, The Extraction of Indoor Building Information from BIM to OGC IndoorGML,2017

The results of testing the proposed method were enough satisfactorily. However, the auto-generation of indoor network may occasionally result in irrational routes such as netlike or radial routes. This problem could be solved by manual digitization. The researchers on their future work will focus on overcoming the problem of inappropriate routes by pedestrian constrains.

3. INDOOR NAVIGATION APPLICATIONS

In this chapter, will be introduced the Indoor Spatial Awareness Initiative (ISA) that aims to standardize the management of indoor spatial data in order to provide interoperability between different systems and environments of indoor spatial data models. Also, most used algorithms for path-finding in indoor spaces, will be presented. Moreover, will be performed an introduction to the Location-Based Service (LBS), which is a software application for a IP-capable mobile device and also will be presented an implementation of this service, the i-locate project.

3.1 Indoor Spatial Awareness Initiative

Spatial awareness is a fundamental functional requirement of ubiquitous computing and used in many applications of ubiquitous computing as an essential component. Although, spatial awareness for indoor space is important little work have been done so far as the spatial awareness has been focusing on outdoor space. The reasons why spatial awareness is important for indoor space is because people spend most of their daily life in indoor space (about 70-80%), it is easier to implement computing infrastructure in indoor space than outdoor and the nature of space in spatial information services is evolving from macro space to micro space as there is the need of spatial information in more indoor spaces such as underground metro stations.

The Indoor Spatial Awareness (ISA) initiative is summarized into fundamental theoretical background for indoor space, a tool for indoor spatial databases, indoor spatial database management systems and ISA services and a bed for ISA services. These are the principle components of ISA initiative that every information system and service is constituted as shown in the below figure.

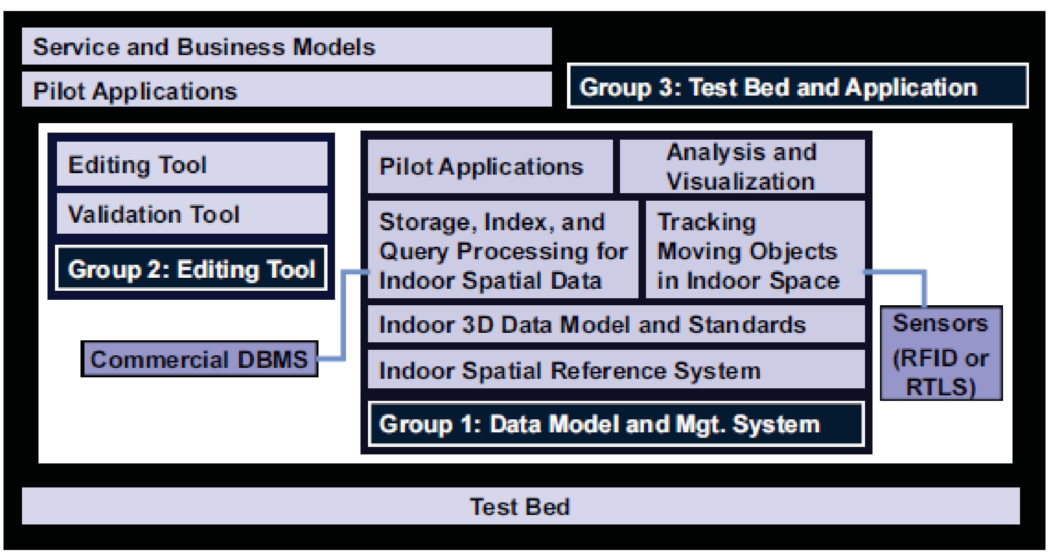


Figure 3.1: Architecture of ISA Initiative

Source: Li and Lee, Indoor Spatial Awareness Initiative and Standard for Indoor Spatial Data,2010

Concerning the theoretical background, the major differences of the indoor space from the outdoor space concludes to the constraints of space. In Euclidean outdoor space there are no constrains, while the indoor space nature results constraints of architectural components, such as doors, corridors, floors, walls, and stairs. In order to analyze the indoor space, should all these architectural components be understood in order to develop an appropriate data model for the recording of constraints in indoor space.

In architectural engineering, several data models have been proposed for this purpose and one of which is IFC (Industry Foundation Classes) by IAI (the International Alliance for Interoperability). However, this model is focused on the construction management and facility management rather than spatial information services.

An indoor spatial data model from GIS view point for the representation of interior 3D space is CityGML (LOD 4), an international standard of OGC. CityGML model is more appropriate for the spatial information systems than IFC standard but intents to visualize the indoor space rather than indoor spatial services and analysis, which may be complicated like evacuation routing analysis.

A complete spatial data model has been made by ISO/TC211, which contains most possible entities of spatial features including geometries and topologies. This model is widely accepted by most application schema of spatial data and also the geography markup language has been developed based on this model. However ISO 19107 and GML are oriented to outdoor space. In such a way indoor spatial theory and indoor spatial data model is to provide a basis of application schemas for indoor space.

An important requirement for indoor spatial data model is related with the notion of *cellular space* (or *symbolic space*). While a region query in outdoor space is given with coordinates such as ($x1$, $y1$) and ($x2$, $y2$), the query in indoor space is often based on cellular notation. For example, the location in a train, which belongs to indoor space, is not identified by its coordinates but by the wagon and seat numbers. While the Euclidean space has geometric and topological properties, the cellular space has only topological properties, which are to be explicitly specified. Among several types of topology in indoor space, the connectivity between indoor space and outdoor space should be considered as well as the topology between indoor cells. Consequently, the spatial information described by cell identifier should be differently stored, managed and processed and spatial information systems of outdoor space must be replaced with new ones due to the difference between cellular space and Euclidean space. Another important requirement of indoor spatial data model is related with sensor coverage in indoor space so the installation of a number of sensors in indoor space is required for positioning systems. The entire indoor space contains not only cellular spaces separated by walls and floors but also coverage spaces of sensors that could be described by a multilayered space model.

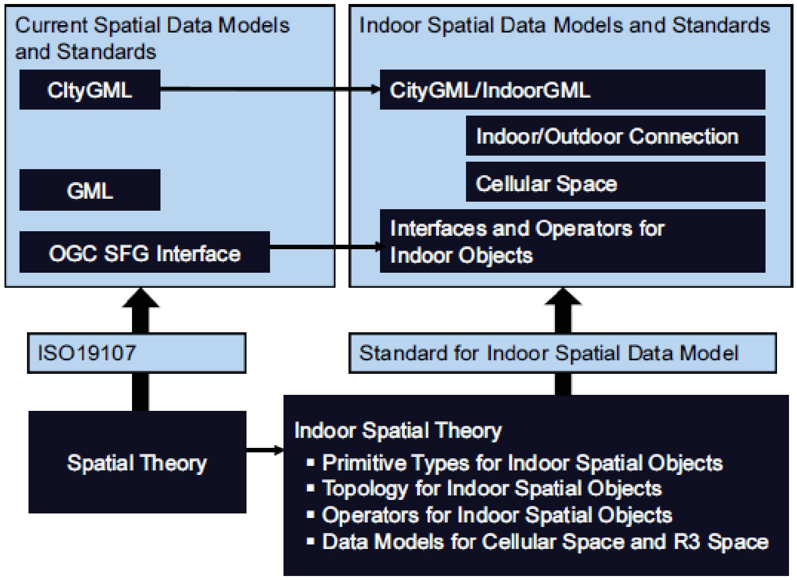


Figure 3.2: New Spatial Theory for Indoor Space

Source: Li and Lee, Indoor Spatial Awareness Initiative and Standard for Indoor Spatial Data,2010

Concerning the indoor spatial data engine, the management systems for indoor spatial databases have different functionalities, which are summarized as follows:

• Representation, storage, indexing, and query processing for cellular spatial databases, 3D geometric databases, and moving objects in indoor space. Integration of cellular space and Euclidean space,

• Real time tracking of moving objects, and

• Continuous query processing for moving objects and broadcasting to clients.

The architecture of the indoor spatial database server, called ISA data engine, is shown in figure below. The first function of ISA data engine is to store and manage indoor spatial objects in a database server. The engine provides a set of primitive object types for indoor spatial objects including stationary objects such as rooms, corridors, stairs, doors, and windows, and mobile objects. The geometry of stationary objects is based on *prism model*. By the prism model, each geometry object in indoor space is represented by the upper and lower boundaries and has several advantages over the 3D solid model of ISO 19107.

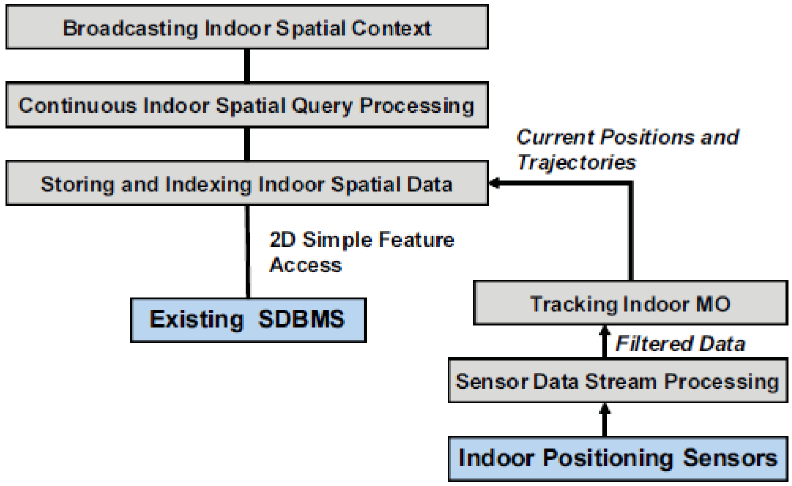


Figure 3.3 : Architecture of ISA Data Engine

Source: Li and Lee, Indoor Spatial Awareness Initiative and Standard for Indoor Spatial Data,2010

By the prism model the large amount of data size is reduced, while any spatial database management can be used for ISA data engine, if it supports the Simple Feature Access specification of OGC. Moreover, the performance of query processing is significantly improved by the prism model, compared with spatial database management systems supporting 3D solid model. The second function of ISA data engine is tracking of mobile objects in indoor space. The detail mechanism of tracking depends on the type of indoor positioning sensors, which are classified into two categories; presence sensors such as RFID and image sensors, and coordinate sensors such as WiFi, UWB, and RTLS sensors. While the position in an outdoor space is relatively easily collected (e.g. by GPS), the indoor positioning technologies are unfortunately immature. No single technology provides a stable positioning method but hybrid approaches are being considered for indoor positioning. And several aspects of indoor space are closely related with the indoor positioning technology. For example, when RFID technology is used for the indoor positioning, the granularity of cell is differently defined from other technologies and tracking methods for RFID are therefore different. Other parts of spatial information systems should be tuned for RFID technique.

As previously mentioned, most applications of indoor spatial information rely on symbolic spatial reference systems rather than coordinate reference systems. It means that the location data collected from positioning sensors should be converted to cell identifiers of symbolic space. For the conversion process, a tracking method should be implemented in indoor symbolic space for presence sensors, and a map matching mechanism for coordinate sensors. The third important function of the engine is to provide indoor spatial data to clients which receive data from server by submitting a query. The ISA data engine employs continuous query and broadcasting for solving the problem of overloading when a large number of clients are using the application. The engine checks the databases if the registered queries are satisfied when there is any related change of state. And if there are any triggered query results, then the engine broadcasts it to all clients.

3.2 Algorithms for path-finding

The indoor navigation process could be generalized and partitioned into three phases : localization, routing, and tracking (to guarantee that people follow the predetermined routes) (Gillieron et al.2004). While localization and tracking depend on indoor positioning techniques, the routing or else path-finding depends on the geometric model of the building. Therefore, a very important phase in routing is the simplification of the building structure to support the routing algorithm as Lui and Zlatanova, 2011 claimed. Navigation models are usually constitutes by network navigation models that derived by building floor plans after regular and irregular cell subdivisions. The geometry that network models represent are referring to a specific moment of time and do not consider the current building status as a reconstruction could be performed. In order the network model to be updated, it is appropriate to derive navigation route on the fly. This requires semantically rich models of buildings to be considered like CityGML or BIM.

Based on the geometry of building, a topological structure could be conveniently derived to facilitate routing computation. Typical representatives are the approaches based on the traditional Dual Graph (DG)(Whitney, 1932). Lee (2001a) proposes the Node–Relation structure (NRS) to represent the connectivity of buildings based on Poincare Duality theory (Munkres, 1984; Corbett, 1985). Lee (2004) extended the NRS to Geometric Network Model(GNM), which introduced geometrical metric and also introduced a skeleton-abstraction algorithm for the development of 3D GNM, which named Straight- Median Axis Transformation (S-MAT) modeling method. S-MAT can abstract linear features from simple polygons and follows the building structure. One of the most important S-MAT disadvantage is that cannot provide a door-to-door route for people. More specifically, figure…. shows that the straight medial axis of a corridor is D1-M1-M2-M3-M4-D4. If a person needs to go to D2, the route will be D1-M1-D2. Door-to-door result is D1-D2. Even if the person could not see a door, e.g. D3 from D1, the door-to-door route will be D1-S1-D3 (the dash line), which means the person will see D3 until he reaches S1. Yet the DG route would be D1-M1-M2-M3-D3 in this case.

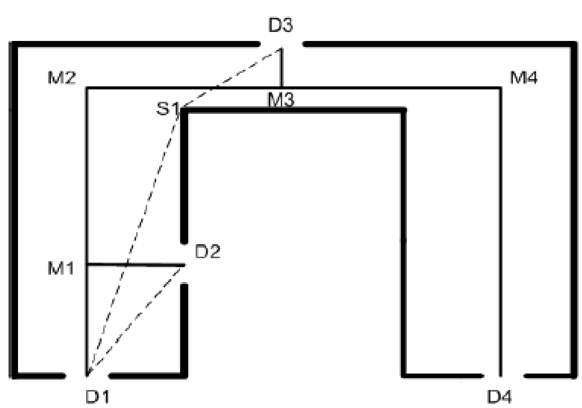


Figure 3.4: Comparison of DG and door-to-door route

Source: Liu and Zlatanova, A “Door-to-Door” Path-Finding Approach for Indoor Navigation, 2011

Lorenz et al., (2006) proposed another approach, in which, the indoor space (2D plan) is decomposed into cells for simplifying complex spaces and facilitate the creation of the graph structure. In this approach, the doors are explicitly considered and the cell centers are connected with doors. However, because of its cell-door-based representation, the network could result in some unnecessary tortuous paths and as S-MAT, it can pass through a cell center that is not indeed as a door is visible and can be directly approached.

Lui and Zlatanova (2011) proposed a door-to-door approach of routing that adapts better to the walking behavior of pedestrians. Furthermore, this approach aims to resolve navigation in complex shaped buildings, consider changes of indoor environments, allow dynamic re-computation of a route and automate route derivation from 3D semantic-geometric models of complex buildings.

Door-to-door approach is mainly interpreted as the direct walking way from a door to the next visible door or the shortest possible way between two invisible doors. Nevertheless, it does not mean people have to strictly follow this way. The way merely provides potentially efficient routes for indoor navigation. The researchers depending on this approach developed a typical network algorithm assuming that the semantic-geometric model of the buildings is known, the model provides (directly or indirectly) connectivity information, the model contains information about all interior objects, such as obstacles at certain moment and the dynamic changes in the interior and the structure of the building are also known.

In this approach the doors (or openings) are approximated with nodes and the rooms with edges, in contrast to other network models that treat doors (or openings) as edges connecting rooms (nodes). As shown in Figure 3.4, door-to-door approach generates a shorter route compared to S-MAT.

The routing strategy is organized as a two-level approach:

- Coarse: it is based on room-to-room connectivity on the floor level to determine the direction of movement. (between rooms in a floor)
- Refined: it is used in a single closed space to avoid all kind of obstructions and make people transfer in a door-to-door way. (within a single room)

In both approaches, Dijstra algorithm (Dijkstra, 1959) was implemented as a certain optimal routing algorithm (e.g. shortest, fastest or safest) in order to determine the rooms that pedestrians will traverse in current circumstance. For a certain person, firstly his/her location should be investigated and the final exit should be specified. Based on this information a route described as “passing which rooms” is generated according to certain path-finding algorithm. When the pedestrian reaches a room, a detailed calculation of the route in the room is carried out complying with door-to-door principle.

This strategy brings two advantages: 1) not all details should be extracted from the building model at once and 2) if some changes occur at indoor environments in emergencies, we could adjust the calculated route on the macro-level (i.e. to pass which rooms in a floor) at first.

Another merit of this approach is that there is no space sub-dividing process (compared with cell decomposition for example).

The door-to-door algorithm was tested with a variety of complex spaces and for a few real building floors. The results show several merits of the door-to-door algorithm. It can serve complex floor plans and provide the door-to-door route in any kind of (concave) spaces with arbitrary number of doors between two neighboring spaces.

An algorithms disadvantage is that is merely applied to one floor, without concerning the vertical connection between floors (e.g. staircases, elevators) in coarse approach and obstacles in refined approach.

3.3 Location Based Service

A location-based service (LBS) is a software-level service that uses location data to control features. LBS is an information service and has a number of uses in social networking today as information, in entertainment or security, which is accessible with mobile devices through the mobile network and which uses information on the geographical position of the mobile device.

Location-based services (LBS) use real-time geo-data from a mobile device or smartphone to provide information, entertainment or security. Some services allow consumers to "check in" at restaurants, coffee shops, stores, concerts, and other places or events. Often, businesses offer a reward — prizes, coupons or discounts — to people who check in. Google Maps, Foursquare, GetGlue, Yelp and Facebook Places are among the more popular services.

Location-based services use a smartphone's GPS technology to track a person's location, if that person has opted-in to allow the service to do that. After a smartphone user opts-in, the service can identify his or her location down to a street address without the need for manual data entry.

LBS is critical to many businesses as well as government organizations to drive real insight from data tied to a specific location where activities take place. The spatial patterns that location-related data and services can provide, is one of its most powerful and useful aspect where location is a common denominator in all of these activities and can be leveraged to better understand patterns and relationships. Many app developers lack the resources to develop software to interpret a smartphone's location and instead use existing solutions via an API to save time and money. Many companies specialize in liaising with wireless carriers to connect companies with smartphone user locations. These companies provide tools to increase user engagement and connect with the most mobile phone users on the market. Companies well known for their LBS software include AT&T Mobile Marketing Solutions, Voxeo and Esri.

LBS include services to identify a location of a person or object, such as discovering the nearest banking cash machine (ATM) or the whereabouts of a friend or employee. LBS include parcel tracking and vehicle tracking services. LBS can include mobile commerce when taking the form of coupons or advertising directed at customers based on their current location. They include personalized weather services and even location-based games. They are an example of telecommunication convergence.

This concept of location based systems is not compliant with the standardized concept of real-time locating systems (RTLS) and related local services, as noted in ISO/IEC 19762-5and ISO/IEC 24730-1. While networked computing devices generally inform consumers of existing data, the computing devices themselves can also be tracked, even in real-time.

The European Union also provides a legal framework for data protection that may be applied for location-based services, and more particularly several European directives such as: (1) Personal data: Directive 95/46/EC; (2) Personal data in electronic communications: Directive 2002/58/EC; (3) Data Retention: Directive 2006/24/EC. However the applicability of legal provisions to varying forms of LBS and of processing location data is unclear.

3.4 i-locate

i-locate is a European Union open project funded under the Information and Communication Technologies Policy Support Programme. The total cost of the programme was up to 4.7million euros and the execution period was from 01/01/2014 to 31/12/2016.

i-locate focuses on the development of a virtual hub based on a large repository of open indoor mapping data regarding publicly accessible spaces. These will allow aggregation of further data regarding indoor facilities, infrastructures, asset management, system maintenance, queue management etc.

The virtual hub is a public geoportal, which is regarded as the “indoor complement” to OpenStreetMap, sharing indoor mapping data regarding indoor spaces according to a taxonomy of different spaces (e.g. hospitals, public offices etc.). As indoor mapping data could consider public building (city councils, hospitals) and private buildings accessible to the public (shopping malls, airports, universities)

The indoor mapping data is aggregated and made freely available through the “hub” (the public portal), for the various pilot locations. The “hub” is available at the official site of the project in the section portal. There everyone after sign in could upload the indoor data of the location he wants to, following the platforms instructions and making the inputs in correct data formats. The indoor data will be used to create innovative application and services based on tracking, routing and asset management services.

The project is attended by 25 partners from 9 European Countries (Croatia, Great Britain, Germany, Greece, Italy, Luxembourg, Malta, Holland, Romania). Further, a mobile client (App) is under development to access the toolkit’s services. In our country, a pilot location has been launched for the Mitera Hospital in Marousi, Athens.

Figure 3.5: "Hub" portal, pilot location Mhtera Hospital, Greece

Source: http://www.i-locate.eu/

As the above figure shows, the "hub" window is divided into two parts. In the left part is listed the pilot locations where the user can choose and in the right part is displayed the map including the indoor data per floor for all the pilot locations.

i-locate is also working on mobile client-side technologies (an App for iOS and/or Android devices) capable to access the toolkit's services via interoperable standards. The mobile technologies will be then customizable to respond to various innovative scenarios.

4. METHODS FOR DEVELOPMENT OF INDOOR NAVIGATION MODELS

In recent years research interests in 3D geospatial information have been increased to provide location based services and to develop various 3D urban models used in many fields such as urban planning, and disaster management. Especially, due to increasing the scale and complexity of buildings, many researchers have studied to provide the services such as indoor navigation for disaster. There are two alternative methods for the development of an indoor navigation model. The first one is to structure a spatial model based on specific requirements of an indoor navigation model and the other method is to develop the indoor spatial data model by extending the developed 3D spatial models which have been developed for outdoor space. In consequence, the two different methods will be represented in more detail with example case studies that have been done so far. A comparison of the methods will remark the advantages and disadvantages of each method. Also, it is represented a related research in which the IndoorGML model is derived by an automatically transformation process for generating IndoorGML from existing building data model given in CityGML LoD4 or IFC, as well as a method for generating navigation logical model from a CityGML model.

4.1 IndoorGML Implementations

According to Kang and Li, 2016, there are three main steps for the implementation of context-awareness by IndoorGML. The first step concerns the indoor map matching, the second the context reasoning from staying interval and the third the context reasoning from visit sequence.

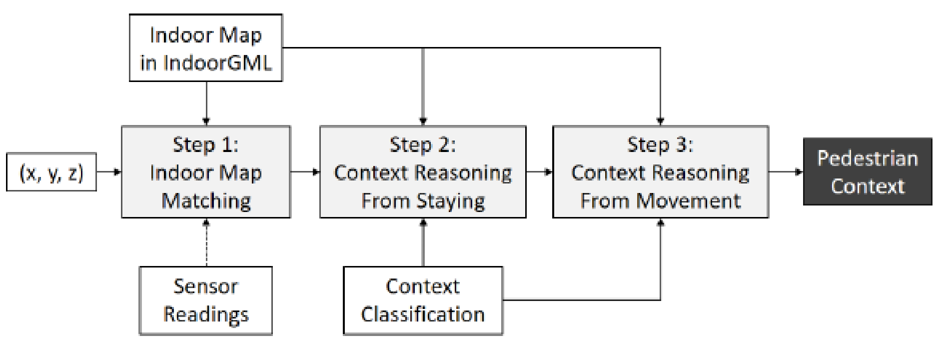


Figure 4.1: Context awareness procedure by IndoorGML

Source: Kang and Li, A Standard Indoor Spatial Data Model –OGC IndoorGML and Implementation Approaches, 2016

In more detail, the first step identifies the cell where the pedestrian is staying either in 3D Cartesian coordinates (x, y, z) or by sensor coverage depending, on the type of indoor positioning methods. In any case, the position acquired from indoor positioning has unavoidably a certain level of errors, which may derive incorrect results of indoor map matching. The IndoorGML information can improve the accuracy of indoor map matching by using appropriate algorithms, which can find the cell containing the current position of pedestrian by point-in-polygon or point-in-polyhedron algorithm with the cell geometry information given by IndoorGML and the most probable cell by analyzing the indoor accessibility graph given in IndoorGML and the past trajectory. After finding the pedestrian's position, a very useful context in pedestrians could be derived from staying and visiting sequences, concerning the current cell and the staying and the visiting time interval.

Concerning the computing of Indoor distances for the IndoorGML module, there are three types of distances, horizontal, vertical and multi-modal. Horizontal is the distance between two points on the same floor. The distance between two nodes p and q in is divided into point-to-door distance and door-to-door distance. For the computation of these distances, are essential the topographic layer and the door-to-door layer of IndoorGML (Figure 4.2).

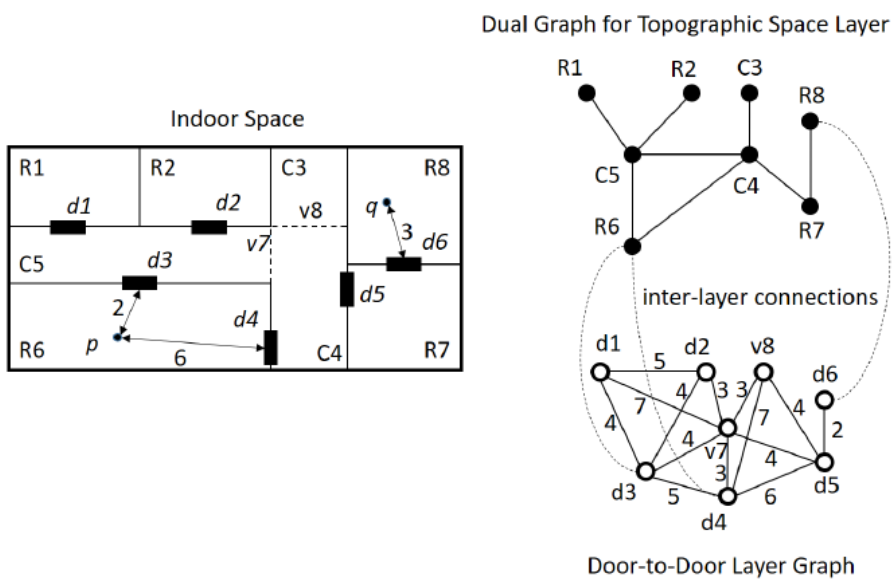


Figure 4.2: Horizontal distance computation using IndoorGML

Source: Kang and Li, A Standard Indoor Spatial Data Model –OGC IndoorGML and Implementation Approaches, 2016

The door-to-door graph is a weighted graph so that the weight of the edge represents the distance between two doors. In consequence, horizontal distances are computed by using the topographic layer, door-to-door layer graph and inter-layer connections of IndoorGML data through an algorithms repetitive procedure.

Vertical distance is the distance between two nodes of different floors. The computation of vertical is common with the horizontal's. However, the weight of each vertical edge in the door-to-door graph must be assigned differently from horizontal edges. Furthermore, the door-to-door graph may be directed since up-speed differs from down-speed and the weight of the edge also depends on the vertical transportation modality, whether elevators, stairs, escalator or ladders. At the preparation of door-to-door graph layer of IndoorGML data, all of the above factors should be taken into account for an accurate computation of vertical indoor distance.

Multi-model distance is the distance between two nodes that demand both horizontal movements and vertical movement in order to get connected. An example of Multi-model distance is the indoor distance between two points in different terminals of an airport, connected via the inter-terminal railway. In this case, the traveling time is a more proper metric of indoor distance than the physical distance between two terminals.
First, an additional layer for indoor transportation is created, and also the terminal topographic layer is created in a similar way with door-to-door layer. The weight of the edge in the indoor transportation layer graph is given as the traveling time between two *nodes.*

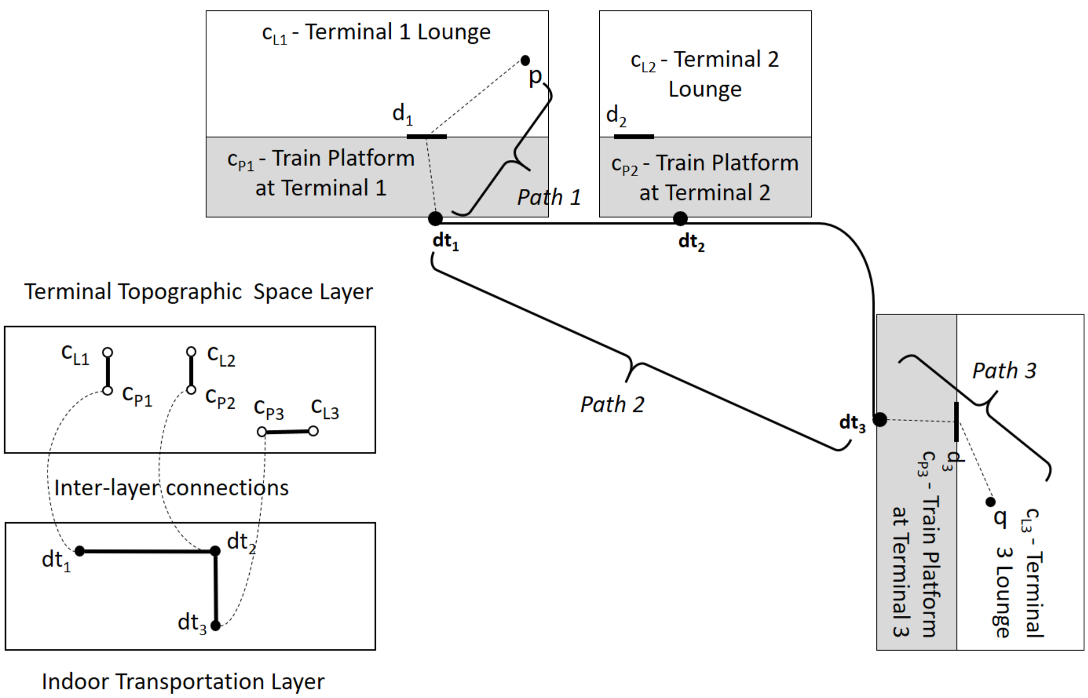


Figure 4.3: Computing Multi-Modal Distance, the example of airport

Source: Kang and Li, A Standard Indoor Spatial Data Model –OGC IndoorGML and Implementation Approaches, 2016

The indoor distance is computed in a similar way given in the previous subsection by replacing the door-to-door layer graph with the indoor transportation layer graph and applying Algorithm 1.

Hwang et al., 2012, in their research developed an editor and a viewer based on IndoorGML schema which is defined with international standardization process. The IndoorGML editor was developed in respect to the NR Structure. 3D spaces are represented as nodes in dual graph and spatial boundaries as edges. In order to increase the editor's convenience in use, researchers added functions settings and editing topology. The IndoorGML editor has four topology editing functions:

1) ZoneTopology for the connection between centroids of opened space such as room
2) ConnectoeTopology for the connection between door to door
3) ZoneConnectTopology for the connection between centroids of opened space and door
4) PathTopology for all paths in the given space

The developed IndoorGML viewer supports the visualization of indoor spatial information using the IndoorGML editor. The viewer provides a visualization function for monitoring based on 3D model. The developed IndoorGML viewer uses MFC, Open CASCADE and Ogre3D, as well as it supports camera operation and various viewport to easily confirm the visualized model.

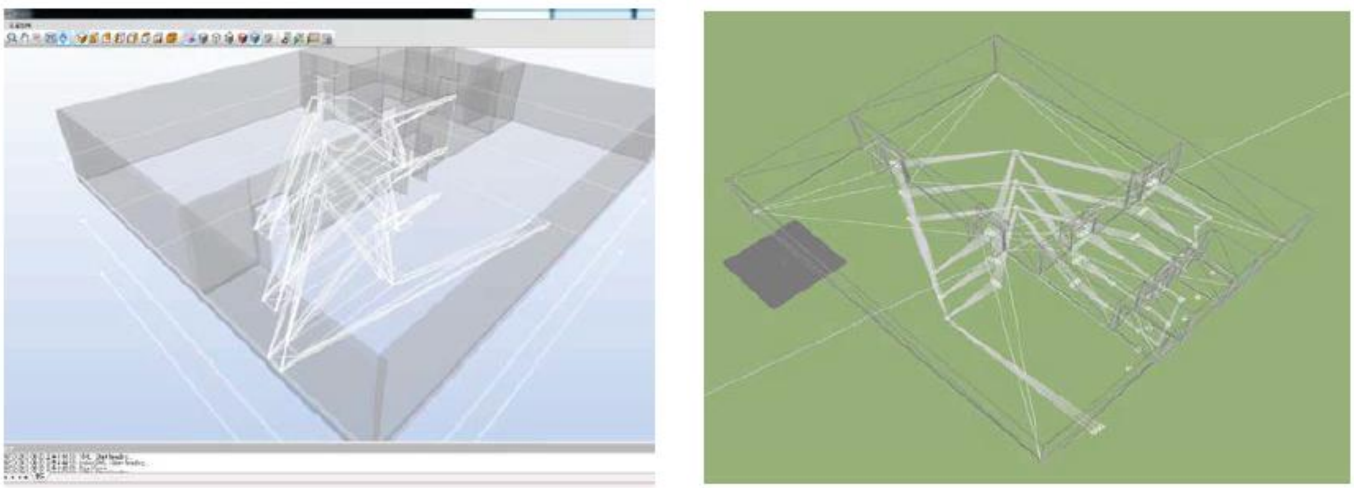


Figure 4.4: Examples in IndoorGML Viewer Left: PathTopology, Right : ZoneConnectTopology
Source: Hwang et al., Development of an Editor and a Viewer for IndoorGML, 2012

4.2 Developing CityGML Indoor ADE

As mentioned above, recent research in 3D geospatial information is oriented to provide location based services and to develop various 3D urban models used in many fields such as urban planning, and disaster management. In such a way, researchers' attempts focused on developing the indoor spatial data model by extending the developed 3D spatial models which have been developed for outdoor space.

Concerning 3DCityGML building models, there is CityGML ADE (City Geography Markup Language Application Domain Extensions) which is an extended model for specific applications based on the concept of CityGML. To construct CityGML ADE, there are two different approaches to integrate between CityGML data and application data. First method is to embed the CityGML objects into larger application frameworks by connecting both CityGML data and application data. Second method is to extend CityGML data model by defining additional attributes of CityGML objects and new feature classes for the specific applications. The second method is more commonly used as it is more useful and can be applied to every situation.

Kim et al., 2014, proposed a CityGML Indoor ADE for indoor facility management applications based on the second method. This CityGML Indoor ADE includes two feature models based on CityGML Building Module, Indoor Space Feature Model and Indoor Facility Feature Model. The Indoor Space Feature Model represents space features like reading rooms, meeting rooms, and office rooms. Indoor Facility Feature Model describes indoor facility features such as disaster facility, convenience facility, and mobile facility. This research was held by the University of Seoul and was supported by a grant from Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government emphasizes on public institutes such as underground metro stations or public complex buildings where are mass transits of people in indoor space.

More specifically, the Indoor Space Feature Model is developed to manage indoor space and each feature that describes indoor space should be represented in it. Additional feature classes description for indoor space are applied by extending CityGML Building Package. The added feature classes based on CityGML Building Model are Indoor::InteriorBuildingObject and Indoor::Storey. Indoor::InteriorBuildingObject is a feature class to represent indoor space and indoor facilities in the space of the building like meeting rooms, office rooms, or parking lots. It is added not only distinguishing between outdoor space and indoor space, but also representing the rooms and facilities as a set feature. The UML diagram of Indoor Space Feature Model is presented in the figure above. The classes of CityGML are colored in orange, and the classes of CityGML Indoor ADE are painted in yellow. Indoor::InteriorBuildingObject inherits all properties from CityObject of CityGML. All of indoor space feature model inherit the attributes of CityObject, which are class, function, and usage. The class represents the classification of the feature, the function describes the purpose of using the class, and the usage shows where the class can be used. IntBuildingInstallation and Room are aggregated with _AbstractBuilding whose attributes are class, function, usage, yearOfConstruction, yearOfDemolition, roofType, measuredHeight, storeysAboveGround, storeyHeightsAboveGround, and storeyHeightsBelowGround.

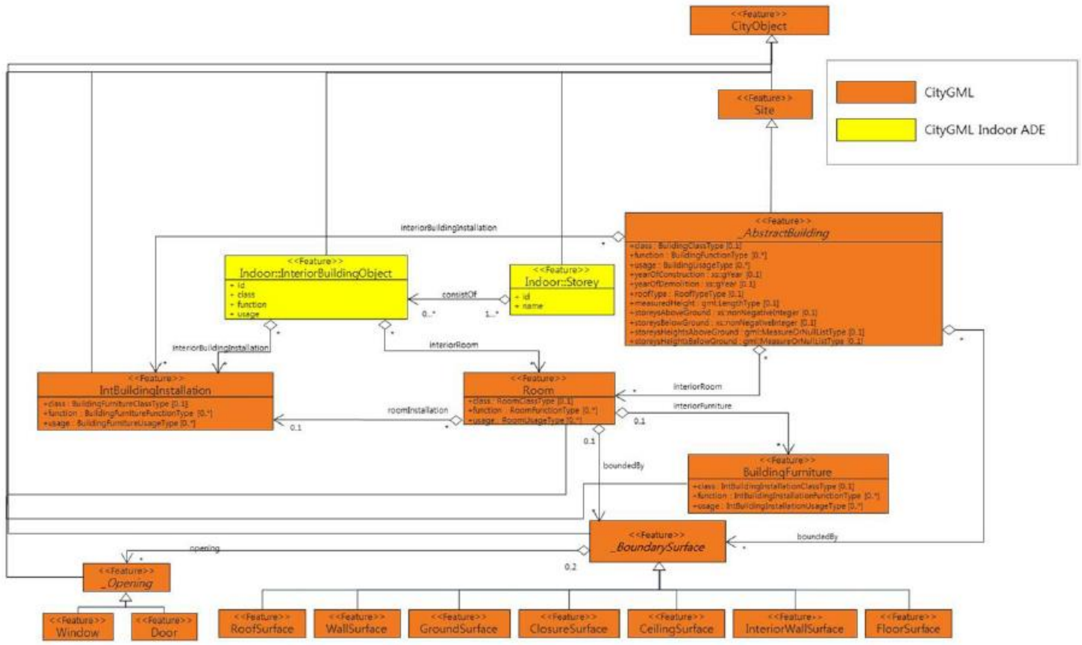


Figure 4.5: Indoor Space Feature Model UML Diagram
Source: Kim et al., Developing CityGML Indoor ADE to Manage Indoor Facilities, 2014

Whereas, Indoor Facility Feature Model is developed for representing indoor facilities and in a way institutes an extending of existing Indoor Space Feature Model. They need additional feature classes for managing public indoor facilities. They define new feature classes and classify them by using and structuralizing the classes. The added feature classes are Indoor::DisasterFacility representing Fire hydrant, emergency call, aid box, Automated External Defibrillator, Indoor::ConvenienceFacility representing telephone booth, digital viewer, railing, information office, information desk and ticket gate, Indoor::OfficeFurniture representing drawer, counseling window, and mirror stand, Indoor::ToiletFurniture in BuildingFurniture representing urinal, and finally Indoor::MobileFacility in IntBuildingInstallation representing elevator, lift, and escalator.

For each application case such as Office furniture or Toilet Furniture, is developed the corresponding UML diagram as represented in the below figure.

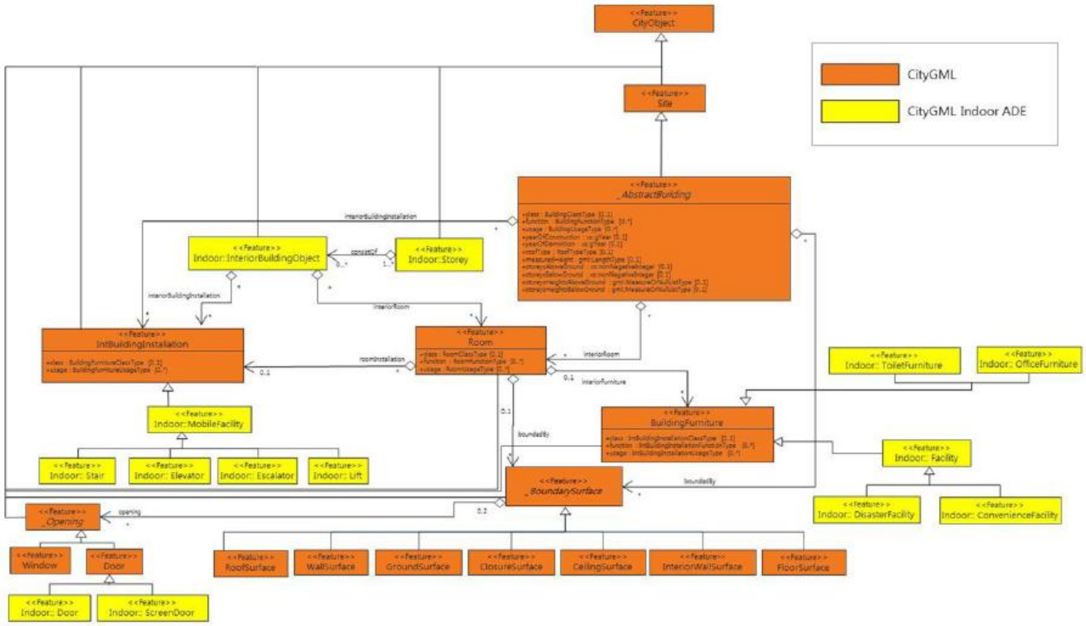


Figure 4.6: Indoor Facility Model UML Diagram
Source: Kim et al., Developing CityGML Indoor ADE to Manage Indoor Facilities, 2014

The proposed Indoor ADE was tested for a complex building office in Seoul. The implementation was done in two steps. The first step includes the validation of the model and the development of an XML schema and a sample XML document based on the schema. Also, representational errors of our model were verified through visualizing sample XML documents. The second step includes the application ability of the proposed data model. In order to show the practical ability of the model, they constructed data of indoor space and facilities in GongBuilder for a 4-storeys building in University of Seoul, Korea. During the data construction, additional attributes are also generated and saved for indoor space features as shown below figures. The material of wall space and ceiling material can be used for facility management. These attributes are used for determining to repair and inspection.

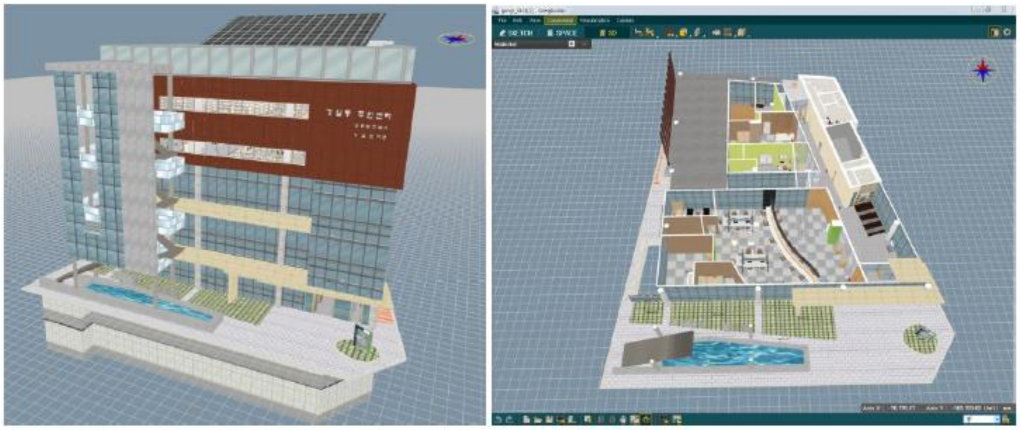


Figure 4.7: Sample Data of Building Office in Seoul
Source: Kim et al., Developing CityGML Indoor ADE to Manage Indoor Facilities, 2014

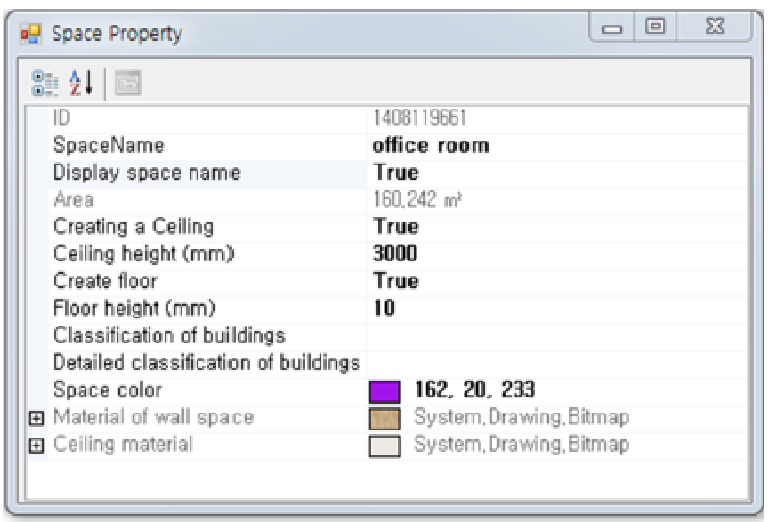


Figure 4.8 :Record of Indoor Space Features
Source: Kim et al., Developing CityGML Indoor ADE to Manage Indoor Facilities, 2014

Indoor facilities also can be applicable for energy management with additional information. For example, speed and capacity properties of an elevator can be used with population of the building to manage flexible operating. Through the implementation of the CityGML Indoor ADE and construction of sample data, we show the CityGML Indoor ADE can be an alternative method for representing indoor space and also can be used for indoor facility management.

4.3 Transformation from CityGML LOD4 to IndoorGML

In terms of interoperability, many researchers tried to integrate and combine existing models in order to take benefit from the respective other area of specialization. Khan et.al 2014, proposed a multi-step transformation process to automatically generate IndoorGML datasets from existing indoor building model data given in either IFC or CityGML LoD4.
Both semantic 3D building models, CityGML and IFC, represent and manage semantic, geometry, and topology information through different approaches, e.g., CityGML uses boundary representations to represent building geometry while IFC mainly uses volumetric and parametric approaches. The researchers' main concern is to exploit data from the existing and use it for other application.

The general concept of the proposed concept is to generate IndoorGML datasets from different semantic 3D building models either represented in IFC or CityGML LoD4 by using the FME tool, developed by Safe Software and determining navigation structures according to the different locomotion types based on their specific navigating constraints.

In order to reduce complexity and to allow the existing semantic 3D building models to be represented both according to IFC and to CityGML, they divided the transformation task into multiple subtasks which are grouped into two main steps. In first step, IFC data is semantically and geometrically transformed to CityGML LoD4 and the topology is analyzed, while in step 2, CityGML LoD4 data is semantically, and geometrically transformed to IndoorGML.

In semantic transformation, particular importance was paid to transform the maximum amount of the semantic information related with each indoor object following the schema rules of the IFC source and the CityGML target object. On the other hand in topology transformation and analysis, great importance was paid to meet the requirements in order to have correct topological relations of indoor building model's objects with their connected geometries, e.g., connected door and room geometries must correctly touch each other, there must be no overlap and they must determine boundary geometry.
IFC standard gives the opportunity to a user to establish a semantic 3D building model in many different ways. In such a way, the transformation tool that is implemented for the first step transformation from IFC to CityGML should be flexible and cover lots of situations
In the second step, the transformation from CityGML to IndoorGML has relatively fixed rules for the semantic and geometric transformation and the research focuses on transforming boundary geometries from CityGML to volumetric space objects in IndoorGML including their semantic information. For example a multi surface room feature is translated into a room solid with its boundary geometries.

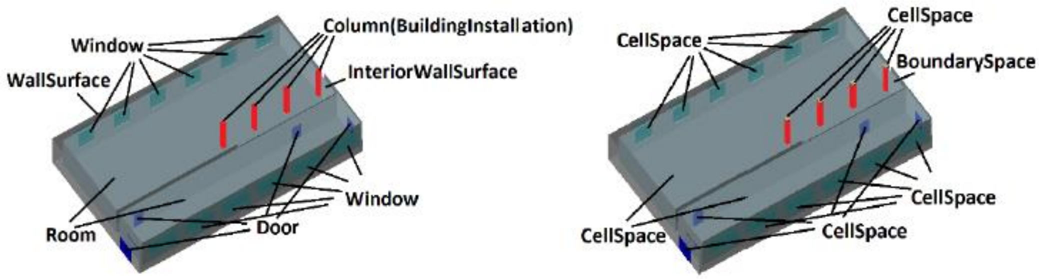


Figure 4.9: Left : 3D Building Model in CityGML, Right :3D Building Model in IndoorGML
Source: Khan et al., A multi-step Transformation Process for Automatically Generating Indoor Routing Graphs from Existing Semantic 3D Building Models, 2014

The third step, after having deriving the IndoorGML building model from IFC or CityGML, includes the computation of routing graphs for the different types of locomotion based on their specific navigating physical constraints. Each type of locomotion, i.e., flying, driving, and walking, as well as Unmanned Aerial Vehicle (UAV), wheelchair, and a walking person respectively were taking into consideration. The indoor navigation constraints of each locomotion type are based on the locomotion type's constraints model defined in Khan and Kolbe (2012). The computation of the navigable spaces for the locomotion types mentioned above was carried out through configuration space mappings based on Minkowaski's sum method. The decision to determine a specific element of the indoor space as navigable or non-navigable for the given locomotion type was taken by considering the physical navigating constraints of the locomotion type and spatial information (semantic, geometric, and topology information) of the element. For example, if the length and width of the door is greater than the length and width of the wheelchair, then the door is considered to be navigable. The indoor space element, which is determined as non-navigable, will determine obstacle space around it to be deducted from the free space.

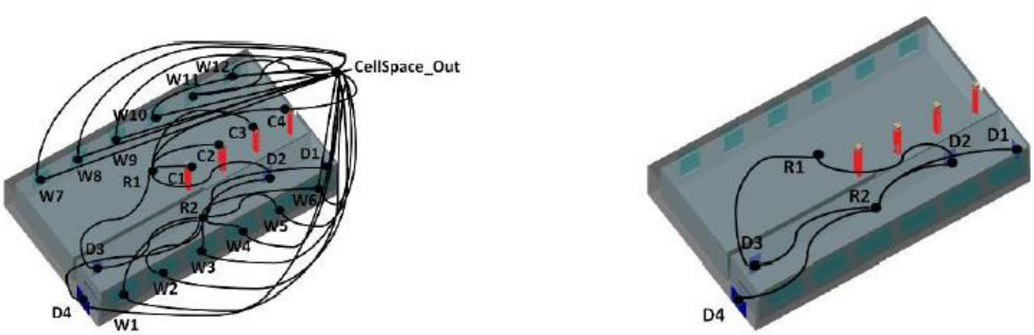


Figure 4.10: Left: Topographic Layer in IndoorGML, Right :Navigable Subspace computed for Wheelchair Navigation
Source: Khan et al., A multi-step Transformation Process for Automatically Generating Indoor Routing Graphs from Existing Semantic 3D Building Models, 2014

The navigable space that is computed through graph based approaches, in essence, used only some geometric position (centroid of the object) and connection information be-tween spatial objects (topological graph). The semantic information (e.g. types of spaces, and properties of building components) and the actual geometry of the object have not been considered yet. In contrast, the subspacing that is proposed was carried out through the configuration space approach uses fully geometric and semantic information from a semantic 3D building model. In addition, if there are obstacles within an indoor space (e.g. column), the methods based on the graphs will fail or be not precise enough for approximating the reasonable navigable space, which may limit the path planning in many route planning applications.

The main result from the whole approach, is that is apparently necessary to compute the accurate subspaces at the geometric level for the given locomotion type and to extract the network models from the navigable space. Also, the fact that the subspaces were created at the geometric level reinforce precise and consider semantic and geometric information of 3D building model in contrast to other approaches. Moreover, a detailed representation of the 3D building model's elements conduce to correct and detailed graphs for indoor navigation. In conclusion, the proposed procedure for the automation of the transformation process and the subspacing is capable to support different types of locomotion for the indoor navigation and also simplifies the process and prevent from manual errors.

4.4 Generating Navigation Logical Model from CityGML

Research on indoor navigation models mainly focuses on geometric and logical models. Geometric models provide information about the structural (physical) distribution of spaces in a building, while logical models indicate relationships (connectivity and adjacency)between the spaces. In many cases geometric models contain virtual subdivisions to identify smaller spaces which are of interest for navigation (e.g. reception area) or make use of different semantics. The geometric models are used as basis to automatically derive logical models. However, there is seldom reported research on how to automatically realize such geometric models from existing building data (as floor plans) or indoor standards (CityGML LOD4 or IFC).

Liu and Zlatanova,2013, presented their experiments on automatic creation of logical models from floor plans and CityGML LOD4, by using Indoor Spatial Navigation Model (INSM) which is specifically designed to support indoor navigation. INSM is a semantically rich model, which follows quite closely the original subdivision of a building but contains different naming of spaces. More specifically INSM, institutes an intermediate model between the existing data and the desired logical model, providing advantages in two directions: it helps in further specification of semantics after a space is identified as NSC and it contains semantics that can facilitate path finding.

The generation of a logical model includes two steps: 1) dividing indoor space into subspaces (which represent nodes), and 2) deriving the topological relationships between the subspaces (which represent edges). Automatic space subdivision is the main challenge in this process. Two approaches can be distinguished here: 1) semantic subdivision, which aims at identifying meaningful subspaces (such as coffee corner or reception) and 2) geometric subdivision, which decomposes the space according to a geometric criteria (grid, triangulation, Voronoi diagrams, etc.). The two approaches have controversies as if the automatic decomposition is ensured, the semantics is unclear and if the semantics of the subspaces is well-defined, it is difficult to provide automatic subdivision algorithm.

The main steps for the automatic extraction of logical navigation models from existing building data are represented in below figure.

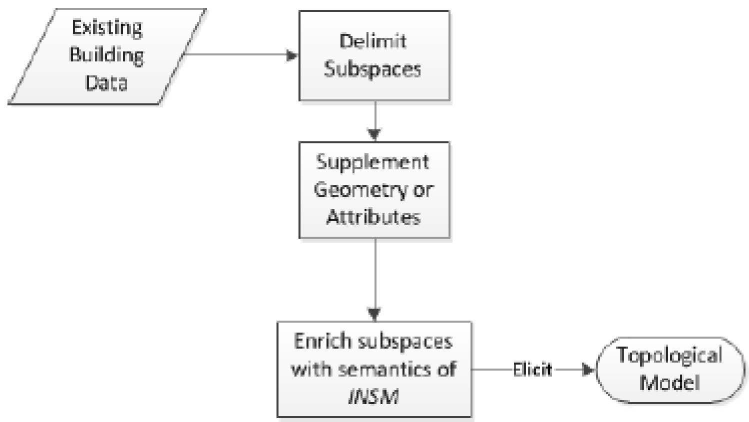


Figure 4.11: Workflow of generating topological model

Source: Liu and Zlatanova, Generating Navigation Models From Existing Building Data, 2013

First, for each specific subspace the boundary is defined and all geometric shapes are identified. Then, all the necessary geometry or attributes are added and all the subspaces are assigned according to definitions of INSM. Finally the logical network is derived.

The conversion from existing building data to INSM data is completed under several assumptions and rules. The main difficulty of automation is declaring the relations between subspaces. As mentioned above to support the conversion from original building data to INSM, some preprocessing of original data is required. Depending on the complexity and semantic richness of data, some information has to be revised.

As mentioned above, the researchers presented two experiments to demonstrate navigation model generation. The first one is based on semantic models and the second one is based on floor plans containing very limited semantics.

More specifically, for the first experiment the used CityGML LoD4 data that was derived by an automatic procedure from OSM as Goetz proposed in 2013.

In order to extract the connectivity network from CityGML file, they checked the semantic relations between rooms and openings, concerning the unique id of each object. In consequence all the openings in the CityGML file were scanned. The connected rooms of every opening were identified and topological relations were built.

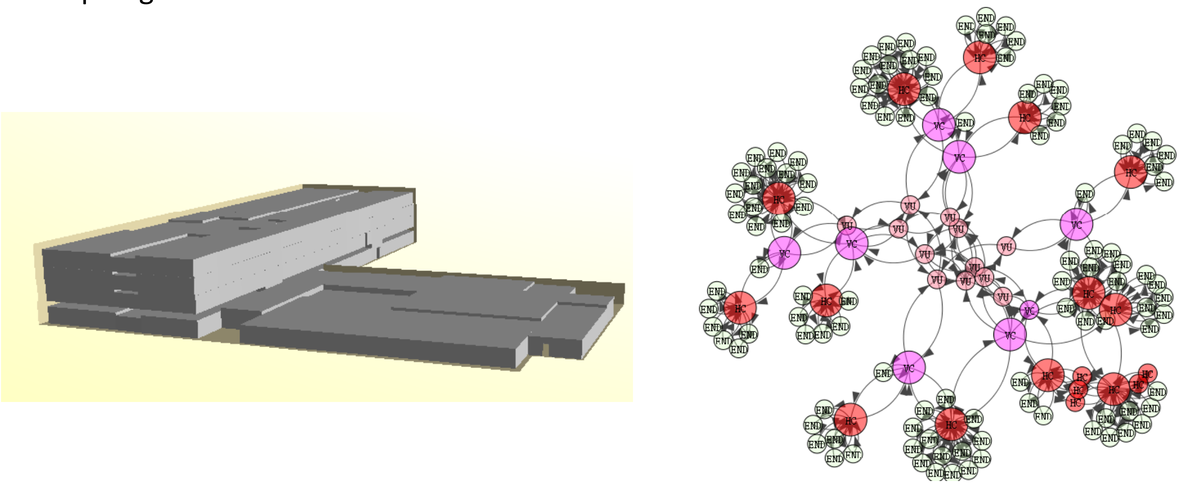


Figure 4.12: Left: The test building, Right: Connectivity Network Enriched with INSM Semantics

Source: Liu and Zlatanova, Generating Navigation Models From Existing Building Data, 2013

However, this reconstruction procedure cannot generate indoor furniture (e.g. desks, chairs, coffee machines, etc.) and also could not provide details for staircase. This problem is overlapped by creating a staircase as a room and getting relatively accurate geometry of regular rooms, doors and windows while adding explicit words ‘stair’ and ‘elevator’ in<gml:name> under the tag <bldg.:interiorRoom> in order to distinguish stairs and elevators.

The second experiment was to create INSM from floor plans. In this case all geometries are polygons and the connections between subspaces are created by checking if neighboring polygons overlap or meet. The floor plans used here are from the high-rise building at Delft named “Vermeer Toren”. The floor plan was created by digitizing manually the image of the floor plan in Bentley Systems and only rooms, including stairs and elevator, corridors, and doors were created. The connectivity per floor was created by checking the overlapping between the geometries in the floor and connections are automatically detected by geometric overlap as well.
The main disadvantage of this procedure is that semantics are rarely included in the original floor plans basically they are pure geometric shapes. Thus, the manual reconstruction of 2.5Dmodel proposed, introduces necessary semantics and rules (overlapping) to facilitate the generation of navigation model.

In overall, semantically rich data sets (CityGML and IFC) are generally straightforward to transform to INSM, while datasets with little or no semantics at all (as the floor plan mentioned above) need additional human interpretation to identify spaces.
However, CityGML lacks direct concepts for vertical building components such as elevators and stairs, which would require either manual interpretation or processing on attributes or geometry.

4.5 Comparison Between CityGML and IndoorGML

CityGML and IndoorGML are both OGC (Open Geospatial Consortium) standards that have been developed for the interoperability between services and reusability of indoor maps. Although CityGML and IndoorGML provide frameworks of standard data models for indoor spaces, the goals and approaches of each standard is different and in such a manner they are used for different purposes.

CityGML, institutes an OGC standard for 3D city model and as an extension of GML consists of core module, appearance module, and thematic modules such as buildings, transportation and vegetation. It also provides five LoDs (Level of Detail), for the representation of the building model. The first level, LoD0 describes the footprint of the building while the last, LoD4 describes the interior spatial objects of the building module. Most feature types of CityGML LoD4 are defined to support indoor objects such as ceiling, openings and furniture. Even though, it can support the indoor objects, CityGML is not appropriate for applications of indoor spatial information, as it does not meet the requirements below:

- Cellular Spatial Representation: in indoor space, the location is indicated by a cellular identifier rather than coordinates. However it is implicit or unclear in CityGML.
- Topology: the topology is extremely important in indoor navigation application as it defines the connectivity graph of indoor space. In CityGML, topology is represented either in implicit or explicit ways but it is not complete.
- Multiple Representations of a single indoor space: a single indoor space can be interpreted in different ways depending on context, such as walk or wheelchair. It is difficult to derive these different interpretations of space by CityGML.

IndoorGML is a standard data model to represent, store and exchange indoor spatial information and a XML application schema based on GML 3.2.1. In contrast to CityGML which focuses on feature types of building components such as roof, ceiling, door, and wall, IndoorGML focuses on the representation of spaces in indoor, in Cells, the basic space unit of the standard. IndoorGML provides a well-structured framework for the representation of geometry, topology, and semantics of cells in indoor space that is appropriate for indoor navigation application.

Hyung et al., 2015, in their research compared the two standards on use case experiments with two real sites a shopping mall at Lotte World Mall (LWM) and a subway station Gongro 5-gain Seoul, South Korea. The indoor spatial data in CityGML has been constructed in two ways for the use case. First the data for LWM has been constructed by using GongBuilder software, which converts its internal 3D building model to CityGML document. Second, the data for Gongro 5-ga subway station has been built in Sketchup by using a plugin which exports the model in CityGML document. Concerning, the development of IndoorGML model for both sites, they used JINedit, a simple editing tool to make indoor network and extracted the geometry of cells and cell boundaries from the Room footprint of CityGML.

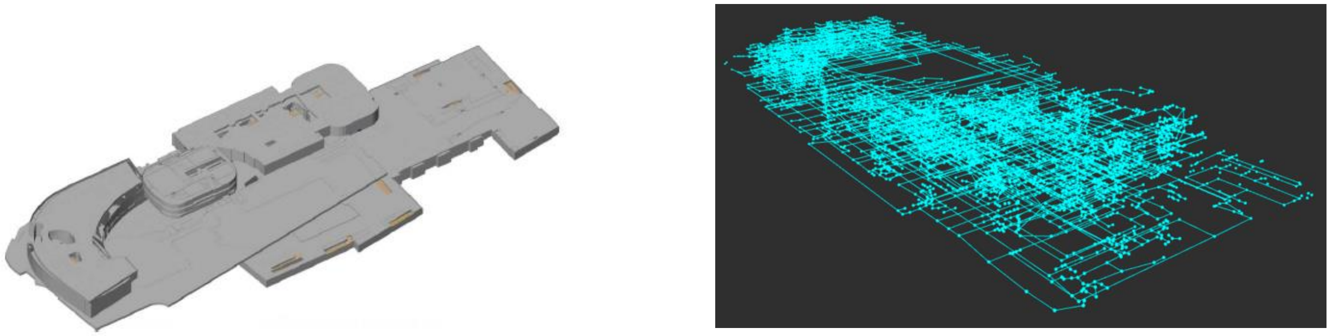


Figure 4.13 : Left :CityGML data for LotteW orld Mall, Right : IndoorGML data for Lotte World Source :Ryoo H-G et.al, Comparison Between two OGC standards for Indoor Space –CityGML and IndoorGML, 2015

The researchers defined the differences in both construction and application view point of the two standards. Concerning the construction point of view the main differences between two standards are noted below:

- In CityGML, a cell can be represented only as an instance of Room. In such manner, the geometry of staircases is defined but it is not mandatory to define an additional feature in order to identify the cell's use. In IndoorGML, however stairs are not included to the module's structure, they are represented as a cell of closed space.
- In CityGML, some part of boundary of wall and door can be missing. For example, no CeilingSurface or FloorSurface are defined for walls. However, in IndoorGML wall boundaries could be defined as an independent cell by thick-wall model.
- In CityGML, there is no explicit topological constraint between and a room can be located in a room. On the other hand, in IndoorGML something this fact is strictly forbidden. The nesting room must be defined a solid with holes and the nested room must be another solid located at the hole of the nesting room.
- In CityGML, the decomposition is not mandatory with the exception of the case that is needed to distinguish the attribute of cell such as function or usage. However, in IndoorGML the decomposition of big cell is an important requirement and the rule for decomposition depends on type of applications.
- In CityGML, a door is attached on two instances of Interior WallSurface with different orientations respectively. However, in IndoorGML it is not possible to distinguish the face orientation of door as the wall surface as a type of space, where objects are located and events take place is not considered.
- In CityGML, every wall surface is considered as a feature with attributes and textures. However, in IndoorGML wall surface is defined as an independent feature and texture is not

assigned since the visualization is not among the purposes and more precisely no orientation is defined for wall surface.

Concerning the application point of view, the researchers developed a set of application scenarios for the use-case site at Lotte World Mall. The scenarios were not implemented but were merely virtual application services. The differences between the two standards that derived by the implementation of each scenario are noted below:

- Scenario 1 :Visibility Analysis from Attraction Point

Both standards require performing the visibility analysis. CityGML for the viewshed computation step and IndoorGML for the Searching stores within viewshed.

- Scenario 2 :Visibility Analysis from Attraction Path

Visibility analysis from attraction path is very similar with visibility analysis for attraction point except that the viewshed is computed from a curve. CityGML supports the computation of viewshed from curve since while IndoorGML does not include detail 3D geometry information of features. However, it is impossible to find the stores overlapping with the viewshed with CityGML if the geometry of Room is not closed solid.

- Scenario 3 :Path Analysis Between two Attraction points

Not a single standard covers the entire process of this application scenario and a proper integration of CityGML and IndoorGML is required to handle this service.

- Scenario 4 : Trajectory Analysis

IndoorGML supports the indoor trajectory analysis better than CityGML as the cellular space model is more relevant to analyze indoor trajectories than Euclidean space.

- Scenario 5 : Movement Pattern and Context Analysis

IndoorGML supports the step of context analysis to determine whether a visitor is staying or moving better than CityGML. The other functions of context analysis are difficult and complicated that only a proper integration of CityGML or IndoorGML could support them.

Briefly the comparison results are depicted on below table.

Viewpoint	**CityGML LoD 4**	**IndoorGML**
Model	Feature Model	Cellular Space Model
Visualization	>	
Geometric analysis	>	
Cell finding	<	
Hierarchical Representation	<	
Route analysis	<	
Context analysis	<	

Figure 4.14: Summary Table of Comparison
Source: Ryoo et.al, Comparison Between two OGC standards for Indoor Space –CityGML and IndoorGML, 2015

In overall, although CityGML can be used to represent indoor space in LoD4, it is not an appropriate data model to manage indoor space facilities. CityGML may need to define detailed classes to describe facilities in indoor space, because CityGML data model is focusing mostly on urban space. In other words, CityGML Building Model needs to be expended to deal with additional classes used for indoor facility management application. On the other hand, IndoorGML is appropriate for indoor navigation applications as this standard includes the geometry, topology and the semantics of cells in indoor space.

5. CASE STUDY

This section presents an implementation of the theoretical background that was analyzed in the previous chapters. More specifically, an IndoorGML model was developed for the building complex of Rural and Surveying Engineering of the National Technical University of Athens. The development of the IndoorGML model was generated directly by an IndoorGML Editor and not via transformations from other models. Moreover, the developed model was visualized by an IndoorGML Viewer. In consequence, it will be presented in detail all the techniques and methods that were followed for the development of the IndoorGML model.

5.1 Building Information

The IndoorGML model was developed for the complex of buildings of the Rural and Surveying Engineering Department of the National Technical University of Athens. The buildings are located within the University 's Campus Area, in Zografou, Athens. The building complex is consisted of two main buildings, which are connected by an overhead bridge. The older and bigger building (Lampadario Building) has been through many expansions mainly on its southern eastern part and overlays in 3 floors for its most extend. The north western building (Vei building) was later constructed and is consisted of a basement, a ground floor and two more floors above. The bridge connection is made by the ground floor of Lampadario building to the first floor of Vei Building.

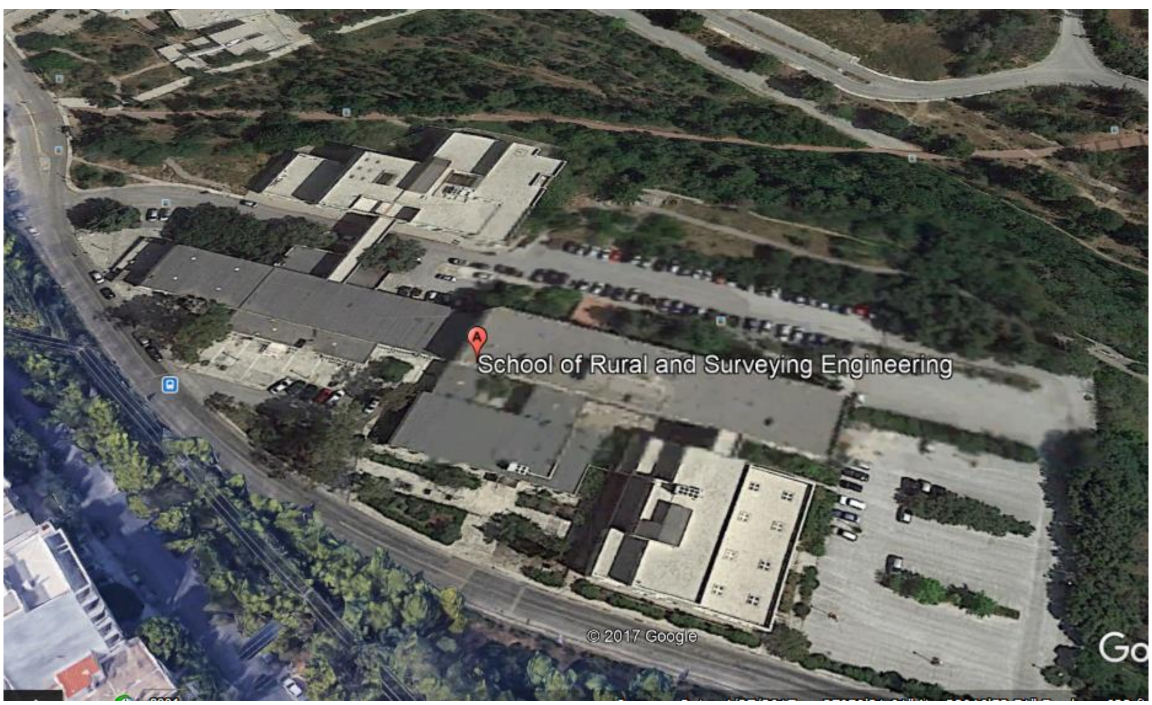


Figure 5.1: Case Study Buildings

5.2 Tools and Data

As IndoorGML standard has been published in 2014, there are few tools dealing with it. Open Source Tools have been developed for handling spatial data, but they are not that progressive in indoor space. To this end, the development of new tools or implementation of additional function for IndoorGML on existing tools is required. Within this framework, different universities in South Korea have been through research for developing tools for editing and visualization of IndoorGML models. As mentioned in chapter 4, researchers from the Korea Institute of Construction Technology developed an editor and a viewer based on IndoorGML schema according to international standardization process. The editor and the viewer support editing and visualizing the indoor space as represented in IndoorGML standard. These tools are not available for download and use through Internet.

Whereas Dongun Seo from the Pusan National University of North Korea, launched JInedit (Java IndoorGML Editor), an open source Java program that provides tools for simple editing IndoorGML data. JInedit licensed under the LGPL **L***esser* **G***eneral* **P***ublic* **L***icense*) the license that accompanies some open source software that details how the software with accompany source code can be freely copied, distributed and modified. JInedit is available for download in the platform of GitHub and its set up requires the installation of two more tools Java Development Kit 8 (JDK 8) and Maven-Apache, a software project management and comprehension tool.

Concerning the IndoorGML viewer Soojin Kim and Hyung-Gyu Ryoo from the Pusan University of North Korea, developed a WebGL IndoorGML Viewer by using Three.js, browserify and jsonix. This project is licensed under the MIT License and it is available for downloading in GitHub platform. This tool is user friendly as is easily getting started by dragging the index.html file into an internet browser and just import the IndoorGML file. The tools interface is divided into two parts, the scene where the model is visualized and the side bar where the model's information appears. Also by clicking an element, you can see not only the details of element in PROPERTIES tab, but also geometry highlighted in Viewer. The properties that are shown are: id, name, xlink of connected element, duality and so on about clicked element.

The JInedit and the WebGL IndoorGML Viewer are the two tools that were implemented for the development and the visualization of the developed IndoorGML model accordingly.

Regarding the required data for the development of the IndoorGML model for the University Building the available data is listed below:

- Architectural Design (floorplans) for all floors of the Vei building and their sections in dwg format
- Architectural Design for all floors of the Lampadario building and its sections in dwg format
- Architectural Design of Extensions-New Offices in dwg format

From the floor plans the space layout of the each building's floor, the buildings openings, the stairs and elevators and each room operation were defined. Moreover, the buildings' location were specified by the Orthophotos Viewing Service available from of National Cadastre and Mapping Agency S.A.

5.3 Implementation

As mentioned above, JInedit java program was used for editing the IndoorGML model of the case study's buildings. As an open source Java program, JInedit requires the installation of Java Toolkit (JDK 8) and a software project management and comprehension tool (Maven-Apache). After these installations, the JInedit was executed via the Command Prompt. The program's interface is presented in the figure below (see Figure 5.2).

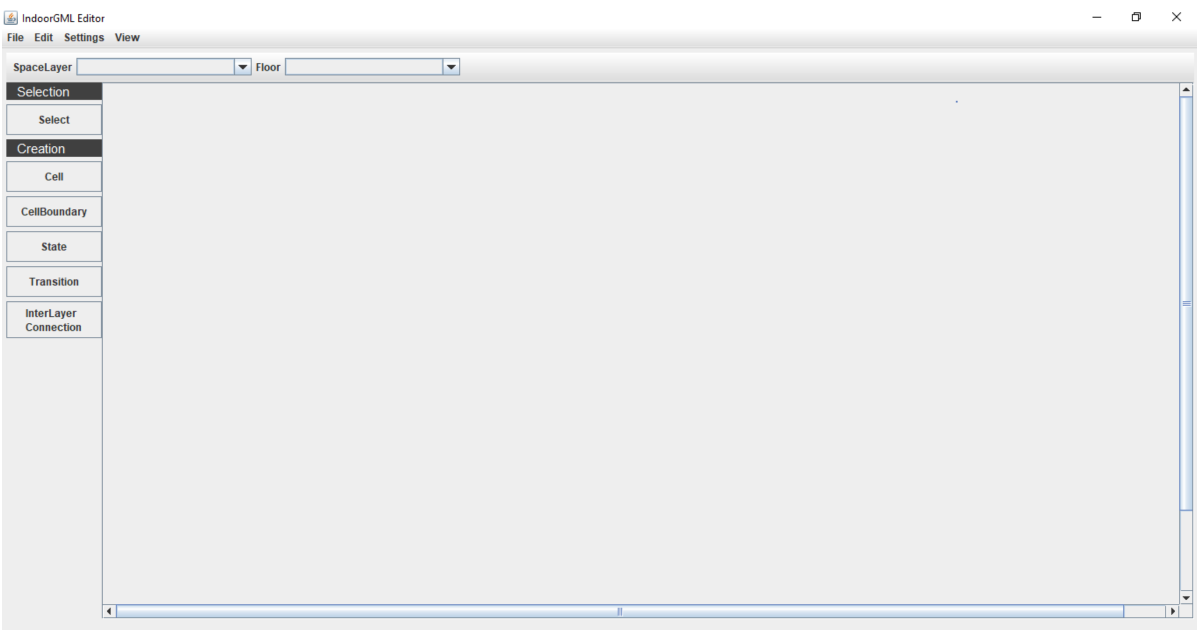


Figure 5.2: JInedit Software Interface

JInedit is a user friendly editing IndoorGML tool, for the floor layouts to be to the program. Then the user defines the rooms' boundaries by digitizing polygons as well as the states (nodes) and transitions (edges) by making the appropriate connections with lines.

JInedit can only import the layouts as images in jpeg format, so the buildings architecture designs need first to be exported from AutoCAD software to pdf format and then the pdf files are transformed to jpeg files via an internet tool.

As there is an overhead bridge to connect the two buildings, the architectural designs of the two building were joined into one file for each floor. This procedure resulted in five layouts, one for each floor (underground, ground floor, 1^{st}, 2^{nd} and 3^{rd} floor) in jpeg format.

After the implementation of the JInedit program all the floor layouts were inserted one by one. Each jpeg file inserted, was accompanied by semantic information about floor: the level, the coordinates of left bottom point and right top point, the ground, the ceiling and the door height. (see Figure 5.3)

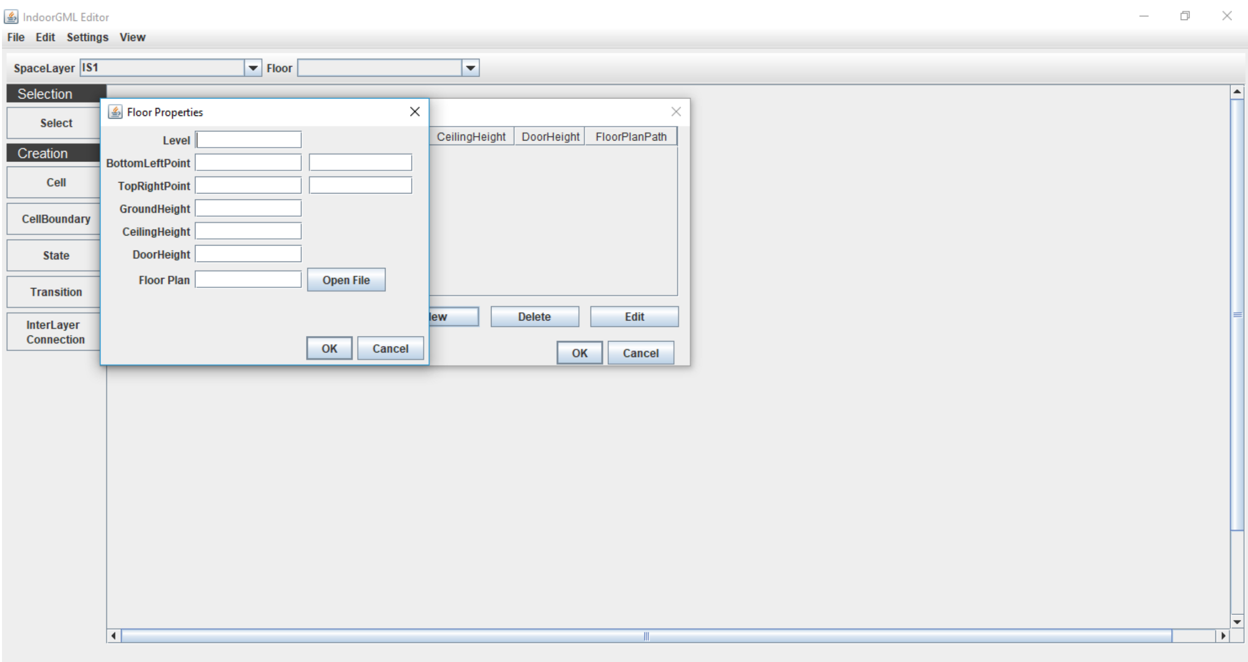


Figure 5.3: JInedit Window Dialogue insertion of Floor Properties

After creating the floors' information, each floor was selected and IndoorGML data was edited. First, the CellSpace Objects were defined by selecting Cell and digitizing a polygon for each room according to layout. Each cell represents a room and the cells must not overlap. Following, the Door- Thick Door Model was created as cells and then by right clicking the cells were defined as Doors. The same procedure was performed for the elevator, stairs and corridors. (see Figure 5.4)

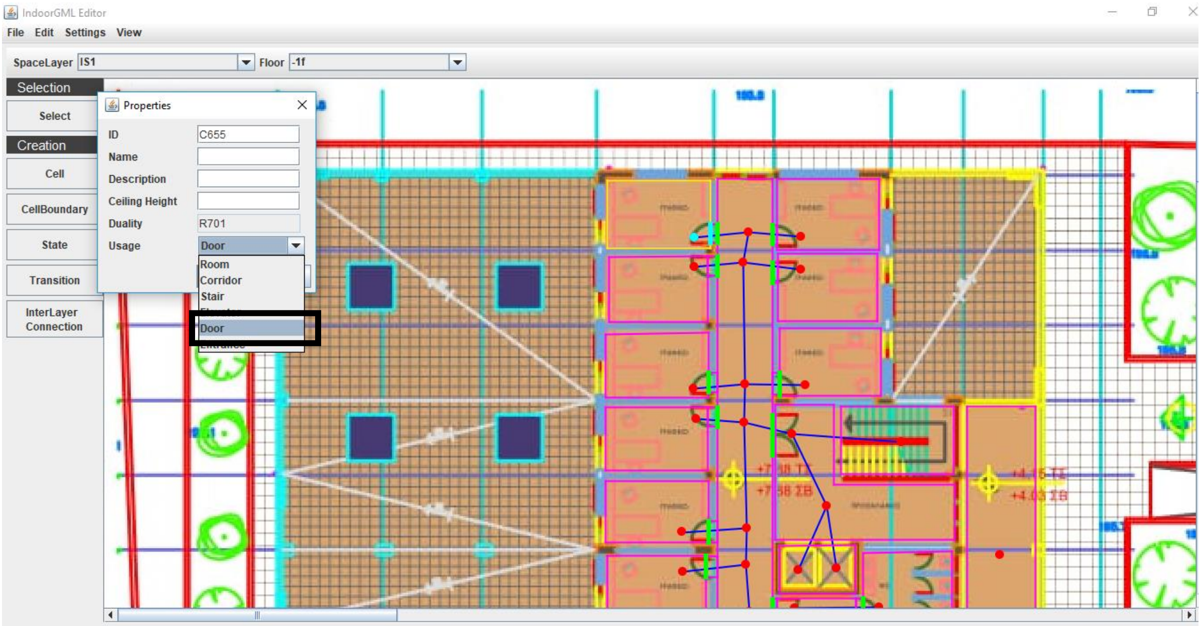


Figure 5.4 : JInedit Window Dialogue defining Door Model

Each cell by its generation has a state. The next step was to connect the states and make transitions through the space layout. The transitions were made between states that approach each other and were characterized by duality. In such a way, the IndoorGML data of each floor was structured, concluding to a SpaceLayer that involves all floors IndoorGML data that can be exported to IndoorGML format.

The topological relationships such as adjacency and connectivity are defined by explicit associations within the IndoorGML data model. In the Structured Space Model, topological relationships between 3D (or 2D) spatial objects are represented within topology space. By applying the duality transformation, the 3D cells in primal space were mapped to nodes (0D) or states as are called in IndoorGML standard in dual space. The topological adjacency relationships between 3D cells were transformed to edges (1D) or transitions for IndoorGML standard linking pairs of nodes in dual space.

The SpaceLayer represents a separate interpretation and a decomposition layer and it is composed of States and Transitions which represent nodes and edges of NRG for dual space, respectively. The NRG and state-transition diagram for each layer are realized by SpaceLayer. Basically the NRG as part of the Structured Space Model is implemented in IndoorGML model.

Also, JInedit gives the opportunity to create more SpaceLayers since the same indoor space is often differently interpreted depending on application requirements. Each SpaceLayer results in a NRG. For example, the layers for topographic space layer, WIFI sensor space layer, and RFID sensor space form independent structured spaces and each layer results in a different NRGs. Moreover, SpaceLayers of the same real space could be connected by InterLayer Relations. The combination of the SpaceLayers is made by matching common states into each SpaceLayer.

The last step in JInedit was to make the export in IndoorGML either in 2D space as an NRG or in 3D space by representing also the cells volumes.

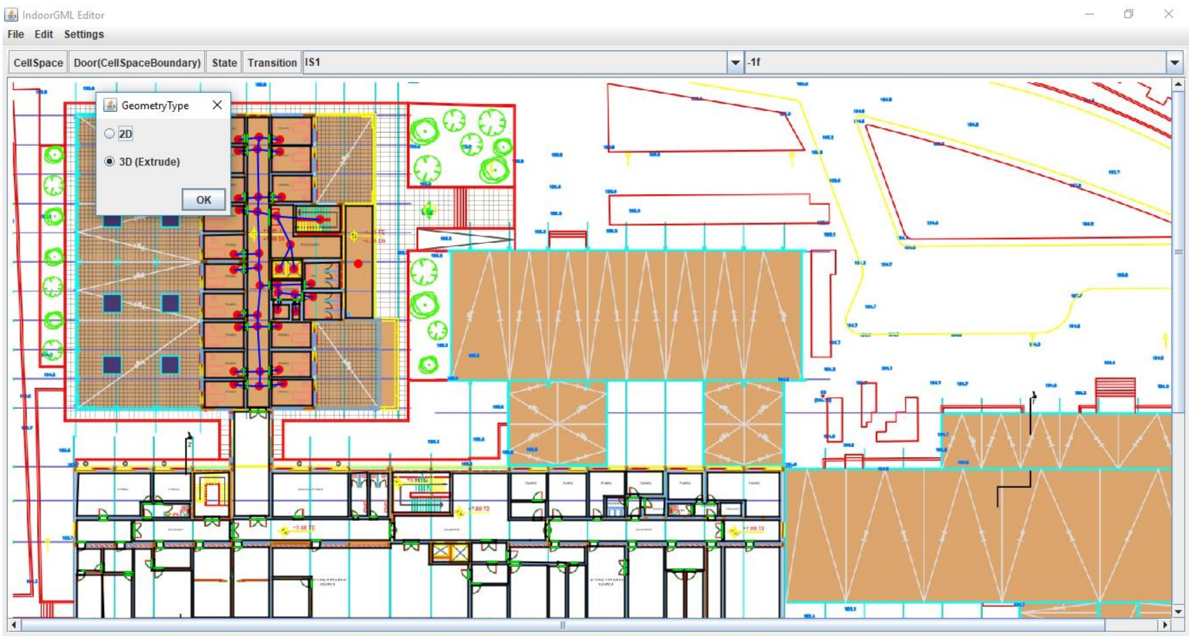
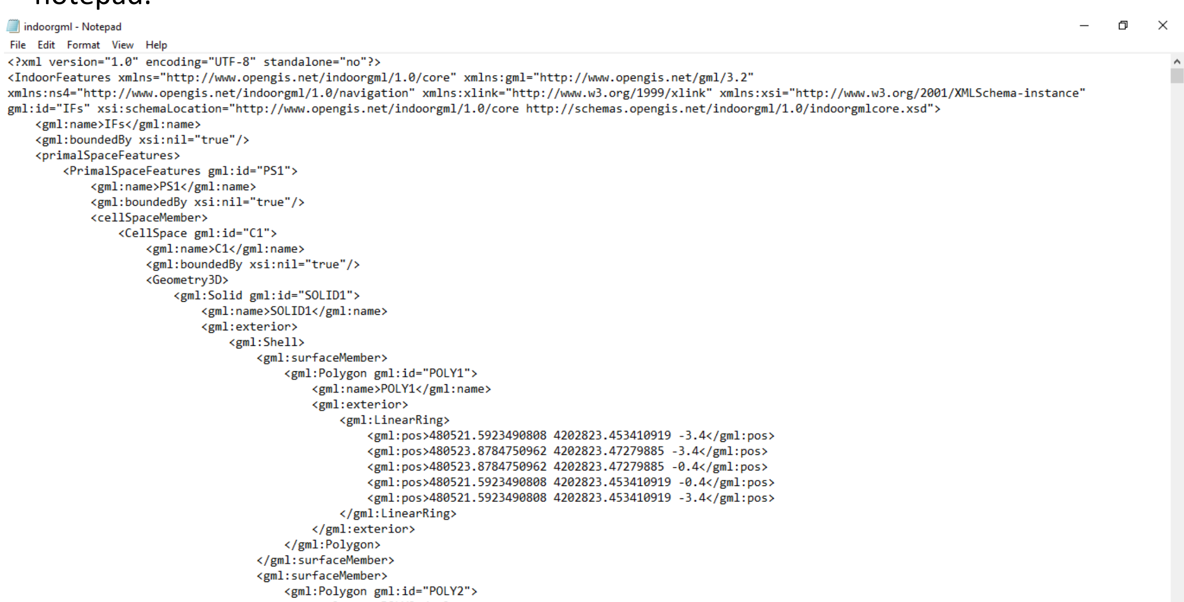


Figure 5.5 : JInedit Window Dialogue Exporting in IndoorGML format

The generated IndoorGML file has no file extension and is a file in xml that could be opened by notepad.




```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<IndoorFeatures xmlns="http://www.opengis.net/indoorgml/1.0/core" xmlns:gml="http://www.opengis.net/gml/3.2"
xmlns:ns4="http://www.opengis.net/indoorgml/1.0/navigation" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
gml:id="IFs" xsi:schemaLocation="http://www.opengis.net/indoorgml/1.0/core http://schemas.opengis.net/indoorgml/1.0/indoorgmlcore.xsd">
    <gml:name>IFs</gml:name>
    <gml:boundedBy xsi:nil="true"/>
    <primalSpaceFeatures>
        <PrimalSpaceFeatures gml:id="PS1">
            <gml:name>PS1</gml:name>
            <gml:boundedBy xsi:nil="true"/>
            <cellSpaceMember>
                <CellSpace gml:id="C1">
                    <gml:name>C1</gml:name>
                    <gml:boundedBy xsi:nil="true"/>
                    <Geometry3D>
                        <gml:Solid gml:id="SOLID1">
                            <gml:name>SOLID1</gml:name>
                            <gml:exterior>
                                <gml:Shell>
                                    <gml:surfaceMember>
                                        <gml:Polygon gml:id="POLY1">
                                            <gml:name>POLY1</gml:name>
                                            <gml:exterior>
                                                <gml:LinearRing>
                                                    <gml:pos>480521.5923490808 4202823.453410919 -3.4</gml:pos>
                                                    <gml:pos>480523.8784750962 4202823.47279885 -3.4</gml:pos>
                                                    <gml:pos>480523.8784750962 4202823.47279885 -0.4</gml:pos>
                                                    <gml:pos>480521.5923490808 4202823.453410919 -0.4</gml:pos>
                                                    <gml:pos>480521.5923490808 4202823.453410919 -3.4</gml:pos>
                                                </gml:LinearRing>
                                            </gml:exterior>
                                        </gml:Polygon>
                                    </gml:surfaceMember>
                                    <gml:surfaceMember>
                                        <gml:Polygon gml:id="POLY2">
                                            <gml:name>POLY2</gml:name>
```

Figure 5.6 : IndoorGML Model file

Then the IndoorGML file was opened in the WebGL IndoorGML Viewer, which executes via an Internet Browser and the IndoorGML Model was visualized in 3D space.

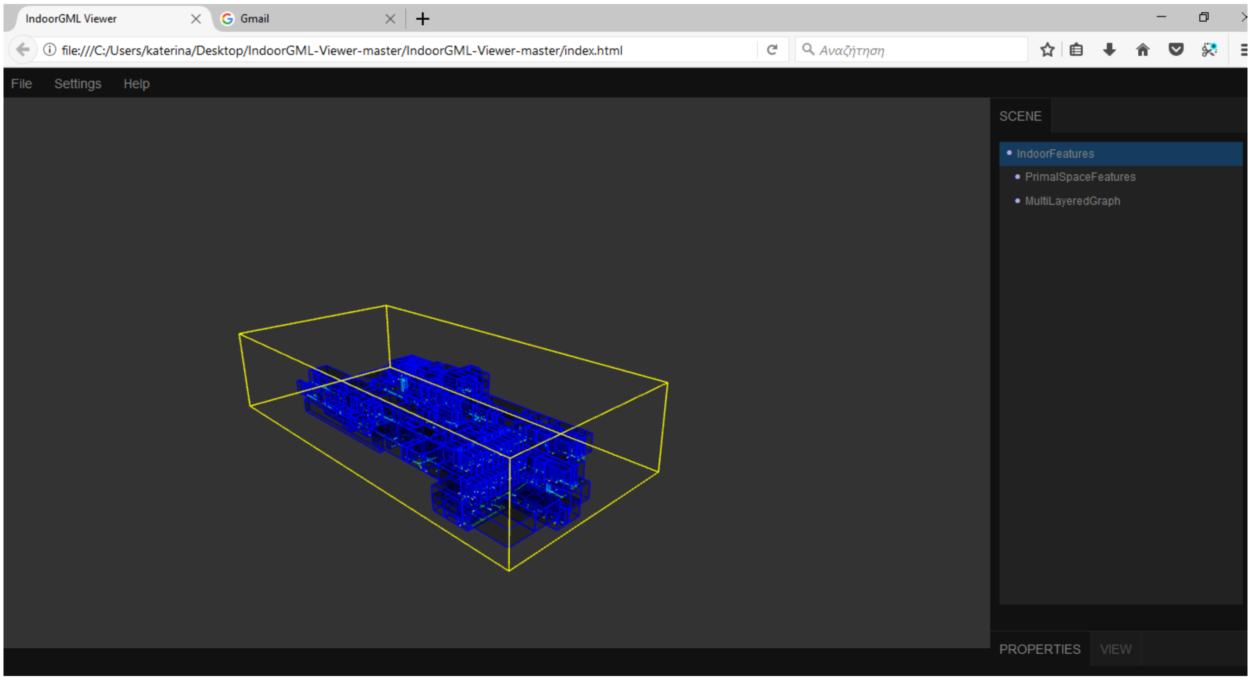


Figure 5.7: Visualization of IndoorGML Model in 3D space

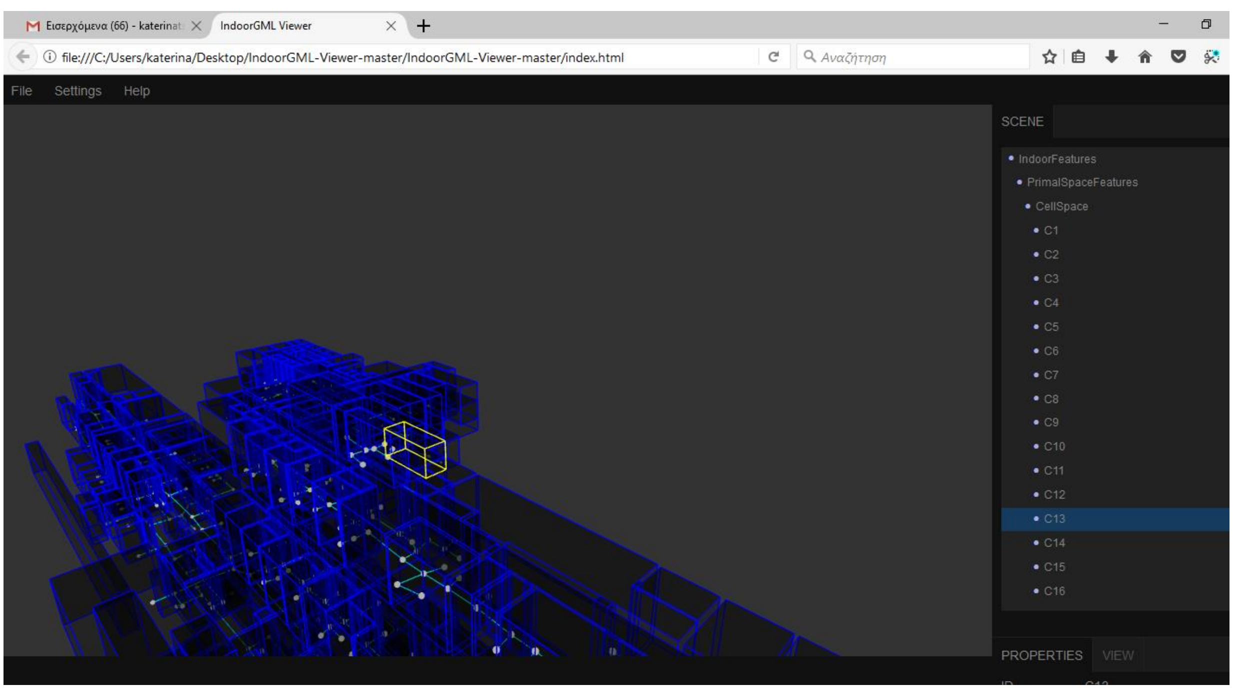


Figure 5.8: Visualization of IndoorGML Model in 3D space –Model Information

As shown in the figure above, the cells are visualized as volumes and the NRG is also shown for each floor. The side bar contains the model's information and also by clicking a model's element such us space volume, cell boundary, state or edge, the name of element is appeared in PROPERTIES tab, and the geometry is highlighted in Viewer. Accordingly, by choosing an element from the list in the side bar, the geometry of chosen element is highlighted in model 's view

5.4 Results

From the case study examined and the IndoorGML model procedure, several advantages, disadvantages as well as difficulties were arisen and are presented in this section.

For the development of the IndoorGML model via the JInedit tool, the data required is not difficult to be found as just the floors layouts in jpeg format, the ground, ceiling and door height and the building coordinates are only needed.

Concerning the tools that were used, the main tool of the implementation, JInedit tool was not proved that efficient. Despite the fact that it is relatively user-friendly, especially for users with skills in design and GIS programming, some skills in programming are necessary so that the program is installed, as it is an open Java program. Moreover, difficulties were faced at the development of the model as the program was not always well responding. More specifically, the program didn't respond to the model requirements as the data size was increasing. However, unlike the operation problems the JInedit editor is efficient as gives the ability to aggregate indoor objects by defining the type of each CellObject (room, door, entrance, stairs, elevator). Also, it enables inserting semantic information for the created items (cells, states, transitions) as for each one the user can define a name and a description. Finally, the option of creating more than one SpaceLayers for a model, make InterLayerConnections and develop multilayered space event models is provided.

The visualization by WebGL IndoorGML Viewer was proved adequate for the specific implementation. This tool is simple in use and can display all the IndoorGML model properties in an efficient way.

Concerning the developed IndoorGML model, it seems that it is an indoor model that can be used in many indoor navigation applications. However, this model could not support information about furniture, balconies, terraces and sheds.

An interesting potential of the developed model is to create SpaceLayers for emergency situations (such as fire, flood or earthquake) by creating escape routes. Another interesting prospective could be to create a SpaceLayer for accessibility options (prohibition or allowance) of each cell according to the status of each navigation user. For example students do not have access to storage rooms or building's administration rooms.

6. CONCLUSION /DISCUSSION

In this thesis, an IndoorGML model for a complex of building was developed by using an open Java IndoorGML editor, visualized in a WebGL Viewer.

As IndoorGML standard has been recently published, there are few tools dealing with it. Open Source Tools have been developed for handling spatial data, but they are not that in advanced yet in indoor space. In such a way, the development of new tools or implementation of additional function for IndoorGML on existing tools is required. In our days indoor navigation is necessary, so there is the need for a tool that generates and edits data and a whole computer and network structure that could support the IndoorGML standard.

IndoorGML editing tool needs to be able to edit indoor spatial and network information. Also, a Data Format Handler, handling IndoorGML and other Data Format is required. GDAL/OGR supports and handles various format types such as shp, dwg and dxf. For indoor space, the Data format handler needs to support representative data models such as IndoorGML, CityGML and IFC. Moreover, a Spatial DBMS that stores not only geometric data but also indoor network data is required and similar to PostGIS, a module for the network data needs to have the option to be extended from Postgresql. Furthermore, a data server that can perform various queries like GeoServer would be productive for the indoor geospatial data management. Last, an indoor viewer for 2D and 3D space is required, where the 2D indoor viewer, switches a floor in multi-story building and the 3D viewer that could support various navigation modes.

Nowadays, the term of interoperability is fundamental in all research fields. To this end, existing data should be able to apply by different standard and applications. Concerning, IndoorGML there is no exclusive need to construct IndoorGML data from the scratch if there are indoor data in other formats such as CityCML or IFC models as it was presented in chapter 4.

Since IndoorGML is still at its first stage, many additional concepts and features need to be added as future works from the following viewpoints. First, more use-case studies on IndoorGML are required, from indoor routing services to indoor context-awareness and indoor data analysis. Moreover, additional extensions of IndoorGML may be developed for common application domains and the development on the core part of IndoorGML is also expected throughout these case studies and extensions.

An interesting IndoorGML extension that is under research is the connection of IndoorGML with LADM, from Zlatanova et.al, 2016 in Deft University. The connection appears natural and could have benefit for both models. IndoorGML can be augmented with space cell based on rights, restrictions, responsibilities and LADM can inherit the geometry from the IndoorGML partitioning and/or aggregation. The next researcher objective to establish a set of geometric and topological operations which can ensure that the descriptive definition can be accurately modeled which is the most appropriate for enhancing IndoorGML space definition (a space layer or direct link).

BIBLIOGRAPHY

- Anagnostopoulus, C., Testsos, V., Kikiras, P., Hadjiefthymiades, S. P., (2003), OntoNav: A Semantic Indoor Navigation System. *In: First International Workshop on Managing Context Information in Mobile and Pervasive, Cyprus 2005*
- Becker T., Nagel C. , Kolbe T.,(2008) A Multilayered Space-Event Model for Navigation in Indoor*, 3D Geo-Information Sciencies,* pp. 61-77
- *Hwang J-R., Kang H-Y, Choi J-W, (2012),* Development of an Editor and a Viewer for IndoorGML*, Proceedings of the Fourth ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness*
- Kang H-K, Li K-J, (2017), A Standard Indoor Spatial Data Model-OGC IndoorGML and Implementation Approaches, *ISPRS International Journey of Geo-Information 2017*
- Khan A-A, Donaubauer A., Kolbe T.,(2014), A multi-step Transformation Process for Automatically Generating Indoor Routing Graphs from Existing Semantic 3D Building Models,*9th 3DGeoInfo Karlsruhe, Germany 2014*
- Kim Y., Kang H., Lee J., (2014),Developing CityGML Indoor ADE to Manage Indoor Facilities, *Innovations in 3D Geo-Information Sciences,* pp. 243-262
- Kim Y.-J, Kang Y., Lee J., *(2013), Development of Indoor Spatial Data Model Using CityGML ADE, ISPRS 8th* 3D GeoInfo Conference & WG II/2 Workshop, Istanbul, Turkey, 2013
- Kolbe T.,(2009), Representing and Exchanging 3D City Models with CityGML, *3D Geo-Information Sciencies,* pp. 15-31
- Lee J., Li K.-J, Zlatanova S, Kolbe T., Nagel C., Becker T., (2015), OGC® IndoorGML, Open Geospatial Consortium, 2016
- Li K-J and Lee J., (2010)Indoor Spatial Awareness Initiative and Standard for Indoor Spatial Data*, Proc. IPOS 2010*, pp.76-80
- Li Joune-Ki, (2016), IndoorGML – A Standard for Indoor Spatial Modeling (extended abstract) , *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B4, 2016 XXIII ISPRS Congress*, Prague, Czech Republic
- Li K.-J., Ryu H.-G., Kim H.-K, Lee J.-H.., Lee J.-H, (2016), Comparing CityGML and IndoorGML based on a use case at Lotte World Mall, *Open Geospatial Consortium,2016*
- Li Y., Zizhang HE, 2008, 3D Indoor Navigation : a Framework of Combination BIM with 3D GIS*, 44 th ISOCARP Congress, 2008*
- Lui L., Zlatanova S., (2011*),* Towards a 3D network model for indoor navigation*, Urban and Regional Data Management: UDMS Annual 2011,* pp.77-92
- Liu L., Zlatanova S.,(2011) A ”Doo-to-Door” Path-Finding Approach for Indoor Navigation, *Proceedings Gi4DM 2011: GeoInformation for Disaster Management, Antalya, Turkey, 2011*
- Liu L., Zlatanova S.,(2013) Generating Navigation Models From Existing Building Data, *ISPRS Acquisition and Modelling of Indoor and Enclosed Environments Cape Town, South Africa, 2013*

- Mirvahabi S., Abbaspour R., 2015, Automatic Extraction of IndoorGML Core Model from OpenStreetMap, *International Conference on Sensors & Models in Remote Sensing & Photogrammetry, Kish Island, Iran,2015*
- *Mortari F. , (2013),* Automatic Extraction of Improved Geometrical Network Model From CityGML for Indoor Navigation, *Master Thesis*
- Nagel C., Becker T., Kaden R., Li Ki-Joune, Lee J., Kolbe T.,(2010), Requirements and Space-Event Modeling for Indoor Navigation, Open Geospatial Consortium
- Ryoo H-G, Kim T., Li K.-J.,(2015),Comparison Between two OGC standards for Indoor Space –CityGML and IndoorGML*, 2015*
- Teo T-A, Yu S-C, (2017),The Extraction of Indoor Building Information from BIM to OGC IndoorGML, *FOSS4G-Europe – Academic Track, Marne La Vallée, France 2017*
- Zatlanova S., Oosterom V., Lee J., Li K-J, Lemmen C.H.J,(2016) LADM and IndoorGML for Support of Indoor Space Identification, *11th 3D Geoinfo Conference, Athens, Greece,2016*
- Zatlanova S., Oosterom V., Li K-J, Lemmen C.H.J, Oosterom P. (2016),Indoor Abstract Spaces : Linking IndoorGML and LADM, *11th 3D Geoinfo Conference, Athens, Greece , 2016*