Delft University of Technology

The -Integration of LADM and IndoorGML to Support the Indoor -Navigation Based on the User Access Rights

Alattas, A.F.M.

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

The Integration of LADM and IndoorGML to Support the Indoor Navigation Based on the User Access Rights

Abdullah Alattas

The Integration of LADM and IndoorGML to Support the Indoor Navigation Based on the User Access Rights

Abdullah Alattas

A+BE | Architecture and the Built Environment | TU Delft BK

The Integration of LADM and Indoor GML to Support the Indoor Navigation Based on the User Access Rights

———

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, prof.dr.ir. T.H.J.J. van der Hagen
chair of the Board for Doctorates
to be defended publicly on
Friday 11 March 2022 at 10:00 o'clock

by

Abdullah Faisal Mohammed ALATTAS
Master of Science in Cartography
Technical University of Munich, Germany
born in Jeddah, Saudi Arabia

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus,	chairperson
Prof.dr.ir. P.J.M. van Oosterom	Delft University of Technology, promotor
Prof.dr.techn. S. Zlatanova	University of New South Wales, copromotor

Independent members:

Prof.dr.ir. C.H.J. Lemmen	University of Twente
Prof.dr.ir. P.H.A.J.M. van Gelder	Delft University of Technology
Prof.dr. L.C.M. Itard	Delft University of Technology
Prof.dr. K.-J. Li	Pusan National University, South Korea
Prof.dr. Ü. Işıkdağ	Mimar Sinan Fine Arts University, Turkey

To my father:
Every day has been difficult without you, but today, in particular,
I cannot help but think how much I want you to be here with me.

Acknowledgments

I went through my whole PhD journey in my mind while writing the acknowledgments, the last section of my dissertation. I have had the honor of working and learning from some of the most inspiring people I know throughout this journey. So many people have helped me with my dissertation, and I want to show my deep appreciation to everyone, but I will name a few of them here.

I would like to express my greatest gratitude to my supervisors, Prof. Peter van Oosterom and Prof. Sisi Zlatanova. I am eternally grateful for their outstanding mentoring, which has been invaluable during my doctoral studies. As my promotor, I am really appreciative of Prof. Peter's patience and effectively bringing me onboard. During our conversations regarding the study, you provided me with guidance and motivated me to investigate a wide range of options. My co-promoter Prof. Sisi was always there for me when my faith waned, and she was able to refocus my attention whenever I lost it. I really appreciate your confidence in me to become a better researcher. Thank you so much for everything. The structure of this thesis was approved by both of you and numerous concepts were improved with your guidance. I owe you a debt of gratitude for what I have learned from you.

I would like to extend my sincere thanks to all members of the GIS Technology group: Dr. Mathias Lemmens, Dr. Martijn Meijers, Edward Verbree, Marianne de Vries, Wilko Quak, Eftychia Kalogianni, Dr. Abdullah Kara, Haicheng Liu, Dr. Dongliang Peng, Dr. Jesús Balado Fris, and others. It has been an honor and a joy to collaborate with each and every one of you. I would like to express my gratitude to Prof. Christiaan Lemmen from the University of Twente for his participation, suggestions, and amazing discussions during the research. Also, a great thanks to Prof. Ki-Joune Li for his assistance and involvement in chapters 3 and 6. Additionally, a huge thank you to Dick Hoeneveld for his support and participation in chapter 8. Also, I would like to thank Mohammad Eid, Fahad Alghamdi, and Thamer Alzahrani for their help in collecting the data I needed for this research. I would like to express my gratitude to the Secretaries/Secretariat of OTB and the Architectural Engineering and Technology departments for their administrative assistance throughout my stay in Delft.

I had the pleasure of visiting the University of New South Wales' GRID for a research visit. In particular, I want to express my gratitude to Dr. Ben Gorte and his colleagues Dr. Abdoulaye Diakité, Dr. Jinjin Yan, Dr. Mitko Aleksandrov, Dr. Jack Barton, and

Contents

TOC

TOC

List of acronyms

AEC	Architecture, Engineering, and Construction
BIM	Building Information Modelling
CAD	Computer-aided design
CDM	Combinatorial Data Model
CRS	Coordinate Reference System
DBMS	Database Management Systems
DSMM	Department of Survey and Mapping Malaysia
DSR	Design Science Research
EPA	Environmental Protection Agency
ERT	Emergency Response Team
ETSI	European Telecommunications Standards Institute
FIG	International Federation of Surveyors
FK	Foreign Key
FM	Facilities Management
FSS	Flexible Space Subdivision
GML	Geography Markup Language
GNM	Geometric Network Model
GPU	Graphics Processing Unit
GUI	Graphical User Interface
GVD	Generalized Voronoi Diagram
HVAC	Heating, Ventilation, and Air Conditioning
IAI	International Alliance for Interoperability
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
KML	Keyhole Markup Language
LADM	Land Administration Domain Model
MLSM	Multi-Layered Space Model
NDCDB	National Digital Cadastral Database
NDP	National Development Policy
NEM	New Economic Model
NEP	New Economic Policy
NRG	Node-Relational Graph
ODBC	Open Database Connectivity

OGC	Open Geospatial Consortium
PK	Primary Key
RRRs	Rights, Restrictions, and Responsibilities
RFID	Radio-Frequency Identification
SQL	Structured Query Language
UML	Unified Modelling Language
VD	Voronoi tessellation is a diagram
WebGL	Web Graphics Library
XML	Extensible Markup Language
2.5D	Two-and-a-half Dimensional
2D	Two Dimensional
3D	Three Dimensional

Summary

The existence of indoor navigation applications has gained widespread acceptance due to their ability to provide vital information to the users of the indoor environment. Over the years, various researchers have developed a range of applications for the indoor navigation field. Most of the researchers' work has focused on the diverse aspects of indoor navigation models, including localization, indoor path computation, and human spatial cognition. However, getting a proper navigation model that provides acceptable routing results for different users is a concern that needs to be addressed. Unfortunately, the current indoor navigation systems do not take into account the user's access rights when it comes to navigating safely and efficiently. This issue has motivated this research to develop an approach that considers the user's rights, restrictions, and responsibilities on different days or times (e.g., in the evening, during daytime office hours) for indoor navigation.

To address this issue, this research proposes enhancing the IndoorGML conceptual model in the form of the Unified Modeling Language (UML) class diagram. The UML class diagram has been improved to contain all attributes (incl. their code lists) for each class, as well as a more explicit explanation of primal and dual space, more precise terminology, and the addition of geometry as a class attribute. Using a UML class diagram that more accurately depicts the standard classes can help avoid any misconceptions. The study then proposes utilizing Land Administration Domain Model (LADM) to develop a 2D country profile for the Kingdom of Saudi Arabia in order to represent the rights of parties on spatial units (parcels). By integrating all of the information required to create a property registration document, the 2D country profile facilitates communication among all shareholders (Ministry of Municipal and Rural Affairs, Ministry of Justice, Real Estate General Authority, and Ministry of Housing) to obtain land registration. Aside from that, the 2D nation profile helps understand local laws. The spatial and non-spatial classes were established in accordance with Saudi Arabian legislation.

For the Kingdom of Saudi Arabia, this study also suggests utilizing LADM to create a 3D country profile. Using Saudi Arabia's subdivision procedures as a basis, the 3D country profile illustrates the identified principles for multi-owner buildings. As a consequence, a mapping from Building Information Modeling (BIM) / Industry Foundation Classes (IFC) to the LADM framework for conceptual modeling and individual units with their geometry and topology has been proposed. This makes it

possible to differentiate between three distinct types of spaces: private, common, and exclusive common spaces. With the use of a real-world example IFC file, the proposed method is assessed, highlighting problems that must be addressed, such as recommendations for the Architecture, Engineering, and Construction (AEC) sector in order to create an IFC file that can be utilized as input for 3D Land Administration with the least amount of user interaction. Saudi Arabia was used as case study, but the followed approach should also work well for other countries.

The development of an integration model of LADM and IndoorGML is then proposed in this study in order to define the accessibility of indoor spaces based on ownership and/or functional right for use. Users form relationships with buildings based on the kind of building and the functionality of the spaces. As a result, the indoor spaces of each building serve a variety of functions and are utilized by a wide variety of users. By defining the user types of the indoor spaces for example student, teacher, visitor, etc., LADM makes it possible to create a connection between the indoor space and the users who will be using them. Furthermore, LADM assigns rights, restrictions, and responsibilities to each indoor space. These rights, restrictions, and responsibilities indicate which places are accessible to which types of users. The assignment of such functional rights together with the three-dimensional (3D) geometry of the building based on the access time and the indoor space condition (e.g., disaster or normal) are used to provide additional information to route planning for an individual or a group of users. This will result in a more appropriate and easier navigation process since the navigation route will avoid any non-accessible spaces based on the user's rights, making it more appropriate and simpler. Aside from that, the integrated model of LADM and IndoorGML offers a diverse range of information classes, including (indoor 3D) cell spaces, connectivity, spatial units/boundaries, (access/use) rights and restrictions, parties, individuals, and groups of them.

The conversion from the conceptual model to the technical model allows for the assessment of the conceptual model to determine its strengths and shortcomings when analyzing this step of the Implementation. More automated transformation methods from the conceptual model to the technical model are investigated. Then, on the basis of the integrated model of LADM and IndoorGML, this study proposes defining the access rights for users of indoor environments during a crisis, which was simulated on 17-7-2018 in the Physics building of the TU Delft. The integrated approach has been extended to include access rights for different types of educational building users. The Wi-Fi access points throughout the building were used to gather information on users' movements, which was then used to depict their movements as individuals and groups depending on their Wi-Fi connection. Therefore, this research demonstrates that the combined LADM-IndoorGML model may aid in the decision-making process during an incident in an educational building context.

The research concludes by proposing the development of a 3D web-based application for indoor navigation taking into account the access rights assigned to the user at different time intervals (e.g. day, night, working day, weekend). According to their access rights, the web-based application enables users of an educational facility (students, teachers, guests, etc.) to establish indoor navigation routes in accordance with their needs. It is possible to access the web-based application from a variety of devices, including personal computers, laptops, tablets, and smartphones. A web-client GUI based on Cesium JS was used to configure the parameters (user, time, start, and destination) and represent the indoor navigation routes. The prototype for the Architecture building of the TU Delft is still online at http://pakhuis.tudelft.nl:8080/edu/cesium74/Apps/routing/ and shows the rich possibilities of the earlier developed integrated LADM-IndoorGML conceptual model in an easy to access and use manner.

In future research, it is proposed that the integrated model of LADM and IndoorGML be expanded by examining various kinds of buildings and parties, such as hospitals, hotels, railway stations, and airports, in order to guarantee that all sorts of parties are represented during their navigation activity in the indoor environment. Additionally, future work will focus on improving the present conceptual model of LADM-IndoorGML to include trajectory data associated with the indoor model's cell spaces / spatial units. For the next edition of LADM, we propose to include an appendix that outlines the combined model of IndoorGML and LADM that allows for indoor navigation based on rights, restrictions, and responsibilities. Furthermore, the 2D and 3D country profiles that have been presented in this research should be expanded to include other categories of information, such as subsurface, marine, valuation/taxation, and spatial plan information, in addition to the types of information that have been proposed. According to Saudi Arabia's subdivision rules, the 3D country profile may also depict a mix-use building and other kinds of buildings with multiple sections, different functions, and different ownership types. Following that, a technical model and database for data management should be implemented, as well as a user interface for visualizing land and building ownership.

Samenvatting

Het bestaan van indoor navigatietoepassingen is wijdverbreid geaccepteerd vanwege hun vermogen om vitale informatie te verstrekken aan de gebruikers van de indooromgeving. Door de jaren heen hebben verschillende onderzoekers een scala aan toepassingen ontwikkeld voor de indoor navigatie. Het meeste werk van de onderzoekers was gericht op de diverse aspecten van indoor navigatiemodellen, waaronder lokalisatie, indoor padberekening en menselijke ruimtelijke cognitie. Het verkrijgen van een goed navigatiemodel welke toegestane routeringsresultaten biedt voor verschillende gebruikers, is echter een punt van zorg dat moet worden aangepakt. Helaas houden de huidige indoor navigatiesystemen geen rekening met de toegangsrechten van de gebruiker als het gaat om veilig en efficiënt navigeren. Dit probleem heeft dit onderzoek gemotiveerd om een benadering te ontwikkelen die rekening houdt met de rechten, beperkingen en verantwoordelijkheden van de gebruiker op verschillende dagen/tijden (bijvoorbeeld 's avonds, overdag tijdens kantooruren) voor indoor navigatie.

Om dit probleem aan te pakken, stelt dit onderzoek voor om het conceptuele model IndoorGML te verbeteren in de vorm van het Unified Modeling Language (UML) klassendiagram. Het UML-klassendiagram is verbeterd door openemen van alle attributen (inclusief hun codelijsten) bij elke klasse, evenals een meer expliciete uitleg van primaire en duale ruimte, preciezere terminologie en de toevoeging van geometrie als attribuut. Het gebruik van een UML-klassendiagram dat de standaardklassen nauwkeuriger weergeeft, kan misvattingen helpen voorkomen. De studie stelt vervolgens voor om met behulp van Land Administration Domain Model (LADM) een 2D-landprofiel voor het Koninkrijk Saoedi-Arabië te ontwikkelen om de rechten van partijen op ruimtelijke eenheden (percelen) te kunnen representeren. Door alle informatie te integreren die nodig is voor eigendomsregistratie, vergemakkelijkt het 2D-landprofiel de communicatie tussen alle betrokkenen (Ministerie van Gemeentelijke en Plattelandszaken, Ministerie van Justitie, Algemene Autoriteit Vastgoed en Ministerie van Volkshuisvesting) om kadastrale registratie te verkrijgen. Afgezien daarvan helpt het maken van een 2D-landprofiel de nationale wetten beter te begrijpen. De ruimtelijke en niet-ruimtelijke klassen zijn vastgesteld in overeenstemming met de Saoedi-Arabische wetgeving.

TOC

Voor het Koninkrijk Saoedi-Arabië suggereert deze studie ook om een 3D-LADM landprofiel te maken. Op basis van de onderverdelingsprocedures van Saoedi-Arabië illustreert het 3D-landprofiel de geïdentificeerde principes voor gebouwen met meerdere eigenaren. Als gevolg hiervan is een mapping voorgesteld van Building Information Modeling (BIM) / Industry Foundation Classes (IFC) naar het LADM-raamwerk voor conceptuele modellering en individuele eenheden met hun geometrie en topologie. Dit maakt het mogelijk om onderscheid te maken tussen drie verschillende soorten ruimtes: privé, gemeenschappelijke en exclusieve gemeenschappelijke ruimtes. Met behulp van een IFC-voorbeeldbestand uit de praktijk wordt de voorgestelde methode beoordeeld, waarbij nog op te lossen IFC-bestandsproblemen naar voren zijn gekomen. Hiervoor worden aanbevelingen gedaan aan de Architectuur, Engineering en Constructie (AEC) sector, om een IFC-bestand te maken dat gemakkelijker kan worden gebruikt als input voor 3D Land Administration met de minste hoeveelheid gebruikersinteractie. Saoedi-Arabië werd als case study gebruikt, maar de gevolgde aanpak zou ook goed moeten werken voor andere landen.

Vervolgens wordt in deze studie de ontwikkeling van een geïntegreed model van LADM en IndoorGML voorgesteld om de toegankelijkheid van binnenruimten te definiëren op basis van eigendom en/of functioneel gebruiksrecht. Gebruikers hebben relaties met ruimtes in gebouwen op basis van het soort gebouw en de functionaliteit van de ruimtes. Hierdoor hebben de binnenruimtes van elk gebouw verschillende functies en worden ze gebruikt door een grote verscheidenheid aan gebruikers. Door het gebruikerstype van de binnenruimtes te definiëren, bijvoorbeeld student, docent, bezoeker, etc., maakt LADM het mogelijk om een verbinding te maken tussen de binnenruimte en de gebruikers die ze gaan gebruiken. Bovendien kent LADM rechten, beperkingen en verantwoordelijkheden toe aan elke binnenruimte. Deze rechten, beperkingen en verantwoordelijkheden geven aan welke plaatsen toegankelijk zijn voor welk type gebruikers. De toewijzing van dergelijke functionele rechten samen met het driedimensionale model van het gebouw op basis van de datum/tijd en de toestand van de binnenruimte (bijv. ramp of normaal) worden gebruikt om aanvullende informatie te verstrekken voor de routeplanning voor een persoon of een groep gebruikers. Dit zal resulteren in een meer geschikt en gemakkelijker navigatieproces, aangezien de navigatieroute alle niet-toegankelijke ruimtes vermijdt op basis van de gebruikersrechten, waardoor het geschikter en eenvoudiger wordt. Daarnaast biedt het geïntegreerde model van LADM en IndoorGML een breed scala aan informatieklassen, waaronder (indoor 3D) cell spaces, connectiviteit, ruimtelijke eenheden/grenzen, (toegangs-/gebruiks)rechten en beperkingen, partijen, individuen en groepen van hen.

De conversie van het LADM-IndoorGML conceptuele model naar het technische model maakt de beoordeling van het conceptuele model mogelijk om zijn sterke en zwakke punten te bepalen bij het analyseren van deze stap van de implementatie. Meer geautomatiseerde transformatiemethoden van het conceptuele model naar het technische model worden onderzocht. Vervolgens stelt deze studie, op basis van het geïntegreerde model van LADM en IndoorGML, voor om de toegangsrechten voor gebruikers van binnenomgevingen tijdens een crisis te definiëren, welke is gesimuleerd op 17-7-2018 in het gebouw Natuurkunde van de TU Delft. De geïntegreerde aanpak is uitgebreid met toegangsrechten voor verschillende typen gebruikers van onderwijsgebouwen. De wifi-toegangspunten in het hele gebouw werden gebruikt om informatie te verzamelen over de bewegingen van gebruikers, die vervolgens werden gebruikt om hun bewegingen als individuen en groepen te visualiseren, afhankelijk van hun wifi-verbinding. Dit onderzoek toont daarom aan dat het gecombineerde LADM-IndoorGML-model kan helpen bij het besluitvormingsproces tijdens een incident in een onderwijsgebouwcontext.

Als laatste evaluatie van het geintegreerde LADM-IndoorGML model, wordt het onderzoek afgesloten met de ontwikkeling van een 3D-webgebaseerde toepassing voor binnennavigatie, rekening houdend met de toegangsrechten die op verschillende tijdsintervallen aan de gebruiker worden toegekend (bijv. dag, nacht, werkdag, weekend). Op basis van hun toegangsrechten stelt de webgebaseerde applicatie gebruikers van een onderwijsinstelling (studenten, docenten, gasten, enz.) in staat om indoor navigatieroutes vast te stellen in overeenstemming met hun behoeften en rechten. Het is mogelijk om toegang te krijgen tot deze webgebaseerde applicatie vanaf verschillende apparaten, waaronder pc's, laptops, tablets en smartphones. Een webclient-GUI op basis van Cesium JS werd gebruikt om de parameters (gebruiker, tijd, start en bestemming) te configureren en de indoor navigatieroutes weer te geven. Het prototype voor het Architectuurgebouw van de TU Delft staat nog online op http://pakhuis.tudelft.nl:8080/edu/cesium74/Apps/routing/ en toont de rijke mogelijkheden van het eerder ontwikkelde geïntegreerde conceptuele model LADM-IndoorGML in een gemakkelijk toegankelijke en gebruiksvriendelijke manier.

Tot slot wordt voor de toekomst voorgesteld om het geïntegreerde model van LADM en IndoorGML uit te breiden met verschillende soorten gebouwen (en bijbehorende gebruikers), zoals ziekenhuizen, hotels, treinstations en luchthavens, om te garanderen dat alle soorten partijen vertegenwoordigd zijn tijdens hun indoor navigatie. Bovendien zal toekomstig werk zich richten op het uitbreiden van het huidige conceptuele model van LADM-IndoorGML om trajectgegevens te kunnen relateren aan de ruimtelijke eenheden van het indoor model. Voor de volgende editie van LADM wordt voorgesteld om een appendix op te nemen die het

gecombineerde model van IndoorGML en LADM schetst. Bovendien moeten de 2D-
en 3D-landprofielen die in dit onderzoek zijn gepresenteerd, worden uitgebreid met
andere categorieën informatie, zoals informatie over de rechten in de ondergrond
en zee, taxatie/belastingen en ruimtelijke plan informatie. Volgens de regelgeving
in Saoedi-Arabië kan een gebouw met gemengd gebruik, d.w.z. het gebouw heeft
meerdere secties met verschillende functies en verschillende eigendomstypes, zijn
toegestaan en dit moet nog worden toegevoegd aan het 3D-landprofiel. Daarna moet
een technisch model en database voor gegevensbeheer worden geïmplementeerd,
evenals een gebruikersinterface voor het bijhouden en visualiseren van land-
en gebouweigendom.

1 Introduction

It is 2026, and I would like to fly to Cape Town, South Africa, to attend the FIG 2026 Congress. I took a public bus to Jeddah International Airport, where my (combined indoor and outdoor) navigation app guided me to check-in and the departure gate. When I arrive at Cape Town's airport, the same app assists me in getting to the taxi stand. Finally, the cab drops me off at the Cape Town conference centre, where the same navigation app directs me to the room of the vast lecture hall, where I will deliver a keynote to a large audience of 2000 people about Saudi Arabia's new 3D Land Administration system. What is needed to make this scenario happen?

Indoor navigation apps need to consider the access right of the users to provide indoor navigation routes based on the users' accessible spaces. Defining the access rights for the users should be based on an international standard that can be used all over the world to cover the relationship between the users and the building. Considering the access rights during the indoor navigation, will provide an optimal indoor route for the users during normal situations and crisis. The presented research solution is based on two international standards (OGC's IndoorGML and ISO's LADM) in order to make sure that in the future any larger building offers the same type of navigation support as part of its infrastructure. Users can use their mobile devices and navigation apps can exploit the building information infrastructure, and this will function all over the world. The thesis does focus on the information modelling, and the 3D path planning aspect of indoor navigation (as demonstrated via prototypes). Note that the indoor positioning aspect is not a core topic of this dissertation.

This chapter contains in section 1.1 more details about the motivation. This leads to the research questions as described in section 1.2. The research methodology is presented in section 1.3. Section 1.4 provides the main contributions of this dissertation. The outline of the dissertation is illustrated in section 1.5 and the list of publications in section 1.6.

1.1   Motivation

Indoor navigation is becoming increasingly crucial in substantial public and private buildings. According to the Environmental Protection Agency (EPA), 75% of the world's population lives in urban areas and spends approximately 90% of their time inside buildings (Harvey 2012). Over the last decade, navigational applications have overgrown as a valuable tool for route planning and wayfinding for indoor and outdoor. However, the indoor differs from the outdoor environment in many ways. The outdoor space is ordinarily larger in scale than indoor space. Outdoor space is typically expressed in two dimensions, while indoor space is represented in three dimensions. Furthermore, the geometry and topology are different between the indoor and outdoor spaces. When comparing the boundary of a room to a coastline, indoor spaces have more "regular" geometries (Giudice et al. 2010). Distances, angles, and coordinates (e.g., latitude and longitude) are all critical in outdoor space, so Euclidean concepts are essential. In indoor spaces, topology takes on higher importance; for example, connectivity takes precedence over the direction.

The positioning technologies that have been used for outdoor is different than indoor. For example, in outdoor space, GPS has been invaluable for navigation. Since GPS signals are not well received in indoor space, other alternative positioning technologies have been used, such as Wi-Fi and RFID. Both distant and local landmarks are identifiable in outdoor space. However, since corners and walls obscure the users' vision, most landmarks used in indoor space are local. Outdoor landmarks are mostly non-changeable, while indoor landmarks are not always. Moreover, agents vary in outdoor and indoor environments. Pedestrians and vehicles are the navigation agents in the open space, while pedestrians are the primary users of indoor navigation.

Indoor environments have been more and more complex in our cities, posing challenges to the users' movement. Our cities contain different type of buildings, such as educational buildings, shopping malls, hospitals, airports, and each type of these buildings has different indoor characteristics. The users face several issues as a result of its complexity as shown in Figure 1.1. Users navigate to specific destinations inside an indoor environment using indoor navigation. Indoor navigation is a large subject of study that includes five primary topics: indoor positioning and localization, indoor modelling for navigation models, indoor path computation algorithms, human spatial cognition and wayfinding, and indoor guide instructions. Among these indoor topics, obtaining a suitable navigation model that represents the geometry, topology, semantics, and other context information for indoor spaces and providing acceptable routing outcomes for various users is necessary.

FIG. 1.1 Difficulties of users to reach their destinations

Several Indoor navigation applications have been developed to support the users during their daily activity inside buildings. Indoor routing research is currently focusing on geometrical features, such as distance, time cost, and number of turns. However, these applications have focused on the geometry and semantics of these indoor environments and not on the relationship between the users and the indoor spaces to represent the accessible and non-accessible space based on the user access rights. Consequently, during the use of these applications, the users do not know which spaces can be accessible for them until they reach a closed-door or restricted area, and that required changing of the indoor navigation route to discover the accessible space.

The main reason of using these indoor navigation applications by the users of the indoor environments is related to the lack of information about the indoor environments, and this required better representation of the indoor environments to help the users to reach their destination without facing additional issues such as the accessibility of the spaces. The accessibility of the indoor spaces has many requirements, such as time of access rights that should be considered during the navigation.

This issue motivated this thesis research to develop an indoor navigation application that considers the relationship between the indoor spaces and the users to define the accessible spaces for individuals or groups of users. Each building has a different type of users; for example, an educational building has several types of users such as staff, students, and visitors. Each user or group of users has different access rights for each space or section of the indoor environment. The students' access rights to the indoor spaces of the building are different from the staff members. In addition, each student has different access rights from the rest of the students based on the student lecture schedule. Another example of access rights is that students do not have the right to access staff members' offices without an appointment. Therefore, each indoor environment has different access right for each user, and these access rights can be defined according to the relationship between the user type and the indoor environment.

Furthermore, these access rights are changeable based on the user type and the condition of the indoor environment. For example, during a crisis, the accessibility will be different from a normal situation. During a crisis, the users need to move from dangerous spaces to safe spaces. Therefore, the accessibility of the indoor spaces has to be modified to allow the user to navigate through different spaces even if the user does not have access right to these spaces in a normal situation.

To define the relationship between the user and the indoor spaces, it is essential to use well-known standards that can be used to define the access rights for each indoor space and generate the indoor navigation route based on these access rights. Additionally, these standards should represent the 3D environment of the indoor spaces for better representation of access rights for each type of user.

IndoorGML is an Open Geospatial Consortium (OGC) standard that provides a framework for developing an indoor navigation system that provides an elaboration of the indoor space and Geography Markup Language (GML) syntax for encoding geoinformation (Zlatanova et al., 2016). IndoorGML consists of two components: the core data model and the semantic data model (Lee et al., 2014). The core model is responsible for describing geometry and topology connectivity. The semantic data model is responsible for providing the navigation process.

The Land Administration Domain Model (LADM) is an ISO standard (The International Organization for Standardization) that focuses on Rights, Restrictions and Responsibilities between (individual or group) parties and spatial units (Lemmen et al., 2015). By defining the indoor environment, LADM could define the relationship between the users and the indoor spaces based on the Rights, Restrictions, and Responsibilities of each indoor space to indicate the accessible spaces for each user

or group of users. Therefore, the integration between LADM and IndoorGML will provide indoor navigation based on the Rights, Restrictions, and Responsibilities for each user based on the type of indoor environment. As a result, the indoor navigation route will be modified based on the Rights, Restrictions, and Responsibilities of each user in order to provide an optimal path from the starting point to the destination by avoiding all the non-accessible spaces.

Both standards deal with 3D geometry, and this can be used to provide indoor navigation in 3D that can be created in different formats such as BIM/IFC. Defining the Rights, Restrictions, and Responsibilities of each indoor space in 3D will provide a better understanding of the boundary of these RRRs during the navigation. Additionally, providing 3D indoor navigation helps the users to understand the indoor environments. The integrated model of LADM and IndoorGML will use the LADM country profile to define the access rights. The LADM country profile is a data model that represents/defines the rights, restrictions, and responsibilities between the user and the land/space according to countries' regulations. Furthermore, the integrated model will provide a well-structured data storage, e.g., DBMS, to support different front-end applications. The integrated model of LADM and IndoorGML is based on two international standards that can be implemented worldwide. As a result, in the future, all buildings should provide their users with the proposed indoor navigation.

1.2 Research questions

This research is investigating the integration of IndoorGML and the Land Administration Domain Model (LADM) to define the accessibility of the indoor spaces based on the ownership and/or the functional right of use. The main research question of this research is:

— **What is an optimal standard-based approach to enrich the IndoorGML semantic 3D model with LADM Rights, Restrictions, and Responsibilities in support to the accessibility of the indoor spaces in different types of building and for different purposes?**

The main research question is subdivided into sub-research questions categorized into three levels:

Standards level

— **Q1. What is the UML class diagram in IndoorGML, and how it should be improved? (Chapter 3)**

This research question focuses on developing the UML class diagram in IndoorGML (as defined in the text document and XML schema of this standard) to have a complete UML diagram during the integration of LADM and IndoorGML. This will provide a clear understating of the function of each class and the associations between the classes, and it will provide indications about limitations or issues related to the UML class diagram. Moreover, it will allow for enhancing the current class diagram for better representation of the indoor navigation routes.

— **Q2. What is the status of Land Administration in 3D indoor environment in Saudi Arabia? (Chapter 4 and 5)**

This research question investigates the regulations of property ownership and the land (space) subdivision procedures in Saudi Arabia. It will provide a clear understanding of the ownership rights, restrictions, and responsibilities for the indoor spaces based on the local regulations. Analysing the information, the tasks, and the relationship between the various stakeholders responsible for the registration of property ownership in Saudi Arabia allowed building the 2D LADM country profile and next, based on this, developing the 3D LADM country profile for better representation of the property ownership/function rights of use.

Conceptual level

— **C1. What is the proper way of linking LADM and IndoorGML conceptual models to define the access rights of use based on the party/user type? (Chapter 6)**

This research question focuses on finding the optimal way of linking LADM and IndoorGML to define the rights, restrictions, and responsibilities for the indoor spaces. It is necessary to understand the function of each class to distinguish which classes have similar functionality in support to exchange of information about the indoor spaces and their characteristics. This knowledge is needed to create a link between the two standards and to keep both standards without any modification.

— **C2. What are the main types of indoor spaces according to the accessibility rights? (Chapter 6)**

This research question addresses the relationship between the parties/users and the indoor environments to define the main types of spaces according to the user type. This step required additional information about the users and the indoor spaces, and it could be collected from the facility management department of the building/indoor environment. Defining the relationship between the parties/users and the indoor environments will define the main type of spaces that the party/user can access and affect the subdivision of the indoor spaces. The indoor navigation routes will be generated for a user or group of users according to their access rights.

— **C3. How the RRRs of the users will affect the indoor navigation during crisis situations? (Chapter 8)**

This research question studies the impact of the access rights of the indoor spaces during an emergency evacuation. During a crisis, the perception of the indoor environment differs from user to user and that plays a critical role in the evacuation. The access rights of the indoor spaces are different from the rights and restrictions during normal times. For example, for a specific user normally open spaces could be closed due to the crisis (danger area) or normally closed spaces could be open (fast evacuation). Therefore, it is very important to study the access rights for the user under such conditions.

— **C4. What is the capability of LADM Party package to represent different types of users in several indoor environments? (Chapter 6 and 8)**

This research question addresses the ability to represent the users of different indoor environments by the party package. By providing a better representation of the user of the indoor environment, the integration model of LADM and IndoorGML will be able to define the relationship between the indoor environments and different users or groups of users. The party package needs to be refined to includes additional sub-classes for different types of users.

Technical level

— **T1. What specifications are needed to map a conceptual model to a technical model and then to an implementation model? (Chapter 7)**

This research question investigates the issues that could occur during the transformation from a conceptual model to a technical model and then to an implementation model in order to assess the conceptual model of LADM and IndoorGML. The assessment of the conceptual model will help to discover the possibilities and the shortcoming/limitations of the conceptual model. These limitations need to be defined and solved to automate the transformation from the conceptual model to the implementation model.

— **T2. How to populate the database with the user information, access rights, geometric, and semantic information of the indoor spaces? (Chapter 9)**

This research question examines the database requirements that have to be developed to store different types of information to generate the navigation graph of the indoor environment based on the integrated model of LADM and IndoorGML. The database should be able to support storing and creating the 3D geometry of the navigation graph**.**

— **T3. What type of web-based user interface has to be used to manipulate/ visualize the data in the cases of selecting, updating, or routing? (Chapter 9)**

This research question investigates the type and specification of the web-based user interface that has to be used to visualize the data in the cases of selecting, updating, or routing. The web-based user interface will allow the users to define the start point and the destination via their laptop, tablet, or mobile phone to navigate.

1.3 Research methodology

The Design Science Research (DSR) approach was used to conduct this research (Hevner & Chatterjee, 2010). Design science research aims to direct human creativity into the creation of useful artifacts. Design science provides a viable solution to the relevance gap that has hampered academic research, specifically in the management and information systems fields. Design science research focuses on solving important unresolved issues in new or novel ways, as well as improving the effectiveness and efficiency of existing challenges. Design science research aims to enhance the environment by providing new and innovative artifacts and the processes for building these artifacts (Simon 1996).

The Design Science Research consists of three cycles: The Relevance Cycle, Design Cycle, and Rigor Cycle, as shown in Figure 1.2. The relevance cycle begins design science research with an application context that not only supplies the study's needs as inputs but also establishes acceptance criteria for the study's final evaluation. Every design science research endeavour revolves around the design cycle. Between creating an artifact, its evaluation, and subsequent feedback to modify the design further, this cycle of research activities iterates more quickly. According to Simon (1996), the nature of this cycle is to generate design alternatives and evaluate them against requirements until a good design is established. The rigor cycle ensures that the research effort is innovative by providing previous information. The researchers must fully explore and reference the knowledge base to ensure that the designs created are research contributions rather than regular designs based on the application of existing design procedures and the appropriation of existing design artifacts.
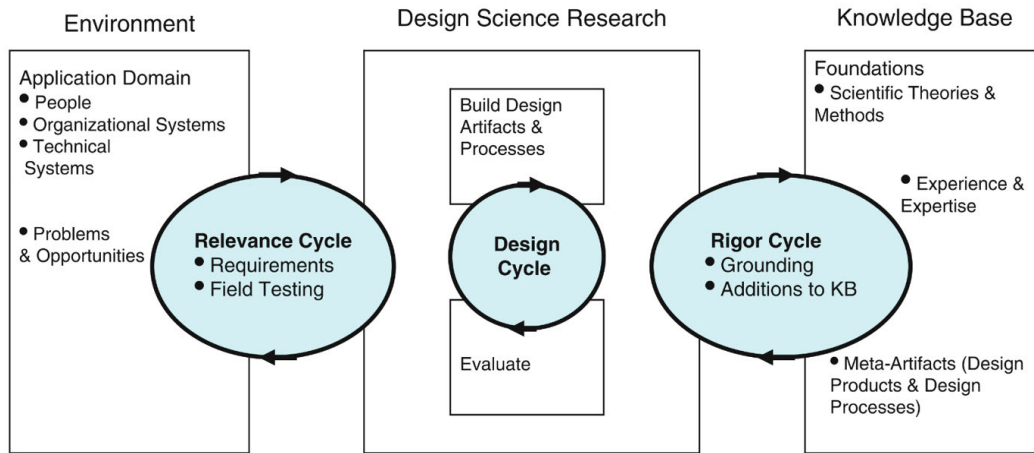
FIG. 1.2 Design Science Research Cycles (Hevner & Chatterjee, 2010)

In this context, the research methodology approach for this research has been developed and it consists of three phases to answer the research questions, as shown in Figure 1.3. This research aims to provide a subdivision approach that considers the user's rights, restrictions, and responsibilities during indoor navigation.

The first phase covers the standard level, and it focuses on reviewing the current subdivision approaches of the indoor spaces that have been developed to support/validate the concept of the integration between LADM and IndoorGML. Furthermore, in this phase, the related standards which are important to the integration process should be reviewed. These standards will be used as a source for well-structured data during the integration process. These standards cover the 3D geometries such as the BIM/IFC standard. The Facility management standard will also be used as a source for the semantic information for the function of the indoor spaces.

The next step in this phase is to assess and enhance the contents of the IndoorGML standard to ensure better representation of the indoor spaces during the integration. The final step in this phase is to study the property ownership regulation in order to understand the relationship between the users and the indoor environments. This step helps to develop a 3D representation of the property ownership regulations for a better representation of the users' rights, restrictions, and responsibilities.

By having all the required information from the first phase, the second phase is the conceptual level, and it consists of several steps that aim to define and develop the integration between LADM and IndoorGML. The first step focuses on defining the link between the LADM and IndoorGML. This step requires exploring the functionality of all the classes of both standards to define which classes could be used to link the two standards. By defining the link between the standards, the second step in the phase is to investigate the relationship between the indoor space and the user by examining an educational building to define the indoor spaces' rights. This step defines the types of spaces according to the accessibility rights. The third step in this phase is to study the impact of the users' accessibility rights during a crisis. The last two steps in this phase lead to the development of the party package of LADM to represents different types of users in different indoor environments. The development of the party package helps to define the relationship between the users and the indoor environment.

The third phase is the technical level, and it consists of three steps. The first step investigates the transformation of the conceptual model to the technical model and then the implementation model. This step aims to assess the integration model to discover the possibilities and limitations. Furthermore, it will be used to automate the transformation of the conceptual model to the implementation model. The second step is to develop a database in PostgreSQL to store the implementation model. In this phase, the database structure will be defined to support computing the indoor navigation routes based on the integrated model. The last step of the phase is to develop a web-based application that can be used by the end-user to generate the indoor routes according to the user access rights.
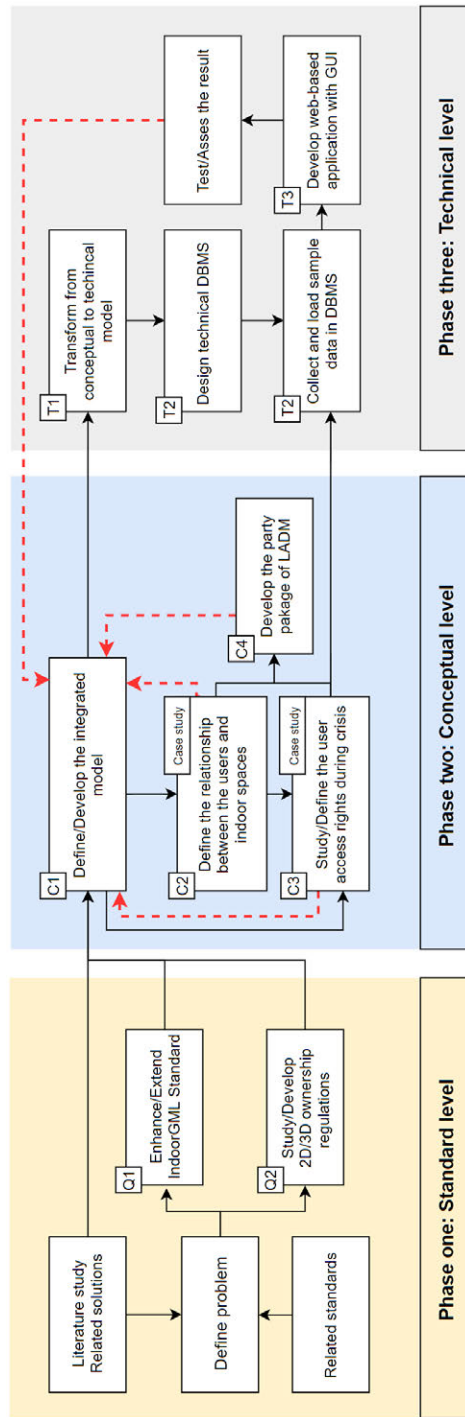
FIG. 1.3 Research methodology (please note the different feedback loop to improve the integrated model)

1.4 Main contributions

This section reflects on the main findings of this dissertation as follows:

— The first significant contribution of this dissertation is developing the integration model of LADM and IndoorGML in order to support indoor navigation based on the user's access rights. The integration model allows to identify the relationship between the users and the indoor environment to define the accessible space based on the user type. Moreover, the LA_Party package has been extended to represent different types of users to support the indoor navigation based on the users' access rights. The integration model of LADM and IndoorGML brings additional value to indoor navigation by providing the indoor navigation route that avoids all the non-accessible spaces based on user accessibility.

— The second contribution of this dissertation is the enhancement of the UML class diagram of the conceptual model of IndoorGML. The enhancement of the UML class diagram has proposed complete attributes and a code list for all classes, better representation of primal space and dual space, clear terminology, and introducing the geometry as attributes of classes. The proposed UML class diagram maps the standard classes in a better way to avoid any misunderstanding during the use of the standard.

— The third contribution of this dissertation is developing the 2D country profile of the Kingdom of Saudi Arabia based on LADM. The 2D country profile brings a better communication system between all the stockholders to secure the land registration by including all the information required to issue the property registration document. The spatial and non-spatial classes have been developed based on the regulations of Saudi Arabia.

— The fourth contribution of this dissertation is developing the 3D country profile of the Kingdom of Saudi Arabia based on LADM. The 3D country profile represents the identified concepts for multi-owner buildings based on the subdivision procedures of building in Saudi Arabia. Therefore, mapping from the BIM/IFC to the LADM approach has been proposed for the conceptual modelling at the level of the individual units with their geometry and topology. This is in support to the identification of three different types of spaces: private, common, and exclusive common spaces. The presented approach is tested with a real-world example IFC file, identifying the issues to be improved, i.e., guidelines for the Architecture, Engineering, and Construction (AEC) sector to produce an IFC file that can be more

easily used as input for 3D Land Administration with minimal manual interventions. This research bridges the gap between the project-oriented world of the AEC sector (with BIM/IFC files) and the legal registration as described through the ISO 19152.

— The fifth contribution of this dissertation is the conversion of the LADM-IndoorGML conceptual model to the technical model. The conversion from the conceptual model to the technical model allows assessing the conceptual model to discover the possibilities and shortcomings of the conceptual model and to enable more automated transformation possibilities from the conceptual model to the technical model.

— The sixth contribution of this dissertation is defining the access rights for users of indoor environments during crisis based on the integrated model of LADM and IndoorGML. The integrated model has been extended to represent access rights for different types of users of an educational building. The Wi-Fi access points of the building have been used to collect information about the movement of the users to visualize their movements as individuals and groups of users according to their connection to Wi-Fi access. The study demonstrates that the integrated LADM-IndoorGML model can support the decision-making process during an incident in an educational building with the proposed extension.

— The final contribution of this dissertation is developing a 3D web-based application for indoor navigation based on user access rights. The web-based application allows the users (students, teachers, visitors, etc.) of an educational building to generate the indoor navigation routes based on their access rights. The web-based application can be used from different platforms such as desktops, laptops, tablets, and mobile phones. The web-client GUI based on Cesium JS was used to specify the parameters (user, time, start, destination) and visualize the indoor navigation routes.

1.5 Outline of the dissertation

The outline of this dissertation is illustrated in Figure 1.4, and it is divided into ten chapters. This thesis is based on journal and conference papers that I have published during my PhD research; see the last subsection. The current chapter introduces the motivation, problem statement, research questions, research methodology, research outcome, and the scope of the research.

Chapter 2 provides the state of art of the space definition and the space subdivision approaches of the indoor environments to generate the indoor navigation routes. This chapter presents three approaches studied and developed by many researchers: 1. the geometric-based approach, 2. geometric-semantic approach, and 3. semantic-geometric approach. Additionally, an overview of the integrated models (LADM and IndoorGML) is presented. Furthermore, an overview of the user profile is introduced and the related standard such as the IFC standard and facility management standard that this PhD research utilizes during the development of the integrated model. This chapter ends with the software and tools that has been used in this research.

Chapter 3 presents the extending of the conceptual model of IndoorGML. This chapter proposes a enhancements to the UML class diagram of the IndoorGML standard. In the current version of the standard, the UML class diagram does not represent all the standard classes included in the XML/GML schema. Moreover, the standard contains additional issues related to unclear association names, unclear class names, classes that are related to the Primal space and the Dual space, code lists not specific per type, untyped relationships to external object classes, and semantically overlapping classes. Therefore, this chapter aims to have a clear and complete conceptual model in the form of a UML class diagram for IndoorGML.

Chapter 4 addresses the development of the 2D LADM country profile of Saudi Arabia. The model aims to build a better communication between all the stakeholders to secure land land registration. Therefore, this chapter introduces the current land administration system in Saudi Arabia. Then, this chapter covers the development of the initial 2D country profile and the methodology for improving the initial country profile. In this process, the spatial and non-spatial classes have been created based on the regulation of Saudi Arabia. In this phase, the initial country profile includes only the necessary information, and there is much critical information related to the property registration still not covered. Therefore, the 2D LADM country profile of Saudi Arabia has been improved by including additional classes and attributes to the spatial and non-spatial classes.

Chapter 5 presents the legislation and regulation related to the use and ownership of building complexes with multiple units (apartments, condominiums) in Saudi Arabia for the 3D registration of the legal spaces. The 3D LADM country profile for Saudi Arabia must be able to represent the identified concepts for multi-owner buildings. In order to support the cadastral registration, this chapter presents a mapping from BIM/IFC to LADM, both at conceptual modelling and at the level of the individual instances with their geometry and topology. This mapping requires that the BIM/IFC file contains sufficient information to identify the different spaces being part of

a property. Three different main types of spaces are identified: private, common, and exclusive common spaces. Private spaces are defined as spaces that belong to one unit, and it does not have any common services. While the common spaces are defined as the spaces that all units share their use, for example, elevators, stair areas, parking areas, and exterior façades of the building. The exclusive common spaces are the spaces that have exclusive use for some units only. In addition to mapping the concepts at class level from IFC to LADM, this chapter presents the extract rules for treating the spaces of various types of walls, slabs, roofs, and constructive elements, such as foundation and pillars.

Chapter 6 introduces the development of the integration of IndoorGML and LADM to define the accessibility of the indoor spaces based on the ownership and/or the functional right for use. The users of the indoor spaces create a relationship with the space depending on the type of the building and the function of the spaces. The indoor spaces of each building have different usage functions and associated users. By defining the user types of the indoor spaces, LADM makes it possible to establish a relationship between the indoor spaces and the users. LADM assigns rights, restrictions, and responsibilities to each indoor space, which indicates the accessible spaces for each type of user. The three-dimensional (3D) geometry of the building will be impacted by assigning such functional rights and will provide additional knowledge to path computation for an individual or a group of users. As a result, the navigation process will be more appropriate and simpler because the navigation path will avoid all of the non-accessible spaces based on the rights of the party. The integration of IndoorGML and LADM covers a broad range of information classes: (indoor 3D) cell spaces, connectivity, spatial units/boundaries, (access/use) rights and restrictions, parties/persons/actors, and groups of them.

Chapter 7 illustrates the conversion of LADM-IndoorGML conceptual model to the technical model. The aim of this chapter is to assess the conceptual model and discovering the possibilities and the shortcomings of the conceptual model via the conversion to technical model. During the work from step to step several issues did appear and they are addressed in this chapter to enable more automated transformation possibilities from the conceptual model to technical model. Most of the issues are quite generic and applicable when converting other conceptual models into technical models. There are a few issues related to our specific conceptual models (IndoorGML and LADM packages) and the Enterprise Architect software (which is the used tool in this case), but most issues are generic: the primary keys that have been created to all tables by the software even if there is an ID attributes. There is further attention needed for the foreign keys, the association multiplicity, the attributes multiplicity, data type, spatial data type, index, spatial index, constraints, and inheritance. Additionally, the current structure of the code

list in the LADM standard has been developed for better semantic meaning during the implementation by creating an intermediate conceptual model class to support the transformation. Many decisions have been taken during the derivation of the technical model to solve these issues.

Chapter 8 addresses the application of LADM-IndoorGML model during a crisis. During an indoor emergency, an efficient evacuation is required to help the users to move to the safe areas. Many types of incidents could impact the movements of users and this requires studying the behaviour of the people during the evacuation. Each user understands and perceives the indoor environment differently and this plays a critical role in the evacuation. Furthermore, the users of the indoor environments have different rights to access the indoor spaces, which affects the movements of the users during an incident. This chapter discusses the evacuation of a building (educational building) by using the integrated model of LADM-IndoorGML applied to the 3D model of the building. This chapter is presenting the initial assessment based on real world application. An evacuation exercise has been held on the 17-7-2018 at the Faculty of Applied Science at TU Delft to study the access rights during an incident. During the evacuation, Wi-Fi data has been collected for the users of the building for further analysis. A 3D model has been built for the Faculty of Applied Science to analyse the movement of the users. The collected data of the Wi-Fi access points have been structured and imported into the open-source database PostgreSQL/PostGIS and appropriate visualisions have been provided in QGIS. This chapter demonstrates the entire process of analysis and visualization of users' movements based on the Wi-Fi logs by using the extended LADM-IndoorGML.

Chapter 9 presents the Development of a web-based application for the integration of LADM and IndoorGML. A web-based application has been developed, exploiting the integrated model of LADM and IndoorGML to provide indoor navigation based on the user's access rights in an educational building. Different types of users (students, teachers, visitors, etc.) have different access rights, which also depend on the exact time (e.g. inside, outside office hours, or during disaster). As this GUI is web-based it can run on different platforms, such as desktops, laptops, tablets and mobile phones, all types of users can use the web-based application to navigate according to their access rights to avoid all the non-accessible spaces. A 3D BIM IFC file of a building has been geo-referenced and converted into a LADM complaint database in PostgreSQL and is enriched with information about access rights based on the relationship between users, time, and indoor spaces. The PostgreSQL extension pgRouting has been used for the actual routing. The database contains several tables representing the core classes of the integrated model nodes, edges, parties (users), and rights to support the access rights-based routing. There is one overall network for the whole building, and database views are used to dynamically

select the relevant nodes and edges based on the time and the user's rights. The Dijkstra algorithm is used to compute the shortest path. Finally, the 3D geospatial web-platform Cesium JS is used to create a client GUI allowing to specify start and destination, the user and time, and to visualize the navigation routes. This Chapter provides a complete description of all the steps to design, develop and test the integrated model of LADM and IndoorGML.

Chapter 10 provides the main Conclusion and Future work of this research.

```
┌─────────────────────────────────────┐
│         Chapter 1 Introduction        │
└─────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────┐
│         Chapter 2 Background          │
└─────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────────────┐
│  Chapter 3 Extending the Conceptual Model of IndoorGML │
└─────────────────────────────────────────────────┘
                    │
                    ▼
╭─────────────────────────────────────────────────────────╮
│  ┌──────────────────────┐    ┌──────────────────────┐   │
│  │  Chapter 4 Developing │ ──▶│  Chapter 5 Developing │   │
│  │  2D LADM Country      │    │  3D LADM Country      │   │
│  │  Profile of Saudi     │    │  Profile of Saudi     │   │
│  │  Arabia               │    │  Arabia               │   │
│  └──────────────────────┘    └──────────────────────┘   │
╰─────────────────────────────────────────────────────────╯
                    │
                    ▼
┌─────────────────────────────────────────────────┐
│  Chapter 6 Combined LADM and IndoorGML conceptual model │
└─────────────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────────────┐
│  Chapter 7 Technical model of the combined LADM and IndoorGML model │
└─────────────────────────────────────────────────┘
                    │
                    ▼
╭─────────────────────────────────────────────────────────╮
│  ┌───────────────────────────────────────────────┐      │
│  │  Chapter 8 The use of LADM-IndoorGML during a   │     │
│  │  building evacuation                             │     │
│  └───────────────────────────────────────────────┘      │
│                    │                                      │
│                    ▼                                      │
│  ┌───────────────────────────────────────────────┐      │
│  │  Chapter 9 Developing a web-based application   │     │
│  │  for the integration of LADM and IndoorGML      │     │
│  └───────────────────────────────────────────────┘      │
╰─────────────────────────────────────────────────────────╯
                    │
                    ▼
┌─────────────────────────────────────────────────┐
│       Chapter 10 Conclusion and Future work       │
└─────────────────────────────────────────────────┘
```
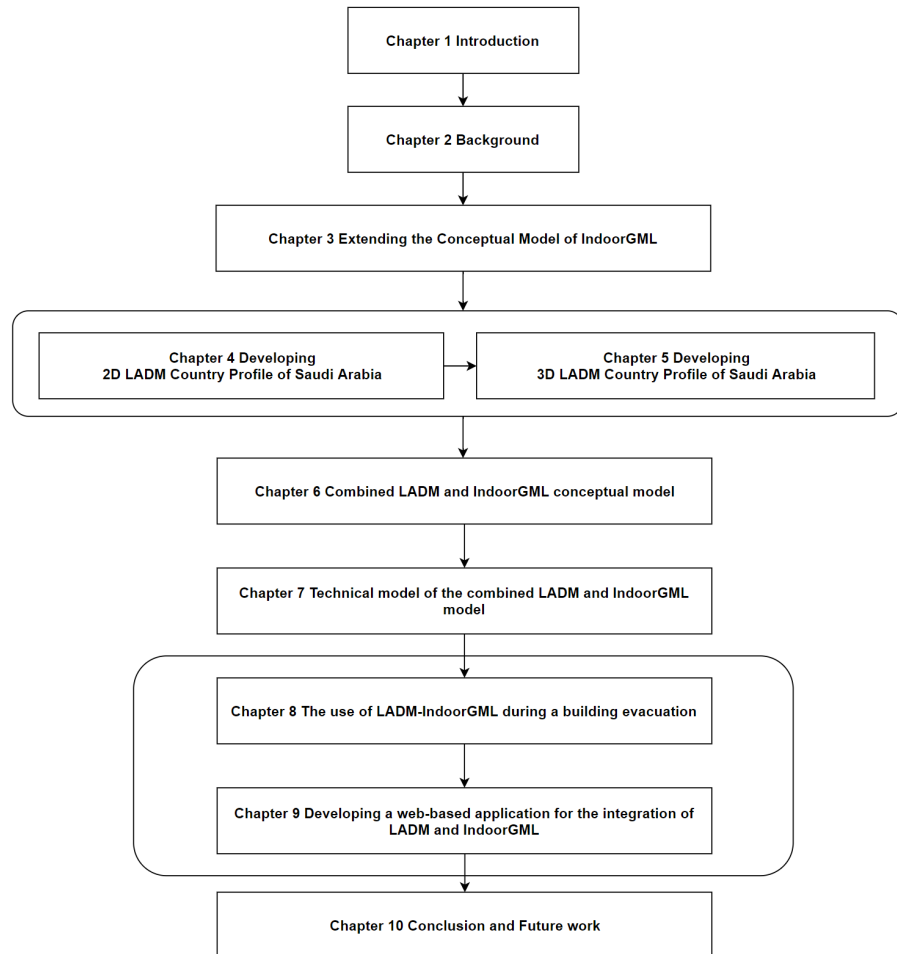
FIG. 1.4 The outline of this dissertation

1.6 List of publications

TABLE 1.1 Lists my publications that are relevant to the chapters of this dissertation.

Chapter	Published Scientific Journal articles	Nr.
6	Alattas, A., Zlatanova, S., Van Oosterom, P., Chatzinikolaou, E., Lemmen, C., & Li, K. J. (2017). Supporting indoor navigation using access rights to spaces based on combined use of IndoorGML and LADM models. ISPRS international journal of geo-information, 6(12), 384.	1
8	Alattas, A., van Oosterom, P., Zlatanova, S., Hoeneveld, D., & Verbree, E. (2020). LADM-IndoorGML for exploring user movements in evacuation exercise. Land Use Policy, 98, 104219.	2
5	Alattas, A., Kalogianni, E., Alzahrani, T., Zlatanova, S., & van Oosterom, P. (2021). Mapping private, common, and exclusive common spaces in buildings from BIM/IFC to LADM. A case study from Saudi Arabia. Land Use Policy, 104, 105355.	3
	Conference proceedings	
7	Alattas, A., van Oosterom, P. J. M., & Zlatanova, S. (2018, April). Deriving the Technical Model for the Indoor Navigation Prototype based on the Integration of IndoorGML and LADM Conceptual Model. In Proceedings of the 7th Land Administration Domain Model Workshop (pp. 12-13). International Federation of Surveyors (FIG).	1
3	Alattas, A., Zlatanova, S., van Oosterom, P., & Li, K. J. (2018). Improved and More Complete Conceptual Model for the Revision of IndoorGML (Short Paper). In 10th International Conference on Geographic Information Science (GIScience 2018). Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik.	2
8	Alattas, A., van Oosterom, P., Zlatanova, S., Hoeneveld, D., & Verbree, E. (2018). Using the combined LADM-IndoorGML model to support building evacuation. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42(4).	3
7	Alattas, A. F. M., van Oosterom, P. J. M., Zlatanova, S., Diakité, A. A., & Yan, J. (2018). Developing a database for the LADM-IndoorGML model. In 6th International FIG 3D Cadastre Workshop.	4
4	Alattas, A., van Oosterom, P., & Zlatanova, S. (2019). Initial Country Profile of the Kingdom of Saudi Arabia based on LADM. In Proceedings of the 8th Land Administration Domain Model Workshop (LADM 2019). International Federation of Surveyors (FIG).	5
	Lemmen, C. H. J., van Oosterom, P. J., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., & Alattas, A. (2019, October). The scope of LADM revision is shaping-up. In 8th Land Administration Domain Model Workshop 2019.	6
	Van Oosterom, P., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., Alattas, A., & Lemmen, C. (2019). Joint ISO/TC211 and OGC Revision of the LADM: Valuation Information, Spatial Planning Information, SDG Land Indicators, Refined Survey Model, Links to BIM, Support of LA Processes, Technical Encodings, and Much More on Their Way! In FIG Working Week 2019: Geospatial Information for a Smarter Life and Environmental Resilience. International Federation of Surveyors (FIG).	7
	Diakité, A. A., Zlatanova, S., Alattas, A. F. M., & Li, K. J. (2020). Towards IndoorGML 2.0: Updates and case study illustrations. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 43, 337-344.	8

TABLE 1.1 Lists my publications that are relevant to the chapters of this dissertation.

Chapter	Published Scientific Journal articles	Nr.
4	Alattas, A. F. M., van Oosterom, P. J. M., & Zlatanova, S. (2020). 2D Country Profile for the Kingdom of Saudi Arabia Based on LADM. Proceedings of the FIG Working Week 2020.	9
9	Alattas, A., de Vries, M., Meijers, M., Zlatanova, S., & van Oosterom, P. (2021). 3D pgRouting and Visualization in Cesium JS Using the Integrated Model of LADM and IndoorGML. FIG 2021 Working Week.	10

2 Background

The research motivation, research questions and methodology of this PhD research has been presented in chapter 1. This chapter introduces indoor space definitions and the approaches for subdividing the space, to give an overview of the current state of the art methods that provide the navigation path for the indoor environment. Additionally, an overview of the most relevant standards (LADM and IndoorGML) is presented.

This chapter is organized as follows. Section 2.1 defines the indoor space. In section 2.2, the approaches of the space's subdivisions are presented. An overview of the IndoorGML and LADM standards is introduced in sections 2.3 and 2.4. More related standards (BIM/IFC and FM standards) are presented in section 2.5. The user profile is introduced in section 2.6. The software and tools that has been used in this research is presented in section 2.7. Finally, the summary of this chapter is presented in section 2.8.

2.1 Space definitions

Several definitions of space could be found from different sources. A general definition proposed by Encyclopaedia Britannica describes three-dimensional space as a range in which objects and events take place and have corresponding positions and directions (Zlatanova et al., 2014). Another definition by Wordnet describes space as unfilled areas that are bounded in some way between things. The Architecture, Engineering, and construction in North America have separately classified spaces by form and spaces by function. LADM only covers the 'legal space'; that is, the space that is relevant for land administration close to the surface of the earth. The legal space is defined by rights, restrictions, and responsibilities and includes all spaces over water and land, and objects above and below the earth's surface (ISO 19152: 2012).

Spaces by form are elementary units of the built environment that are created by physical or absolute boundaries and described by physical form. The function of the space usually forms the legal space in LADM; however, in some cases, the form of the space is not related to the function. On the other hand, spaces by function are the primary units of the built environment that are created by physical or absolute boundaries and described by their purpose. The legal space boundaries in LADM could be related to physical objects or virtual boundaries.

Indoor spaces are prepared and developed to provide support for human activities. Therefore, the illustration of the indoor spaces has to be qualified for these activities (Zlatanova et al., 2014). The subdivision of these spaces has to accommodate their conceptual form and consider the activities in them. In general, humans realize indoor space as a closed volume surrounded by unmovable elements within which people can navigate. The legal spaces influence navigation possibilities for the users. Each space has a semantic meaning, such as room or corridor, which matches the description of the space form. Humans consider the space as an environment that allows them to store resources and participate in activities. Logical classification of resources and activities is imposed to represent subspace, which is usually utilized for workspace, living space, or access and storage.

2.2 Approaches of space subdivision

Zlatanova et al. (2014) defined the indoor subspace as any decomposition of the indoor space into smaller segments that could be totally or partially surrounded by virtual boundaries. Those subspaces may or may not have semantic information, and they are not overlapping and participate with at least one neighbouring element. Based on the usage of the subspace, it could be navigable or non-navigable. The navigable spaces could be used to accomplish activities, while no activities can be performed in the non-navigable spaces. There are many approaches for space subdivision, and they are classified according to different criteria: the dimension of the geometric model, such as 2D, 2.5D, or 3D; the semantic elaboration of the space, such as geometric, topological, and semantic models; or a mixture of (Zlatanova et al. 2013).

2.2.1 Geometric-based approaches

A geometric-based approach refers to a metric or coordinate-based with little or no semantics (Zlatanova et al. 2013, Afyouni et al., 2012). It considers the space as a continuous or discrete entity that mainly includes cell-based and boundary-based geometric representations (Afyouni et al., 2012). The cell-based models tessellate the space into a limited number of non-overlapping areas, and the segmentation includes the entire space, as shown in Figure 2.1. This approach can capture the adjacency between neighbouring cells.

(a) Square-shaped grid
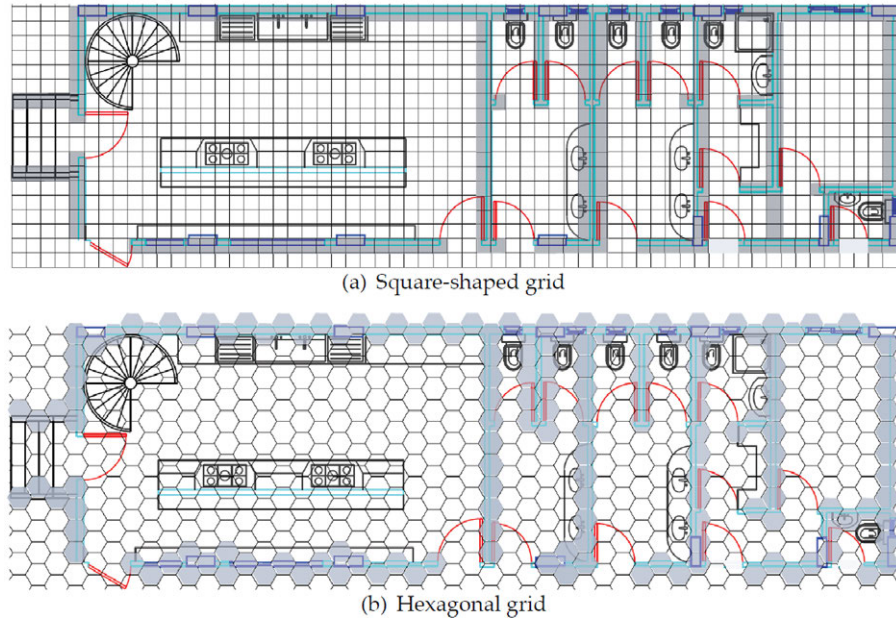
(b) Hexagonal grid

FIG. 2.1 Grid tessellation of a floor plan based on either (a) square or (b) hexagonal cells (Afyouni et al. 2012).

There are two different types of tessellations: regular and irregular. The regular tessellation is a grid-based model, which can simply represent the navigable and non-navigable regions in space by arranging them into different cell states. The occupancy grid, introduced by Elfes (1989) and Moravec and Elfes (1985), provides a probabilistic-based regular tessellation representation to address the issues of mobile robot mapping. The occupancy grid assigns a high value to the cells located within the accessible space and a low value to the cells occupied by objects or obstacles. The accuracy of the grid is based on the cell resolution. Irregular

tessellations have two different techniques that have been proposed: free-space and Voronoi. The free-space tessellations have two types of decomposition: trapezoidal-based and triangulation-based, as shown in Figure 2.2.

(a) Triangulation tessellation   (b) Trapezoidal-based tessellation
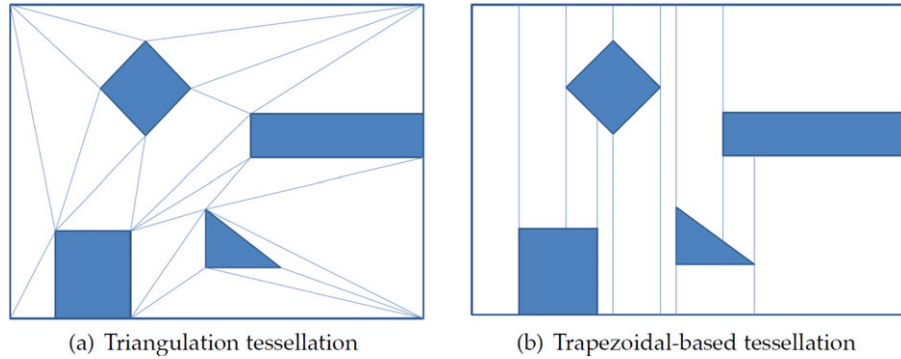
FIG. 2.2 Example of free space tessellation techniques (Zlatanova et al. 2014).

The two models comprise the boundaries of the obstacles by the segmentation of the endpoint lines. The trapezoidal decomposition is generated by projecting a vertical line from each endpoint within the free space until it reaches another barrier and creates trapezoidal cells of different thicknesses (Afyouni et al., 2012). As a result of this decomposition, the cells are long and thick and not suitable for localization. Bandi and Thalmann (1998) have proposed a methodology for automating a global motion path computation for humans in a 3D environment.

The space is subdivided into a 3D grid of uniform cells, and then an optimal path is generated between the starting point and the endpoint, as shown in Figure 2.3. An A* search method is used to find the path by treating the grid as a graph with orthogonal links. By considering that the cell on the upper level of the surface is the only space that a human uses to walk, a massive part of the grid is ignored from the search space, which improves the efficiency of the path's creation. However, semantic information is not considered in this approach.
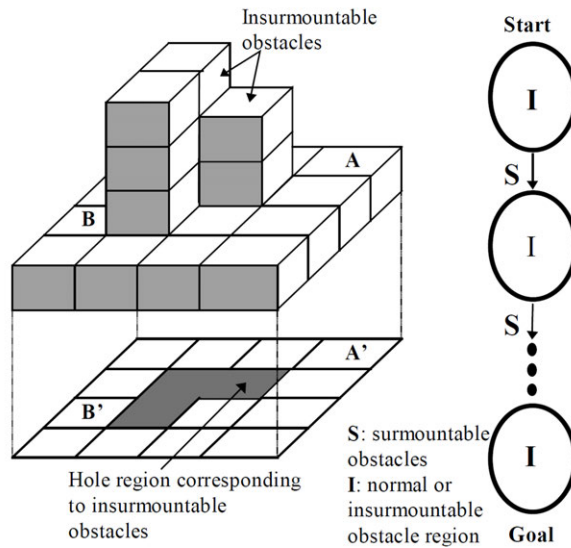
Li et al. (2010) developed a grid graph-based model with an indoor 2D space that considers the structure and spatial properties of the space to represent a built environment. The grid is deemed a reference modelling concept. The indoor space is divided into cellular units, in which each subspace is defined based on the floor plan of the space. The grid graph covers the cellular unit, and the nodes and edges are classified with the value of the membership based on the underlying cellular unit, as shown in Figure 2.4. Then the analysis of the indoor space can be handled based on the result of the grid graph. They also proposed an algorithm to obtain a hierarchical grid graph from the original. This approach allows users to study the spatial spread of any given phenomena, exposing the emerging structural properties of the represented space.

Yuan and Schneide (2010) proposed another approach: a cube-based model to determine the appropriate routes for different users based on their requirements. The representation of the indoor space is done using cu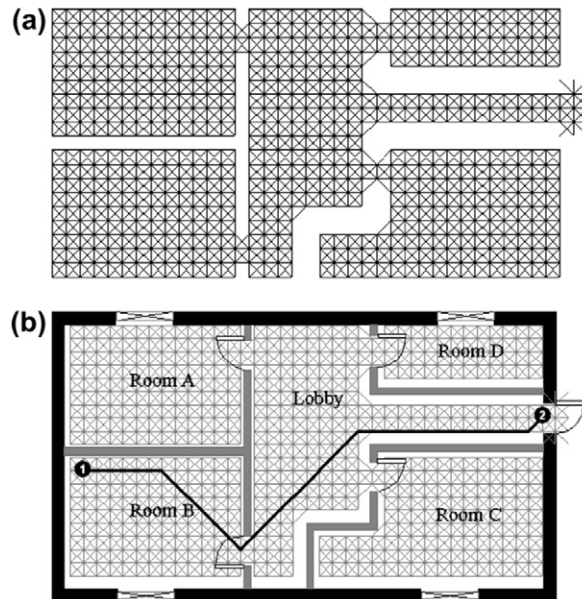bes of different types. Based on the object, the Lego cubes have different heights and types. Each cube is not able to be divided and represents one object or a part of an object. The height of the cubes is based on the distance between the floor and the ceiling. The granularity of the spatial representation is based on the size of the square. The Lego graph provides an implicit path that derives from the structure by merging cubes into blocks and investigating the connectivity between these generated blocks.

Triangulation-based tessellations are created by introducing edges between the endpoints of the boundaries until no more edges can be introduced. This kind of tessellation supports pathfinding by hopping between triangles; however, the result could be thin triangles (Demyen and Buro 2006). The Delaunay triangulation is another approach to triangulation-based tessellations. It is defined as a set of triangles that subdivides the space in such a way that each endpoint is inside the circumscribed circle of any other triangle of the Delaunay triangulation. The Voronoi tessellation is a diagram (VD) of a set of k points that describes the indoor environment as one-dimensional curves of the network that generate pathways across these points and form an irregular tessellation of space (Aurenhammer 1991), as shown in Figure 2.5. The Voronoi diagram can be utilized

with convex objects such as line segments or obstacles. An expanded approach from the Voronoi diagram is called the Generalized Voronoi Diagram (GVD), which provides the distance between a point in space and the nearest point on a geometrical object (Afyouni et al. 2012).
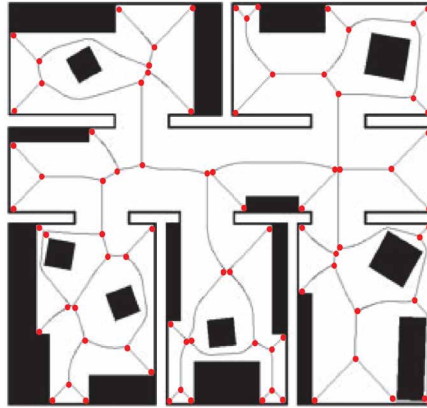
FIG. 2.5 A generalized Voronoi diagram of an indoor space (Afyouni et al. 2012).

The second category of the geometric-based approach is the boundary-based models, representing the boundaries of the obstacles in an indoor space with a series of primitive geometries (Afyouni et al., 2012). In most cases, the boundary-based map is generated by connecting a set of line segments, which are either taken from sensor data to represent the obstacles as polygons or designed by a CAD system, as shown in Figure 2.6. However, the boundary-based models cannot combine with additional object-based semantics, which can cause missing information in the represented spatial entities.
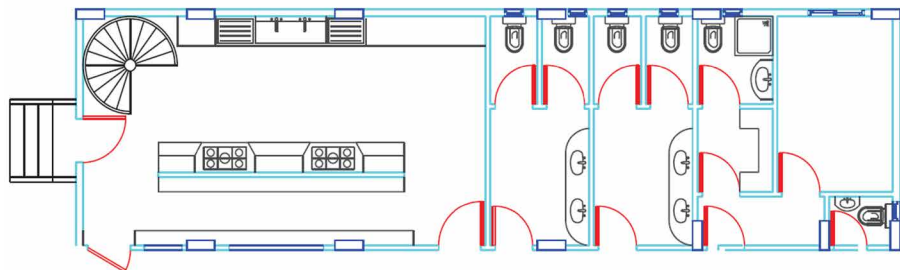
FIG. 2.6 Example of a floor plan designed using a CAD system (Afyouni et al. 2012).
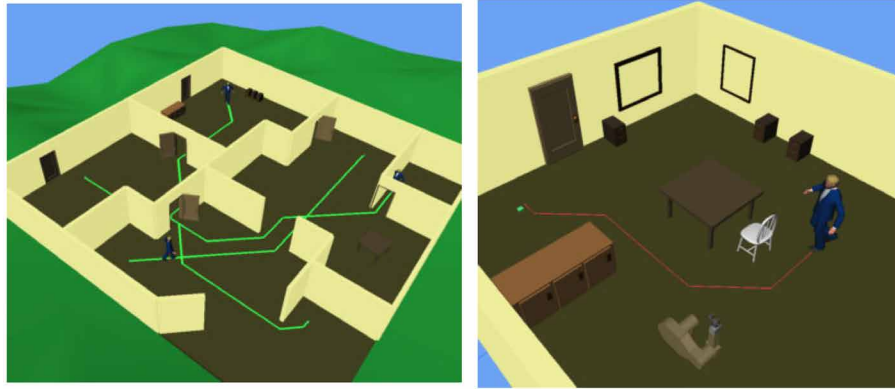
FIG. 2.7 Screenshots of interactive animation sessions. The left image shows multiple characters navigating in an office environment. The image on the right shows a single character in more detail (Kuffner 1998).

Another approach was presented by Kuffner (1998). The authors have developed a new method for computing collision-free navigation for animated characters in the interactive virtual environment. They have used an algorithm to implement the hardware rendering pipeline, which is commonly found on graphics accelerator cards, and achieve fast 2D motion planning. The collision-free navigation path can be estimated between the start point and the goal location by providing the 3D geometric representation of an animated character and the level of the terrain environment. By representing the obstacle geometry as a 2D bitmap for planning, the process will be faster because the bitmap can be searched by any dynamic standard programming technique to create a final path. This approach permits real-time adjustment of the goal location and the obstacle position for several characters in a complicated environment, as shown in Figure 2.7.

2.2.2   Geometric-semantics-based approaches

These indoor subdivision approaches use the irregular subdivision of space from a network, derived by identifying the connectivity or accessibility between indoor spaces (Zlatanova et al., 2013). The symbolic approaches use the topology-based structure graph to model the indoor environments by the connectivity and reachability between spatial units and hierarchies. The advantage of these methods is that the object locations are supplied semantically using human-readable characterization and representation of the topological relationships. There are two categories for the symbolic models: set-based and graph-based (Afyouni et al., 2012).

The primary approach of the set-based models is to distinguish the places or objects of interest and combine these symbolic identifiers into sets. The set-based models are classified into two types: place-based and object-oriented. Place-based models identify a set of places according to the architectural properties of an indoor space. The current approaches model the indoor space by generating sets and subsets of place identifiers based on the properties of an indoor area (Durr and Rothermel 2003, Kainz et al. 1993). The set of floor numbers is defined as a superset, and the lower level defines a subset concerning each floor that collects all room numbers, as shown in Figure 2.8.

The model is hierarchically arranged and considered a tree structure representing different levels of abstraction (Afyouni et al., 2012). The model offers room-level location data that can be used for data exchange and interactions with places. The main disadvantage of place-based model approaches is that they cannot model the connectivity between the areas: for example, two neighbouring rooms may or may not be interconnected. The model is also unable to define quantitative distance efficiently, and the tree-based structure is established based on the containment relationship, which does not allow for the elements to overlap between subsets.

(a) An exit-location area in a building

(b) The corresponding lattice-based model
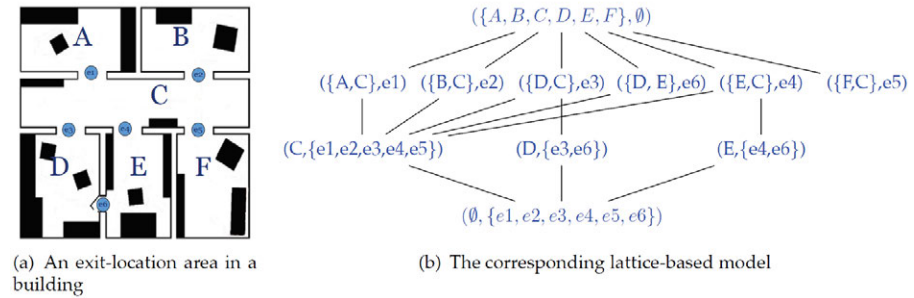
FIG. 2.8 Example of a place-based set model (Durr and Rothermel 2003).

The object-oriented model transacts with all elements that may participate to build a smart environment. This model also introduces a method to connect objects of interest with semantic information based on the architecture properties of the environment, as shown in Figure 2.9. The entities are defined as objects and described by attributes and relations. For example, the Industry Foundation Classes (IFC) model offers an elaboration of an object-oriented data model that provides a data exchange format that inverts information building (Froese et al. 1999, Liebich et al. 2006). The entities within the space, such as walls, doors, and windows, are represented as objects in IFC. The IFC-based models are utilized for planning

and management processes, to provide a better quality of data exchanged and to implement complex management-oriented analysis. Bhatt et al. (2009) have proposed an object-oriented model based on IFC. The indoor space is represented based on the combination of three layers:

— A conceptual layer that sorts terminological and functional features of the architectural entities, such as sensors, sliding doors, and meeting rooms, without considering how and where they will be used.

— A quality module that is used to provide qualitative specifications about the spatial dependencies and the relationships with other entities.

— A quantity module in which the architectural entities are quantitatively represented.
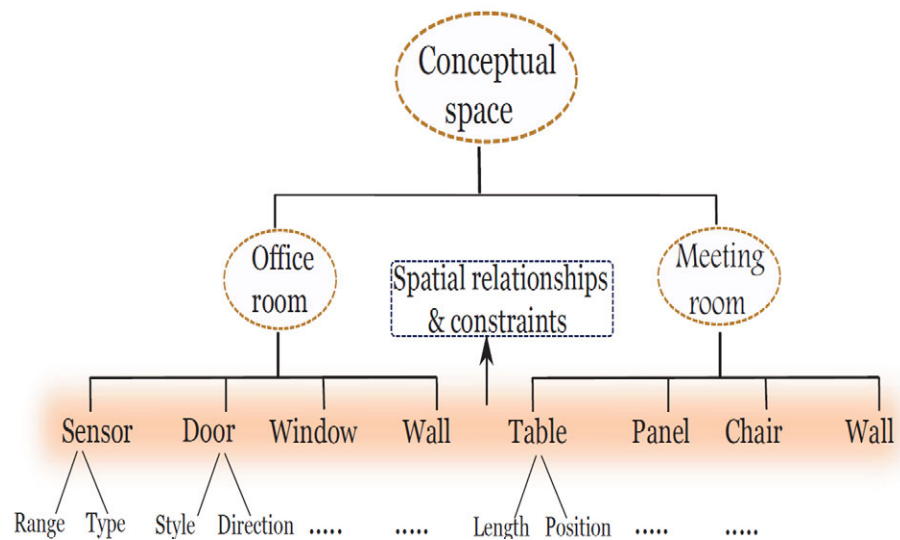
FIG. 2.9 Example of an object-oriented model of an indoor space (Bhatt et al. 2009).

The main advantage of this approach is the ability to qualify different roles played by the objects in the environments. Object-oriented models represent the data of symbolic locations at the object level and provide a semantic data exchange about objects of interest. They can also perform spatial and behavioural analyses. However, these object-oriented approaches do not support suitable navigation tasks because the models do not directly support the geometrical details about the represented objects, or the connectivity and adjacency relationship (Afyouni et al. 2012).

Graph-based approaches describe the indoor environment as a graph that contains nodes and edges. The nodes define the locations such as room, gate, and point of interest and they are obtained manually or automatically from the indoor environment. The edges are the connection between the nodes which allow movement through these locations (Choset and Burdick 2000, Remolina and Kuipers 2004). For example, the topological graph mirrors the architectural floor plans by representing the rooms as nodes and the doorways as edges which extract the correlation relationship between the entities (Franz et al. 2005).

There are two modelling concepts for graph-based approaches: layout-based and layout-independent. The layout-based models depend on the graphs where the nodes are extracted from the structure of the space. This can be presented using a basic graph model that can be pointed out as a place graph or a visibility graph. A Voronoi-based graph is built by extracting the integrating points and boundary points from the space, and these points are referred to the nodes of the generalized Voronoi graph. The fine-grained graphs maintain the structure characteristics of the environment indirectly, since the nodes spread evenly over the whole space. Nodes in layout-independent models are not directly extracted from the structure but derived by means of a sensor deployment over the space (Becker et al. 2009).

The place graph incarnates the topological characteristics of the space. The nodes in a place graph represent the rooms or hallways, and the edges represent the connecting spaces such as doorways, as shown in Figure 2.10. Moreover, with the place graph other topological relations between entities can be concluded, such as adjacency and containment properties (Afyouni et al. 2012). The place graph provides effective navigation between places, planning routes to the end point, and nearest neighbour queries. Because of that, it has been utilized in a wide range of applications. In addition, the place graph provides symbolic data exchange and communication with places. However, this approach does not support interacting objects. The accuracy of the location information is not fine, and the geometric characteristics of the space disappear.
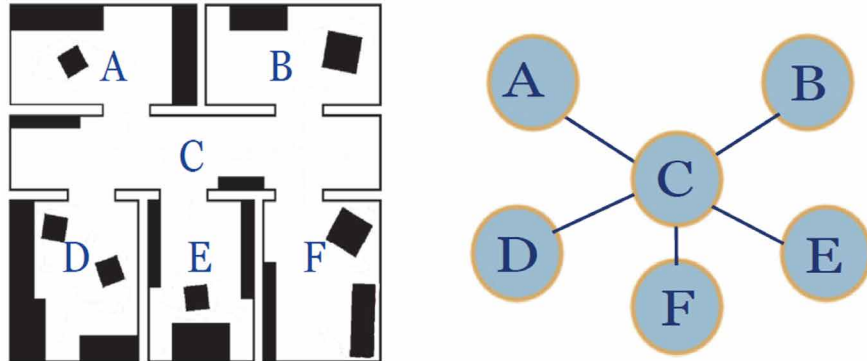
FIG. 2.10 A place graph representing structural entities of an indoor space (Afyouni et al. 2012).

Hu and Lee (2004) have provided a semantic exit-location model that integrates geometric information such as the distance model. This approach represents the space via two types of entities: a location that is represented as a restricted geometric area enclosed by one or more exits, and an exit represented as a gate that allows for movement to or from the location. However, this approach does not support object movements and can only support basic types of services. The visibility graph is based on triangulation that shapes edges between visible endpoints to represent explicit locations and obstacles (De Berg et al. 2008). This graph is considered valuable for some behavioural and spatial analyses (Franz et al. 2005). However, there are also disadvantages to the visibility graph; for example, the location information is not accurate, interactive, or flexible. The dynamic insertion and deletion of objects can also cause variations in the graph topology. The research by Li et al. (2010) has provided a graph-based model at a fine level of granularity that holds continuous and structurally based characteristics of the space. The nodes represent cells in an occupancy grid, and the connection between the cells is embodied by edges, as shown in Figure 2.11.

TOC
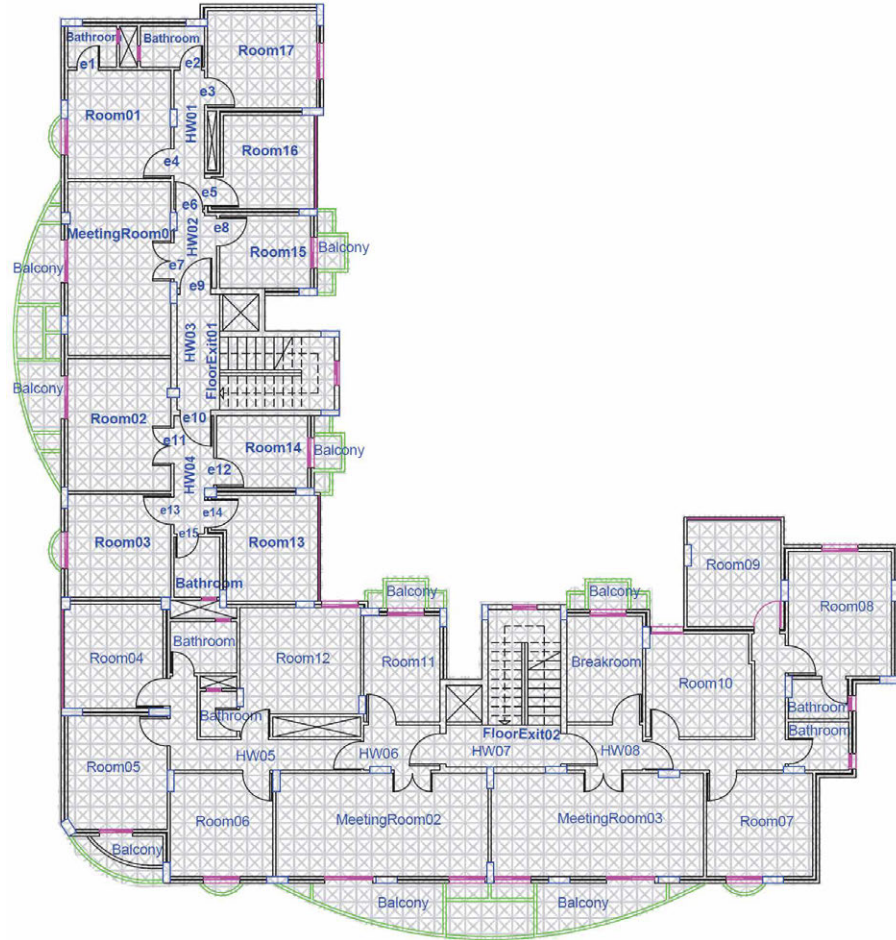
FIG. 2.11 Example of a fine-grained graph of a floor plan (Li et al. 2010).

The nodes and edges in a fine-grained graph are classified based on their relationship to a given spatial unit, such as a room or connecting space. This approach achieves a high coverage of space and can support the accuracy of positioning sensors used for indoor navigation (Afyouni et al. 2012). The geometric characteristics are totally represented by the continuous layout of the graph and obliquely reflect the shapes of the places. This approach provides a high-quality data exchange for fine-grained and continuous analysis. However, based on the size of the indoor space, which could contain a huge number of nodes and edges, real-time queries could take an excessive amount of time and memory processing.

Becker et al. (2008) have proposed a conceptual framework for indoor navigation by separating a diverse space model into a multi-layer representation. Route planning requires a model that reflects the structure of the indoor space, while localization techniques require a model that indicates the properties of sensors and transmitters. The conceptual framework deals with both of these by using the first to facilitate route planning and the second to facilitate localization. It then uses both of them to facilitate navigation. Therefore, each space is separated by primal and dual space on one hand and a geometry and topology representation on the other hand. Then the different spaces are connected by using an n-partite graph, where a node represents the space, and an edge represents events such as leaving or entering the space. The position of the user is represented by the joint statement to help decrease uncertainty, as shown in Figure 2.12.
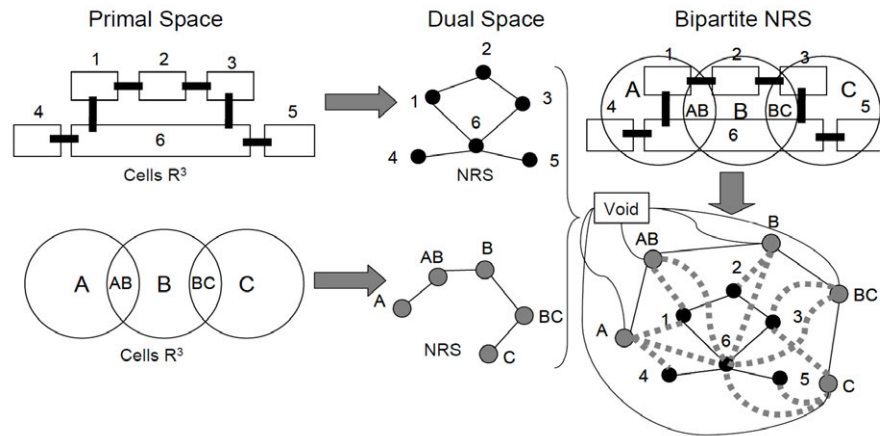
FIG. 2.12 Example of modelling building space using a bipartite graph (Becker et al. 2008).

Another approach presented by Boguslawski and Gold (2010) provides new operators for construction of 3D complex cells with the representation of the Augmented Quad-Edge data structure. The cells are connected using the dual structure and from the mesh, and the structure stores the geometry and topology information of the object model, as shown in Figure 2.13. The mesh can be applied for navigation by using the AQE standard. The geometry and topology are essential for this approach, in order to generate a solid 3D base. The structure includes two graphs, the first for the geometry representation and the second for the connectivity between objects. The operators do not influence the dual space directly. The primal space is utilized for creating and joining the individual faces.
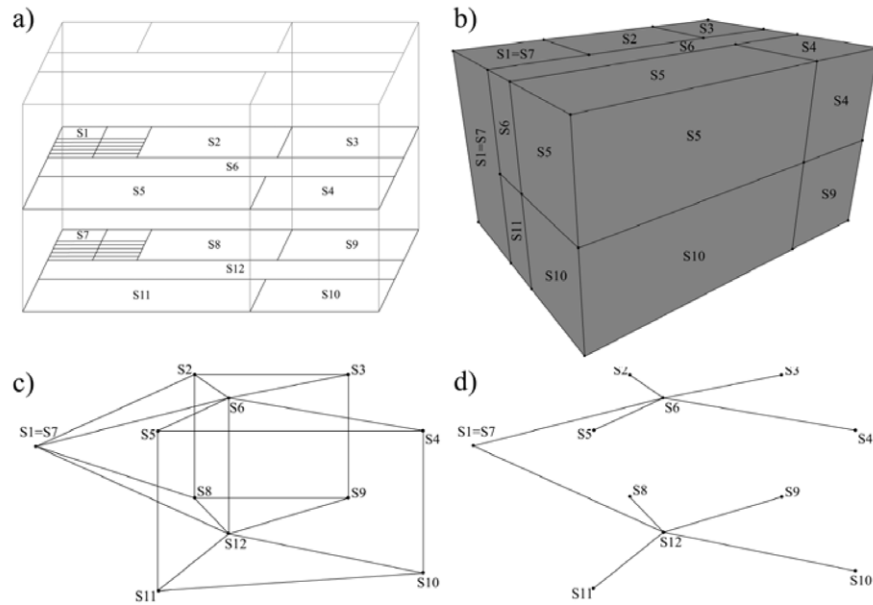
FIG. 2.13 Example structure representing a 3D model of a building interior. S1, S7 – staircases, S2–S5, S8-S11 rooms, S6, S12 - corridor; a) spatial schema – original version, b) volumetric model of rooms, c) complete graph of connections between rooms, d) graph of connections between rooms – only passages (Boguslawski and Gold 2010).

Lee (2004) proposed a new approach to deal with connectivity relationships between 3D objects when applying spatial access analyses in 3D space. To reach this goal, the author introduced the Geometric Network Model (GNM), which is a 3D network of data that was developed by transforming the Combinatorial Data Model (CDM) to characterize the connectivity relationships between 3D objects by using the dual graph, as shown in Figure 2.14. The result of this approach is a 3D data model that represents 3D objects and their topological relationships.

Liu and Zlatanova (2011) developed a door-to-door approach, which provides a new method for indoor pathfinding. This approach delivers a functional algorithm on a 2D floor plan of a building with a complex indoor structure. The algorithm contains two levels of routing: the first level creates a route between the rooms, and the second level is functional inside a single room to increase the detail of the route. The algorithm considers natural movements and the ability to search for a possible exit. The door-to-door approach offers routes that naturalize the behaviour of pedestrians regarding their movements, as shown in Figure 2.15.

(a) 2D GNM

$p(v_i, e_j)$

v_i

e_j

(b) 3D GNM

$Nv_j = (V(Nv_j), E(Nv_j))$

$Nh_i = (V(Nh_i), E(Nh_i))$

FIG. 2.14 Geometric network model of the NRS (Lee 2004).

(a)

(b)

(c)

FIG. 2.15 (a) The floor plan with semantics; (b) the course route on the "floor" level; (c) the entire route between two specific locations on the floor plan (Liu and Zlatanova 2011).

TOC
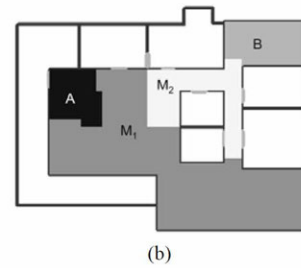
The hybrid spatial model for the indoor environment was provided by Lorenz et al. (2006). This approach contains a hierarchical structure graph that has a type for each edge and node. The edges and nodes can be classified with qualitative and quantitative informatio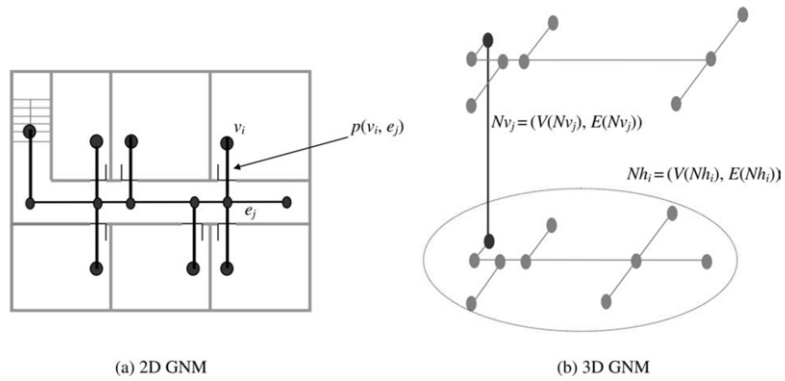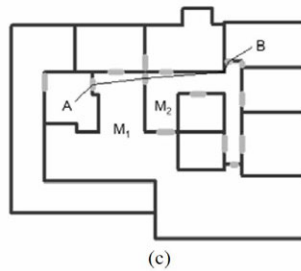n. The model assists in wayfinding and affords information for creating a human-oriented description of the indoor path. The main features of the graph model are: 1) Indoor space is subdivided into cells, and each cell is represented by a node, while each door is represented by an edge; 2) The model supports different abstracting levels of the graph; 3) Each node and edge is labelled with hybrid information to provide a better navigation path, as shown in Figure 2.16. This model also supports human-understandable language for path descriptions.
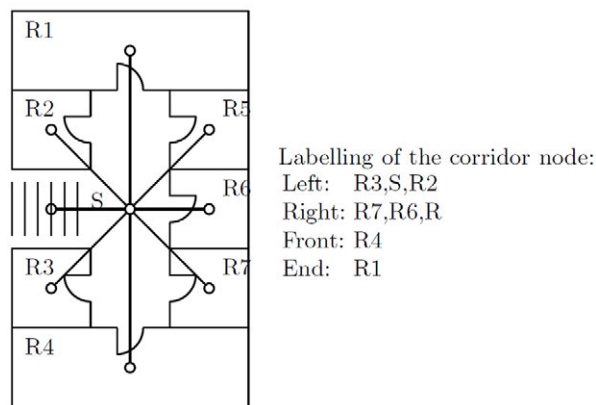
FIG. 2.16 Labelling of the corridor node (Lorenz et al. 2006).

Labelling of the corridor node:
Left: R3,S,R2
Right: R7,R6,R
Front: R4
End: R1

A semantic model that represents the structure of the interiors and can be used for the intelligent computation of evacuation routes was developed by Meijers et al. (2005). The model contains two levels of polygons and sections, which reflect the possibilities for movement through the building. The model uses semantics to classify the polygons as the first level, and the sections are considered level two on the base of the polygon classification. Both polygons and sections are mapped to the nodes and edges of the graph. The geometry of the building and the related graph is prepared in geodatabase management.

The polygon is considered the smallest unit in the model, and each one has a meaning based on its role in allowing people to move inside the building. Polygons are classified based on persistence, existence, access-granting, and types of passing. The classification of the section level is based on the subdivision of the space. The indoor space is subdivided into distinct parts called sections. The building's semantic information is not enough to calculate routes because of the lack of connectivity

between the spaces. This approach uses a graph model to represent the structure of the building, in which every room is represented as a node, and each corridor is represented as an edge, as shown in Figure 2.17. The graph model only considers the end section, granting polygons, and connector section. The authors provide four different methods to derive graphs for the connector section automatically.
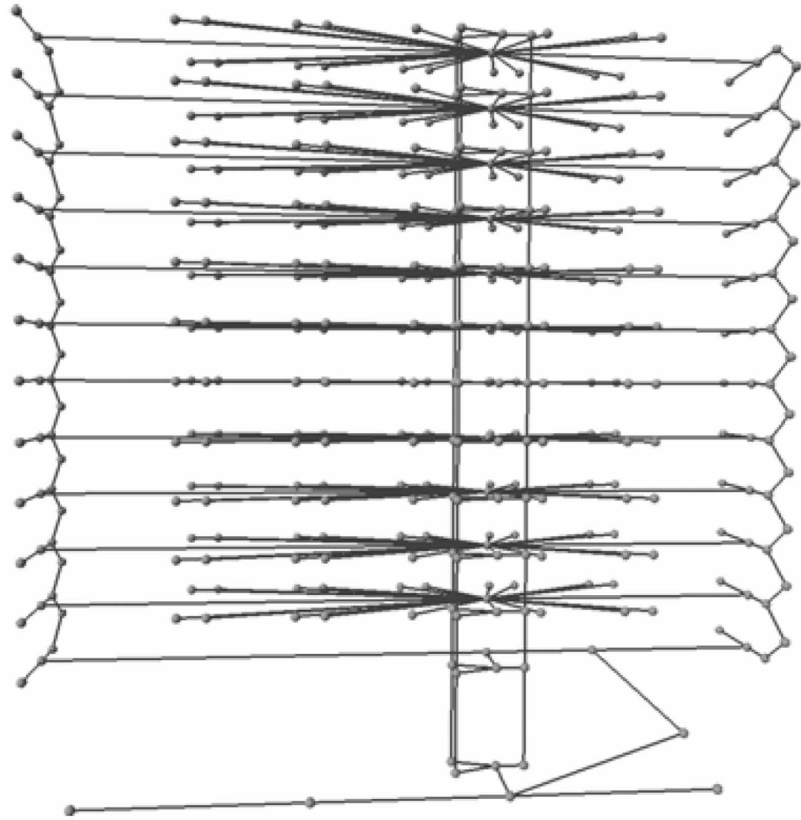
FIG. 2.17 Graph of an office building with 13 floors (Meijers et al. 2005).

Another approach that supports pedestrian routing for multimodal travel has been proposed by Schaap (2010). This 3D model approach concentrates on helping the individual traveller by finding the most optimal route based on their exact preferences and constraints. The main characteristic of this model is that no alteration is made between indoor and outdoor spaces. The model is incorporation between networks and surfaces with corresponding attributes and behaviour. Results are generated by NodeSurfaces and LinkSurfaces to determine the possible route.

Semantic–geometric-based approaches

The third type of approach to indoor space subdivision focuses on semantics by building hierarchical or multi-layered concepts of indoor environments (Zlatanova et al., 2013). These hierarchies are formed by combining building units based on different parameters, such as the division of structure or functional use. Liu and Zlatanova (2012) have provided an indoor data model to support the automatic derivation of the connectivity graph of a building. This new approach, called the indoor navigation space model (INSM), provides an extensive categorization of indoor spaces according to the building semantics, as shown in Figure 2.18.

Additionally, this approach can be used to specify the nodes and edges of the connectivity graph. The model consists of a two-level routing strategy. The logical graph is obtained in the first level, based on an appropriate subdivision of the building. The door-to-door algorithm is applied on the second level to employ metrics and considers the obstacles to obtaining a detailed path. The authors propose explicit indications of the spaces such as navigation usage, connectivity to other spaces and the chances to change floors, and the free area within the space. Based on the usage function of the space, some spaces could be filtered so that only use spaces would be considered for navigation. Their approach provides a method to transform building data from different sources. The model also supports indoor pathfinding and provides further semantic knowledge of building spaces.
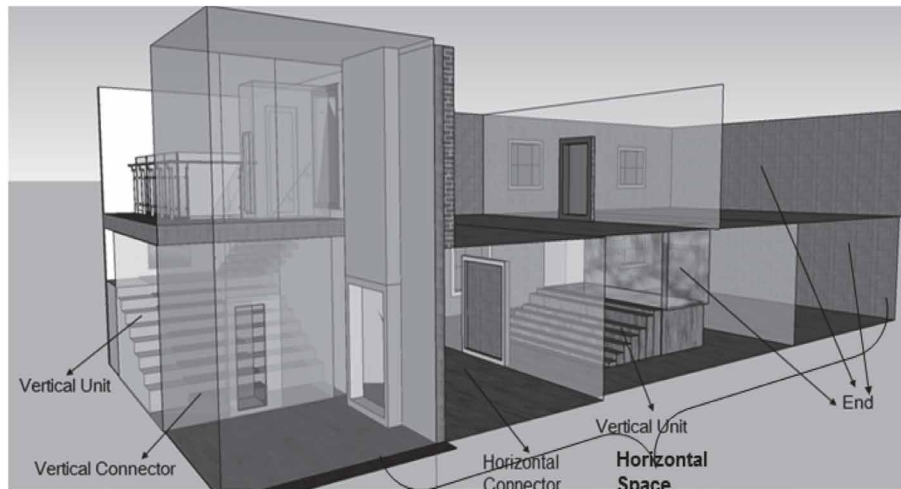
FIG. 2.18 Building spaces as defined in INSM (Liu and Zlatanova 2012).

The requirements for providing hierarchic spatial information to users of an indoor environment have been provided by Richter et al. (2009) and Richter and Winter (2011). There are challenges for at least three different aspects that have to be considered to create these requirements. First, the structure of the indoor space has many breaks, creating the indoor space physically fragmented and clustered. Second, the organization of different groups that will share the indoor space. Third, the function of the indoor space and its different usages. The authors' approach can conceptualize spaces with different user groups and different information for several tasks, as shown in Figure 2.19. They have also presented an algorithm to construct the hierarchic representation automatically.
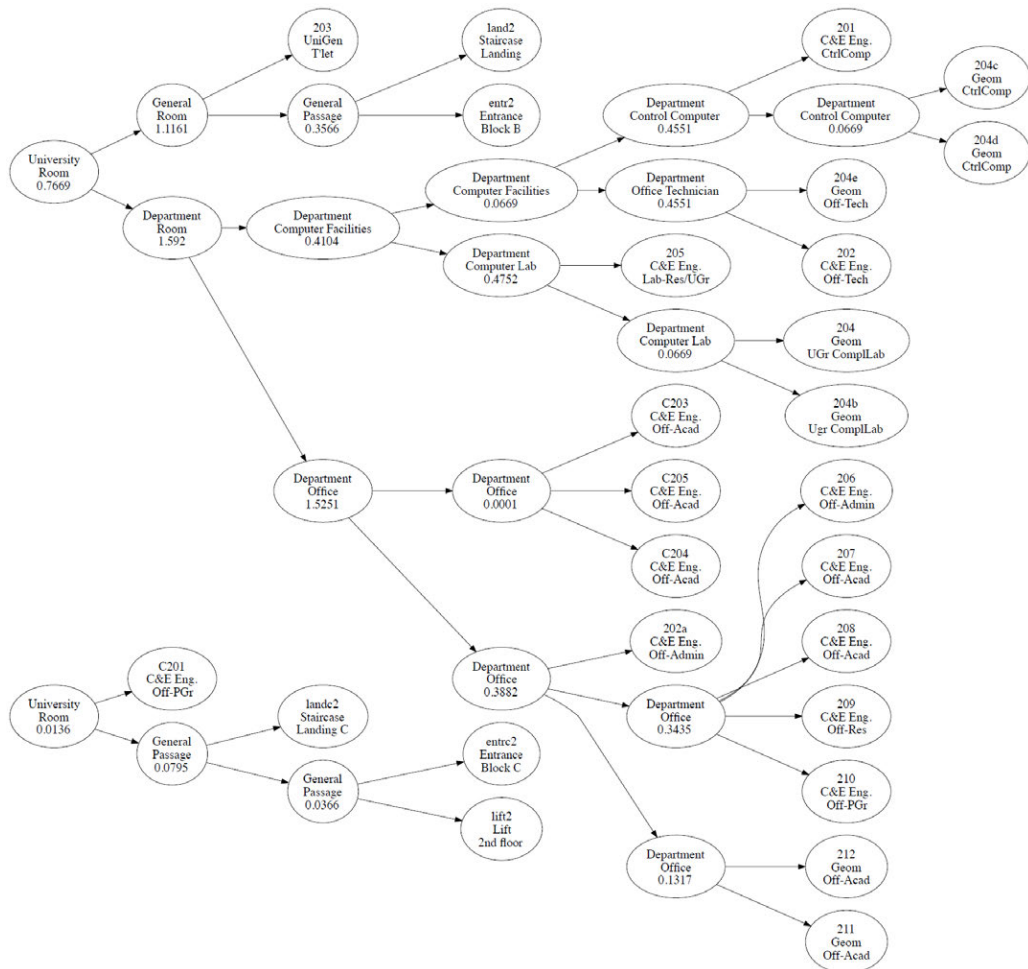
FIG. 2.19 The hierarchy reflecting an IT specialist's view (Richter et al. 2009, Richter and Winter 2011).

Afyouni et al. (2012) have created a survey for indoor spatial models. In their work, the authors represent the value of contextual information, which is considered a critical element in expanding mobile information systems. Contextual information can be defined as information collected and used to enrich the knowledge of the user's state or physical surroundings and their mobile device's capabilities. The main idea behind such context is to consider the behaviour of the user towards the environment and the interfaces they interact with (Afyouni et al., 2012). As shown in Figure 2.20, the context dimensions include:

— The user-centered context defines the user's profile, preferences, physical capability, and user interface.

— The environmental context, which indicates the parameters that affect the user.

— The context of execution models the system's behavior by addressing the infrastructure dimension and the topological organization of the system elements. Moreover, this context evaluates the resource utilization of the system elements and the capabilities of the mobile user device.
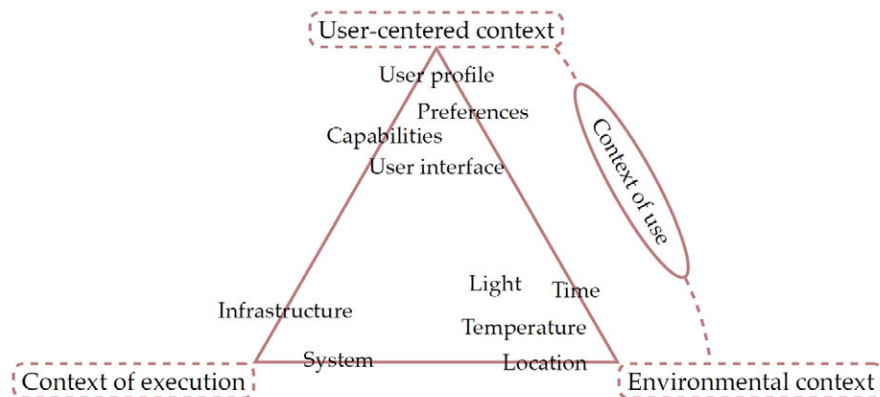
FIG. 2.20 A classification of context dimensions (Afyouni et al. 2012).

The context of use is the relationship between the user-centred context and the environmental context. The design of the context-aware system includes many components that have contributed to be indicated by the spatial model (Afyouni et al., 2012). Therefore, by considering the environment as a dynamic system, integrating the indoor spatial model into a context-aware system, such a system should represent: 1) the features that establish the environment, 2) their spatial

characteristics, and 3) the actions that arise from them. In their work, the authors discuss context-aware services and queries for indoor environments, review existing indoor spatial models, provide suggestions for the development of the spatial reference model from the perspective of a context-aware system, and consider the dynamic properties and activity-oriented intersections of moving objects and their physical surroundings. They also explore the role played by smart devices and the positions of the sensors distributed throughout the space.

Diakite et al. (2017) have proposed a concept study of the space subdivision of IndoorGML to distinguish two significant aspects that require consideration in the space subdivision process. These are the occupancy of the indoor space, which influences the notation of indoor cells, and the description of criteria to support the automation of the space subdivision process. The authors have identified the spaces free of obstacles because the navigable space depends on the indoor furniture, as shown in Figure 2.21.
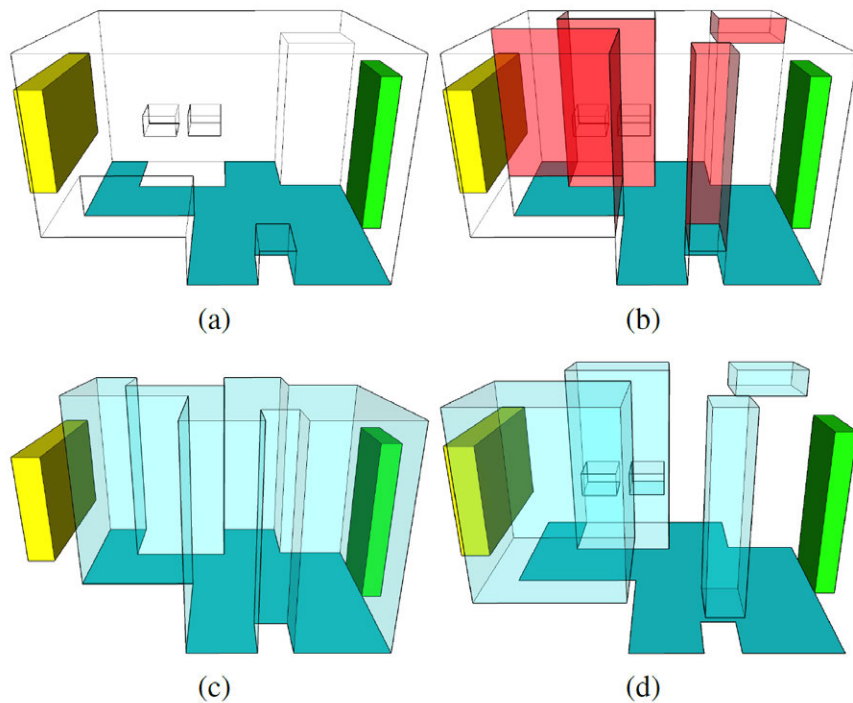
FIG. 2.21 Subdivision based on walk possibility criteria. (a) Walkable surface (dark cyan) in the cell space of 3(d). (b) Cutting faces leading to the targeted sub-spacing. (c) Walkable subspace. (d) Non-walkable subspaces (Diakite et al. 2017).

They have also shown that the functional space has to be recognized, and additional nodes have to be contained in the NRG. The space subdivision could be accomplished by utilizing semantic or topological criteria or a combination of both. Additionally, the authors provide several case studies to illustrate the importance of node locations in the space because indoor navigation systems are dependent on paradigms such as NRG. However, the approach proposed by the authors discusses functional space without addressing the accessibility of the indoor spaces based on user rights.

Another approach has been proposed by Diakite and Zlatanova (2018) to classify indoor objects according to their capacity to autonomously change location. They have also defined a spatial subdivision of the indoor space according to the classified objects and their functions and introduces the Flexible Space Subdivision (FSS). This framework provides an automated spatial subdivision scheme that reflects the complexity of the indoor space. This approach leads to 3D subspaces that can identify the free and non-free indoor spaces based on the objects located within the space and their host activities. It is flexible enough to reflect the static and dynamic alterations of the space. The result of the framework is subspaces that are semantically significant and reply to points of interest or hosts for location nodes on a navigation graph. This framework allows for the production of navigation graphs that can reach a particular object within a given room. Also, by joining the suitable inputs, the subspace establishes sufficient information to allow customized path derivation for the user.

Diakite and Zlatanova (2016b) have introduced an approach that automatically creates a geometrically and topologically valid IfcSpace object in an IFC model. In addition, they have examined the validity requirements of geometric and topological information for indoor navigation versus the IFC rules specified by the standard. By starting from the components of the structure, they were able to identify the interactive surfaces between them and describe the boundary of the indoor space, as shown in Figure 2.22. This approach depends on the combinatorial map data structure to accomplish topological operations while guaranteeing the geometrical and topological validation of the entities' outcomes.
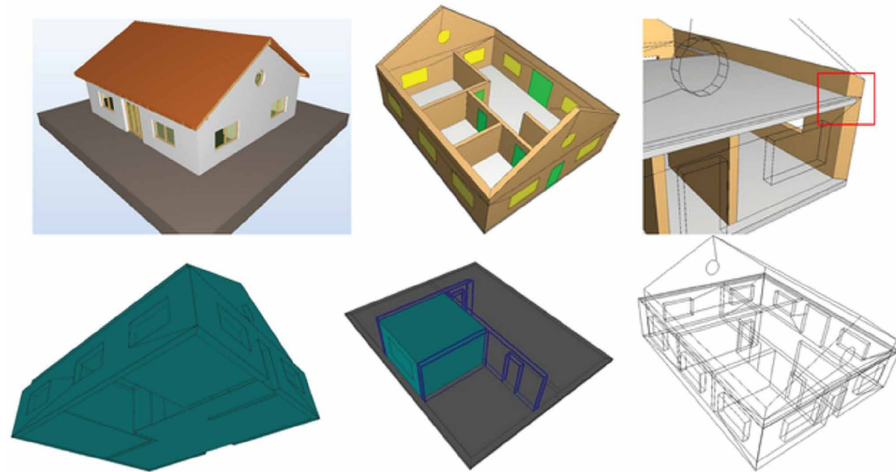
FIG. 2.22 Failed cases of IfcSpace generation due to wrong representation of the structural components in an IFC file. Top row: original IFC model (left), corresponding LCC (middle), zoom on the intersection between the slab of the first floor and the side walls (right). Bottom row: wrongly generated space that aggregates almost all the spaces of the building (left), single correctly reconstructed space (middle) and wire frame view of the generated spaces (right) (Diakite and Zlatanova 2016b).

2.3 IndoorGML

IndoorGML is an OGC standard that provides a framework for indoor navigation, which presents an elaboration of the indoor space and GML syntax for encoding geoinformation (Zlatanova et al., 2016). IndoorGML creates geometry, topology, and semantic models of the indoor spaces used for the components of a navigation network. The indoor and outdoor spaces differ from each other in many characteristics. Based on the indoor requirements for the spatial applications, the standards have to be redefined according to the type of indoor applications. There are two categories based on the indoor spatial applications: 1) management of the components and facilities of the building, and 2) the use of the indoor space. The first category mainly focuses on the architectural elements of the building, such as walls and roofs. The second category deals with the usage and localization features of the indoor space, which includes the requirements of the spatial components for representing rooms, corridors, and constraint elements such as doors. IndoorGML

defines a framework that can locate constant or mobile features based on the indoor spatial information and provide spatial information services by using their positions in indoor space. IndoorGML represents the spatial character of the indoor space and provides a reference (Lee et al., 2014).

The requirements for indoor spatial information are commonly specified according to the type of application: management of building structures, analysis of human activities, air quality, and control, facility management, registration of properties, or indoor navigation. Among these, indoor navigation and indoor LBS are the most prominent applications (Brown et al. 2013, Zlatanova et al., 2014). The goal of IndoorGML is to reflect the requirements for indoor navigation by providing a general framework for specifying spatial models which present the properties of the indoor space and provide a formalism to derive a network for the purpose of pathfinding, as shown in Figure 2.23.

In many ways, indoor space varies from outside space. To fulfill the requirements of indoor spatial applications, key ideas, data models, and standards must be redesigned. Indoor spatial information requirements are divided into categories based on the sorts of applications. Indoor spatial information applications are often divided into two categories: managing building components and indoor services and indoor space utilization. The first category includes building construction and management, as well as facility management. While the first category is concerned with structural elements such as roofs and walls, the second is concerned with the use and location of features (fixed or movable) in indoor spaces. The second category of indoor spatial information comprises needs for describing spatial components like rooms and corridors and limitations like doors. The second category includes indoor location-based services, indoor route analysis, and indoor geo-tagging services.
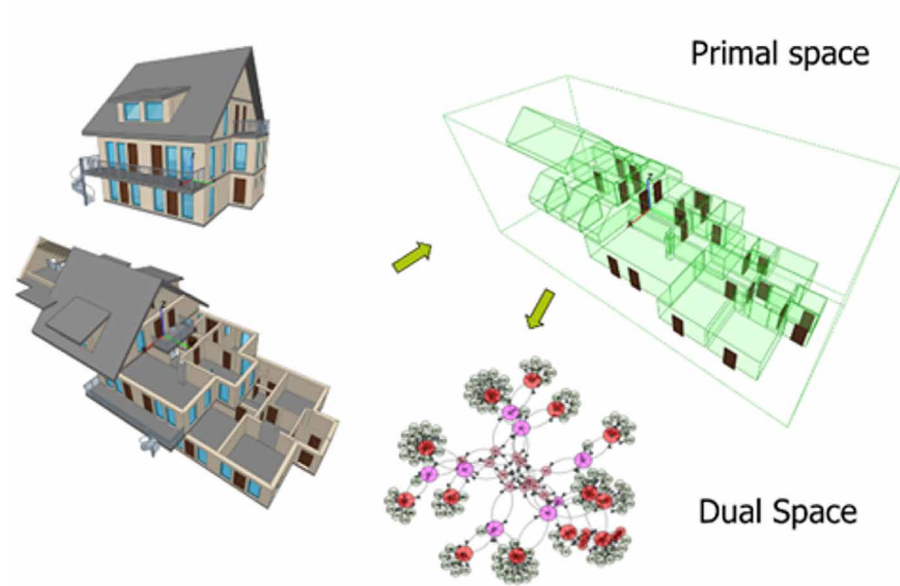
FIG. 2.23 The general concept of IndoorGML: 3D model of a building (left); room (green) and door (brown) spaces used for navigation (upper right); navigation network (lower right).

The purpose of the IndoorGML standard is to create a framework of indoor spatial information to identify fixed or movable features in indoor space and deliver spatial information services based on their locations in indoor space, rather than to describe building architectural components. IndoorGML is aimed to do two activities: representing indoor space attributes and providing a spatial reference for elements in indoor space.

2.3.1 Representation of indoor objects in IndoorGML

Indoor space differs from outdoor space in that it has sophisticated limitations such as corridors, doors, stairs, elevators, and so on, while road network space has just road constraints. As a result, accurate representations of indoor constraints are crucial for indoor spatial information modeling and standards. Indoor constraints are explored in IndoorGML from the following perspectives: Multi-Layer Representation, Cellular Space, Semantic Representation, Geometric Representation, and Topological Representation (Lee 2015).

Definition of indoor space

Indoor space is described as space within one or more buildings that include architectural elements such as entrances, hallways, rooms, doors, and stairs. IndoorGML is not concerned with architectural components (e.g., roofs, ceilings, walls) but rather with the spaces (e.g., rooms, hallways, staircases) formed by architectural components, where things may be identified and navigated. The interconnections between places are also a focus of IndoorGML. IndoorGML does not include components that are not crucial to describing the spaces, such as furniture. While indoor space models can be limited to a single structure, they may also be composed of many buildings or a network of connected structures. A roof does not have to cover all of the structures. An indoor space, for example, might include an inner court or terrace.

2.3.1.2 Semantic representation of indoor space

The semantics of cells is a crucial feature. If multiple criteria are considered, the indoor space might be subdivided into separate cells. For example, the cell subdivision can reflect a building's topography (structure), available WiFi coverages, security zones, public/office spaces. After that, each cell is given meanings concerning the space subdivision semantics. Semantics is employed in IndoorGML for two purposes: categorization and identifying cells and determining cell connections. As a result of semantics, cells that are relevant for navigation can be defined. In topographic space, for example, cells are classified as navigable (rooms, corridors, doors) or non-navigable (walls, obstacles).

The semantics, associated attributes, and semantic interrelations of cells can be used to organize them in a hierarchical framework (specialization and generalization). For instance, a 'room' is a subset of a 'navigable cell,' while a 'non-navigable cell' is a combination of 'walls' and 'obstacles.' Cells formed for one type of space representation can be combined or subdivided for another. For example, a 'check-in area' cell in the security space can be made up of numerous 'room' cells constructed for the topographical space.

The semantics of cells are significantly responsible for connectivity in terms of the ability to navigate through cells. To move from one room to another, for example, we must know that at least one common opening (door, window) cell exists. In addition, a semantically recognized cell's attributes influence connectivity and can function as a navigation constraint. Certain doors, for example, may only allow entry in one way

(emergency exits), deny entry to a certain group of people (security zones), or allow entry only at specified times (e.g., shops). Through the idea of Multi-Layered Space Representation, IndoorGML allows diverse space representations to be merged (Lee 2015).

2.3.1.3 Geometric representation of indoor space

Every cell that defines interior space, such as a room or a hallway, has a form, extension, and location recorded and modeled. IndoorGML may contain geometric data in a variety of ways. IndoorGML uses 3D or 2D Euclidean spaces to illustrate the geometry of cells. The geometry provides a way for the quantitative representation of the spatial features using Euclidean space principles, where a metric space is defined. The ISO19107 (Spatial Schema) standard offers conceptual schemas for describing and modeling real-world objects as features, with cells in indoor space. The geometry package comprises different coordinate geometry classes that are utilized in IndoorGML. The type of Coordinate Reference System (CRS) used to establish a geographic position affects the mathematical functions used to describe the geometry of a cell.

The geometric representation of 2D or 3D features in indoor space is not a significant focus of IndoorGML since they are clearly defined by ISO 19107, CityGML, and IFC. However, for self-completeness, the geometry of 2D or 3D objects may be optionally defined within IndoorGML according to the data model defined by ISO 19107 (Lee 2015). As illustrated in Figure 2.24 there are three options for representing the geometry of a cell in indoor space:

— External Reference (Option 1): An IndoorGML document only contains external links (namely c.xlink, where c is a cell in IndoorGML) to objects defined in other data sets such as CityGML, where the referenced objects in the external data set include geometric information, rather than an explicit representation of geometry in IndoorGML. Then mappings from cells in IndoorGML to related objects in other datasets must be 1:1 or n:1.

— Geometry in IndoorGML (Option 2): An IndoorGML document may include a geometric representation of a cell (specifically c.geom, where c is a cell in IndoorGML). According to ISO 19107, it is GM Solid in 3D space and GM Surface in 2D space. This standard allows for a solid with holes or a surface with holes.

— No Geometry (Option 3): The IndoorGML document has no geometric information.

IndoorGML can include the complete 3D geometry of a feature described in ISO 19107 when used independently without using CityGML or IFC, but it can also just have a 2D footprint when used without referring to CityGML or IFC.
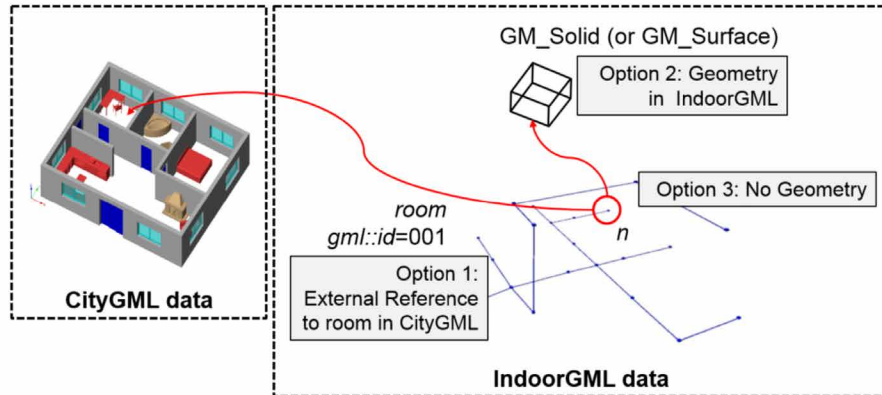
Three options to represent geometry in IndoorGML (Lee 2015)

2.3.2 Primal space

Space subdivisions can be defined based on different properties of a building (construction, functional use, security, sensor coverage) or a user profile (e.g., walking, driving). Each specific space subdivision can be organized in a space layer, i.e., a multi-layered space model in which spaces from different layers may overlap, but spaces from the same layer do not. A specific theme space partitioning can either subdivide or unite several topographic units (rooms), e.g., 'security area,' 'check-in area,' or 'dangerous area.' Such subdivisions may also change dynamically, as in Figure 2.25. The primal space in IndoorGML is whatever main space will be used in the current research to extract the navigation network for different subdivisions of the indoor space based on the user context.

FIG. 2.25 Union of topographic spaces to represent dangerous areas.

The primal spaces of the current version of IndoorGML have the following characteristics:

— IndoorGML provides a UML class diagram and XML implementation.

— Spaces include all architectural components (entrances, corridors, rooms, doors, and stairs), which are essential for moving through the building. Construction elements are seen as obstacles and are clearly indicated as non-navigable spaces.

— Components irrelevant to the description of spaces, such as furniture, are not included in the scope of the current version.

— Spaces are closed objects, represented by areas in 2D and volumes in 3D. They may touch but may not overlap within the same layer.

— Spaces can be bordered by topographic or fictional boundaries or a combination of both.

— Spaces are uniquely identified.

— IndoorGML offers the concept of 'thin' objects (e.g., walls and/or doors), which may be represented as surfaces in 3D or lines in 2D.

— All spaces are semantically classified. The current version of IndoorGML is focused on topographic representation. The top-level semantic consists of navigable (rooms, corridors, doors) and non-navigable (walls, obstacles) spaces.

— Navigable spaces are those used to derive the navigation network. They are further specialized into general (e.g., rooms), connection (e.g., doors), and transition (e.g., corridor) spaces.

General spaces are those in which people stay. Transition spaces are those that people use to move from one general space to another. Doors and other openings are classified as connection spaces. Doors that provide connection to outdoor navigation networks have special meaning and are noted as 'anchor spaces' as shown in Figure 2.26.
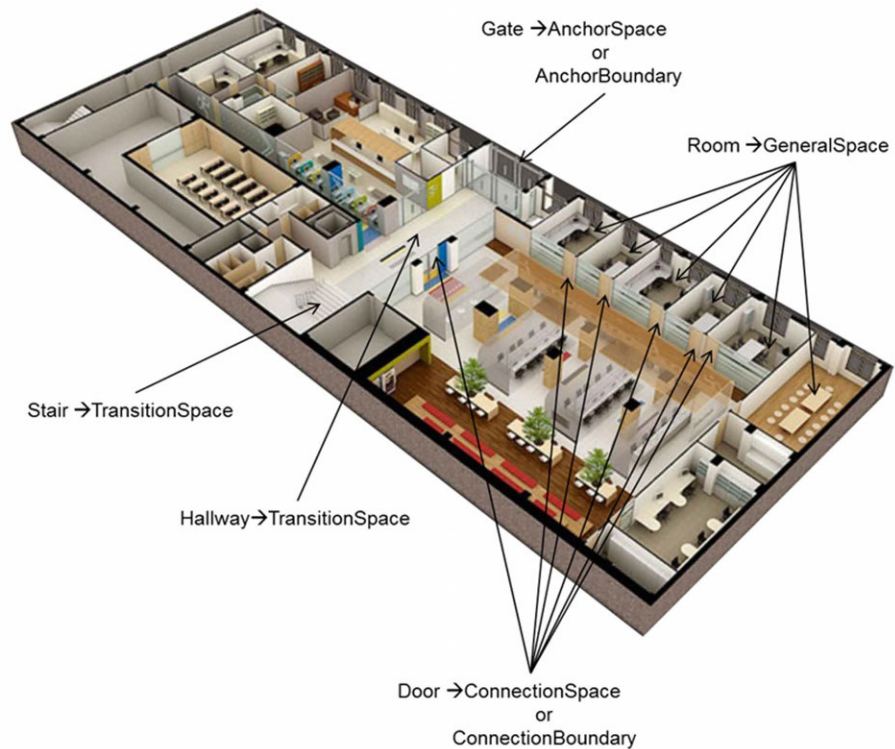
FIG. 2.26 Semantics of the primal space in IndoorGML.

Dual space

The dual model follows directly from the primal model by applying Poincaré duality (Munkres 1984). According to Poincaré duality, a k-dimensional object in N-dimensional primal space is mapped to an (N − k) dimensional object in dual space. Thus, solid 3D spaces in 3D primal space, e.g., rooms within a building, are mapped to nodes (0D objects) in dual space. 2D surfaces shared by two solid objects are transformed into an edge (1D) linking two nodes in dual space (Munkres 1984). While the complete network is derived from the primary space using only adjacency relationships, the connectivity between the spaces relies on semantics (i.e., the notion of doors). As mentioned previously, the type of the obtained graph depends on whether the spaces are navigable or non-navigable. Figure 2.27 shows examples of dual spaces derived from the same primary space. In the figure, W stands for walls, D for doors, and S for spaces, while red lines represent edges in dual space.
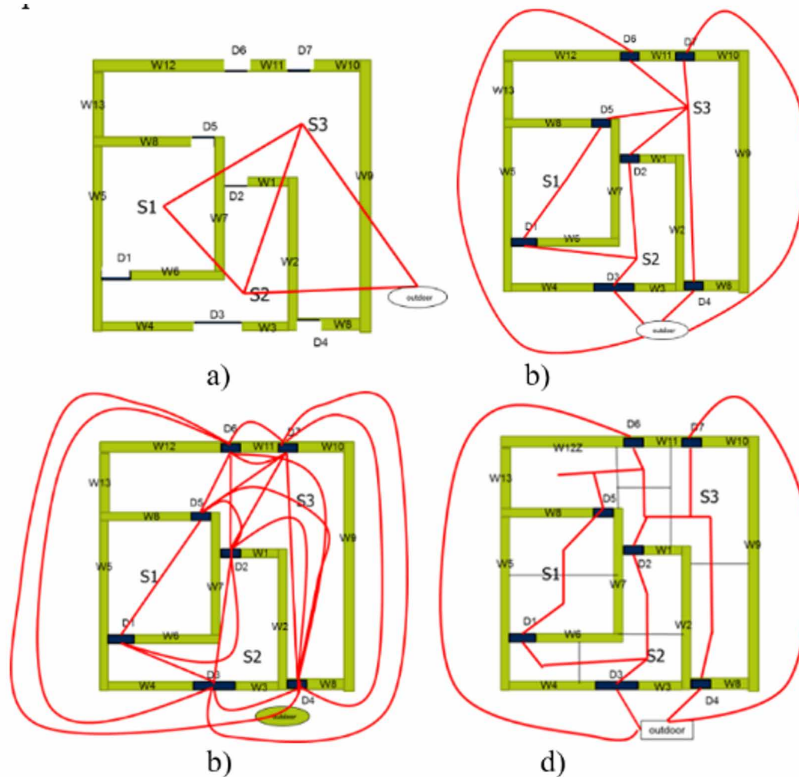
FIG. 2.27 Examples of networks: (a) 'thin' doors, which are used symbolically; (b) 'thick' doors which are considered spaces themselves; (c) only door spaces, including all possible door-to-door connections; and (d) a subdivision of rooms in which each new space has only one door.

The nodes in IndoorGML represent the state of a user, and the edges are the transition between two states, as shown in Figure 2.28. IndoorGML can be used to exchange information in three forms: it can provide both primal and dual space, provide only dual space and integrate it with another semantically rich standard (CityGML, IFC, KML), or provide only dual space (or a dual space path, i.e., a navigation path).
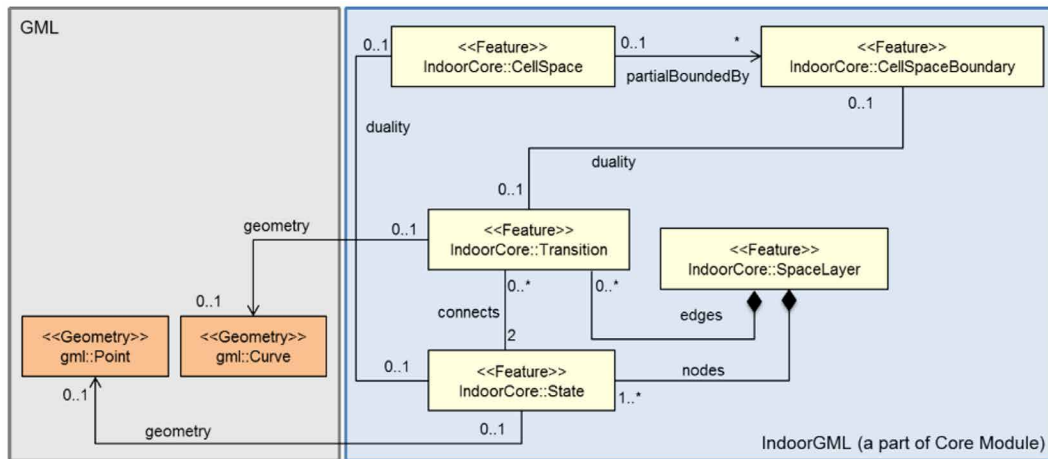
FIG. 2.28 A part of the core IndoorGML (Lee 2015).

2.3.3 IndoorGML core module (Multi-Layered Space Model)

The IndoorGML core module, as illustrated in Figure 2.29 defines the main idea and components of the Multi-Layered Space Model (MLSM). The multi-layered space model provides for the coherence of various spatial decompositions based on various semantics. A distinct space layer represents a subdivision of space, which is methodically separated into primal and dual space on one hand, and geometry and topology on the other. The multi-layered space model is commonly thought of as a conceptual framework for representing space and its topological relations in general. The IndoorGML core module, in particular, allows for the representation of topological connections between indoor spaces in dual space. There are nine classes in the IndoorGML core module:

- **State:** In MLSM's dual space, state is represented as node. A State can be an isolated node, meaning that it is not linked to any other State. For example, space might be connected with a room, hallway, entrance, or other feature inside a primal space building within the topographic space layer. In IndoorGML, it is represented geometrically as a Point. It also has a relationship with the CellSpace class, representing a primal space (or referred to as a geometry object in primal space).

- **Transition:** A transition is an edge in primal space that depicts the adjacency or connection relationships among nodes that represent space objects. A Transition always connects two States within a dual graph structure of one layer. In the topographic space layer, a Transition can also be linked to the border of a room in the primary space.

- **CellSpace:** CellSpace is a basic class that represents indoor spaces. The CellSpace represents space characteristics and geometric representations of space.

- **CellSpaceBoundary:** The semantically defined border of each geographical feature in space is described by CellSpaceBoundary. In 3D Models, the geometry of the CellSpaceBoundary is typically defined by a Surface geometric object.

- **SpaceLayer:** A structured space model is represented by the SpaceLayer class, which is a top class. Each space layer, such as topography, sensor, security space, and so on, is represented by a SpaceLayer. To describe dual space, a SpaceLayer combines State and Transition, which are directly connected with the relevant geometry classes. A SpaceLayer additionally aggregates CellSpace and CellSpaceBoundary, which are directly connected with the respective geometry classes, to represent spatial objects in primordial space.

- **InterLayerConnection:** There are two states in the InterLayerConnection class. Different SpaceLayers define each State. If the intersection of the interior geometries of the layer combinations is not empty, an edge is created; the edge, called InterLayerConnection, can indicate one of the following spatial relationships: contains, overlaps, or equals. Relationships between States in various SpaceLayers are represented by InterLayerConnection.

- **MultilayeredGraph:** The Multi-layered Space Model is represented by the MutliLayeredGraph, which is a fundamental feature of the IndoorGML Core Module. SpaceLayers and InterLayerConnections are gathered here. SpaceLayers and InterLayerConnections form the MultiLayedGraph class.

- **PrimalSpaceFeatures:** PrimalSpaceFeatures is a feature class used to describe primal space characteristics like rooms. It consists of CellSpaces and CellSpaceBoundary as cellSpaceMember and cellSpaceBoundaryMember, respectively.

- **IndoorFeatures:** IndoorFeatures is a root element that represents the indoor space in the IndoorGML Core Module. With PrimalSpaceFeatures and MultiLayeredGraph, it is an aggregated element. The IndoorFeatures include a set of CellSpace and CellSpaceBoundary as PrimalSpaceFeatures and a set of SpaceLayer as MultiLayeredGraph.

FIG. 2.29 UML diagram of IndoorGML's core module (Lee 2015).

2.3.4 Data model of the indoor navigation module
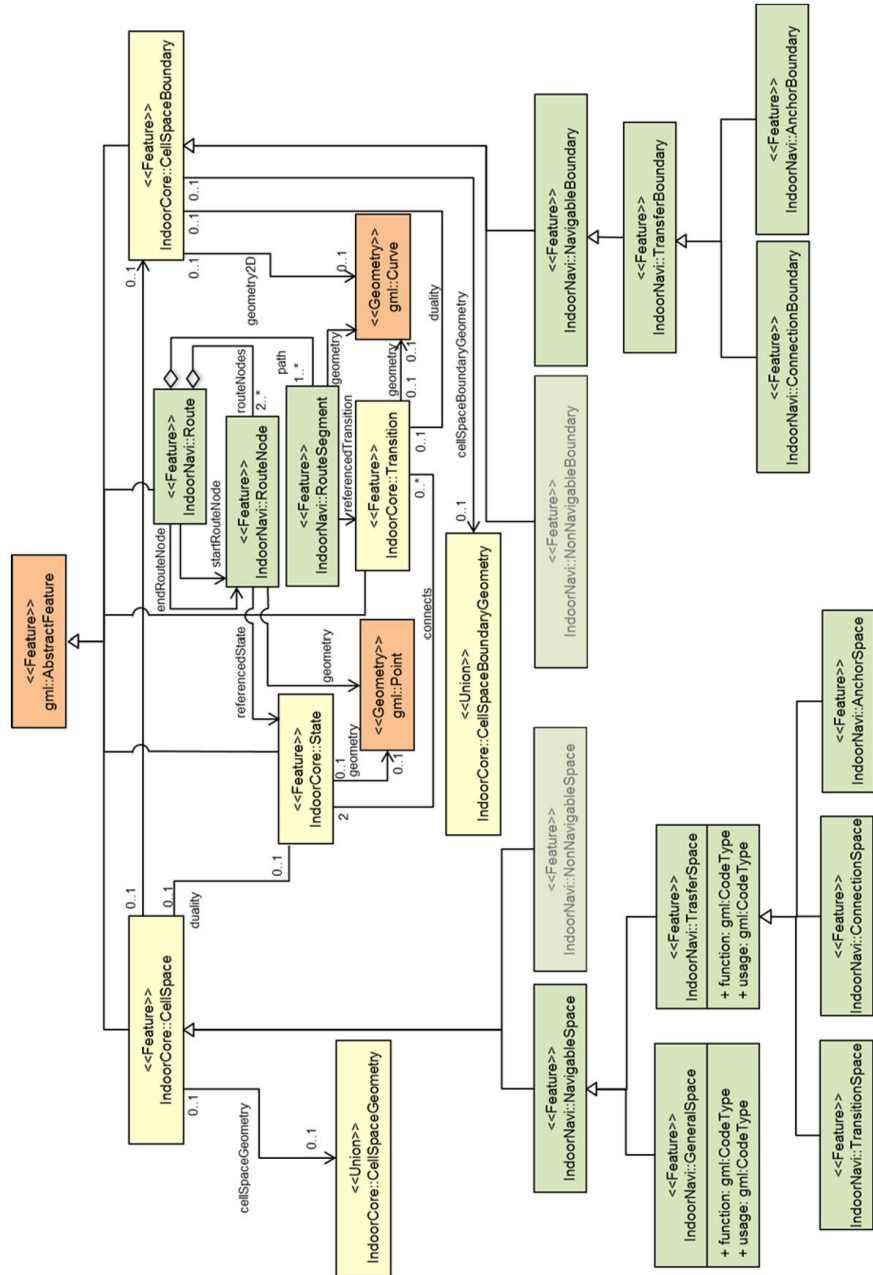
FIG. 2.30 UML diagram of IndoorGML Navigation module

Indoor navigation applications are supported by the Indoor navigation model, which offers semantic information for indoor space. As illustrated in Figure 2.30, space characteristics are divided into two categories: NavigableSpace and NavigableSpaceBoundary. All indoor spaces (e.g., rooms, corridors, windows, staircases) used by a navigation application are represented by NavigableSpace. All characteristics that link the navigation spaces are represented by NavigableBoundary (e.g., door). CellSpace and CellSpaceBoundary classes are used to map Navigable Spaces and Navigable Boundaries. In the IndoorGML Core Module, these are connected with related classes such as State and Transition.

In addition, the IndoorGML Navigation Module describes in detail the core module's general ideas that are necessary for the context of indoor navigation. This might incorporate interior space addressing and georeferencing schemas and concepts for communicating and visualizing navigable route sections. Additionally, additional navigation restrictions such as time access limits, opening hours, or constraints resulting from material qualities of the navigation path might be introduced. Indoor space characteristics must be categorized by functions and uses of space before being mapped to indoor navigation module classes.

Functions, usage, and space classes are all assigned to each space class. Data interoperability can be hampered by misspellings or various names for the same concept or function. IndoorGML allows External Code Lists to describe attribute values such as space class types, space function types, and space usage kinds to avoid interoperability issues. Users will be able to add to or change the external code lists. They can make use of existing models as references. For example, instead of referring to IndoorGML's established values, GeneralSpace codes might be defined using CityGML's code lists. The IndoorGML Navigation module consists of the following classes:

— **NavigableSpace:** The NavigableSpace class represents a space where users may easily move around. GeneralSpace and TransferSpace are their two subclasses. The subclasses are divided into categories based on space's intended use. For example, NavigableSpace represents subdivided spaces such as corridors, lobbies, hallways, and large rooms.

— **NonNavigableSpace:** NonNavigableSpace is a class that depicts space that is obstructed by objects. A wall is a typical NonNavigablespace in a 3D data model.

— **GeneralSpace:** One of NavigableSpace's two subclasses is GeneralSpace. Rooms, patios, lobbies, and other navigable areas are categorized as GeneralSpace.

- **TransferSpace:** TransferSpace is a descendant of NavigableSpace. It has utilized to create a space that can be used to connect GeneralSpaces. ConnectionSpace, AnchorSpace, and TransitionSpace are its three subclasses.

- **ConnectionSpace:** ConnectionSpace is an opening space that connects two interior spaces.

- **AnchorSpace:** An AnchorSpace is a unique opening space that connects an interior and outdoor space.

- **TransitionSpace:** TransitionSpace is a space that connects two indoor spaces, such as corridors, stairwells, and hallway.

- **NavigableBoundary:** The boundary of NavigableSpace, which includes the boundaries of ConnectionSpace and AnchoreSpace, is specified as NavigableBoudary.

- **TransferBoundary:** TransferBoundary is a subclass of NavigableBoundary. It's used to represent a boundary that allows NavigableSpace to connect with each other. ConnectionBoundary and AnchorBoundary are two subclasses of NavigableBoundary.

- **ConnectionBoundary:** A boundary that is connected to two neighboring NavigableSpaces is represented by a ConnectionBoundary. The ConnectionBoundary is represented as a gml:Curve in a 2D space model. In a 3D space model, it is represented as a gml:Surface.

- **AnchorBoundary:** A common boundary between a NavigableSpace and Outdoor area is represented by AnchorBoundary.

- **RouteNode:** A node connected with a routing path is represented by the RouteNode class. It has a relationship with a state in order to obtain further information.

- **RouteSegment:** Connectivity relationships between places are represented by RouteSegment. RouteSegments connect RoutesNodes in a directed manner. A minimum of two nodes will be present on each edge. The RouteSegment comprises two RouteNodes, which are referred to as the connects element, to indicate the start and end positions.

- **Route:** Route indicates a feasible way for navigating indoor spaces. Typically, it is defined as a consequence of path find queries. The Route is made up of a series of RouteNodes. The startRouteNode and endRouteNode nodes indicate the path's start and end points for indoor navigation.

IndoorGML is a relatively new standard, and, therefore, some concepts are not strictly defined or are presented in a simplistic way. They are left for further investigation and clarification. For example, IndoorGML does not provide a strict definition of indoor and outdoor. Therefore, construction units such as balconies, terraces, or sheds are not discussed in the standard. Furniture is also excluded from the scope. However, some researchers have shown that furniture can be an essential indicator for identifying functional areas, such as 'in front of the coffee machine,' 'at the bench,' etc. (Kruminaite and Zlatanova 2014). This approach can be used either for localization or better estimation of spaces free of obstacles, allowing more detailed navigation. Currently, the standard does not have any strict rule on the creation of space layers either. The space subdivisions for a visitor and an employee are generally the same, but the visitor has access to only a subset of the employee's spaces. It is an interesting topic whether these two subdivisions should be organized as two individual space layers ('visitor' and 'employee') or one single layer. The semantics will need to be tested in different use cases to determine whether they are complete or insufficient.

2.4 Land Administration Domain Model (LADM)

Land administration systems (land registration, cadastre) originated in various nations, and data was gathered for different reasons, including taxes and legal security (Simpson 1976). Over time, land administration systems in many nations have increasingly supported spatial development and planning purposes. The phrase "multi-purpose cadastre" is used in this context. The International Organization for Standardization (ISO) developed the Land Administration Domain Model (LADM) (ISO 19152: 2012) on the suggestion of the FIG (International Federation of Surveyors). Land administration is defined in the standard as the process of defining, documenting, and disseminating information regarding people's relationships with land (or rather, "space"). These recognized rights are eligible for registration in principle, with the goal of giving the registered right a specific legal meaning (e.g., a title). As a result, land administration systems constitute a legally significant connection among people and between people and land, rather than just 'managing geographic information.' Several institutions in many nations have utilized the model (http://isoladm.org).

The main characteristics of the LADM can be summarized as follows:

— The model is object-oriented: UML class diagrams support the model-driven architecture (MDA).

— The basic classes of the model are 1) parties (people and organizations); 2) basic administrative units, rights, responsibilities, and restrictions (e.g., ownership rights); 3) spatial units (parcels, and the legal space of buildings and utility networks); and 4) spatial sources (surveying) and representations (geometry and topology), as shown in Figure 2.31 (Hu and Lee 2004).

— The spatial units are abstract spaces. They are geometric/topological representations of rights and administrative units. Spatial units can coincide with topographic features. LA_LegalSpaceNetwork is used to define rights for utility networks (not to be confused with navigation networks as in IndoorGML).

— 3D spatial units can be unbounded, e.g., an open column of space with no top.
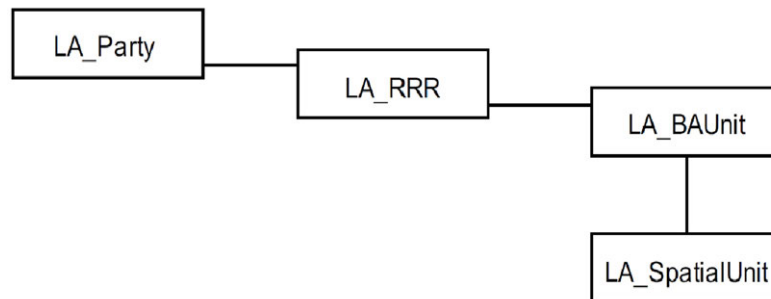
FIG. 2.31 Core classes of the LADM (ISO 19152: 2012)

2.4.1 LADM content and model

The LA_RRR and LA_BAUnit are the two subclasses of the administrative package. LA_Right, LA_Restriction, and LA_Responsibilities are three subclasses of the LA_RRR, which is an abstract class with three subclasses. "A right is an action, activity, or set of activities that a systems member may do on or in relation with a resource" (ISO 19152: 2012). "A restriction is a legal right to desist from doing anything that is granted by the state or not by the state" (ISO 19152: 2012). "A

responsibility is a duty to do something, whether formal or informal" (ISO 19152: 2012). A basic administrative unit ('basic property unit') is defined by the LADM standard as an administrative entity subject to registration (by law) or recording, consisting of zero or more spatial units ('parcels'), against which one or more unique and homogeneous RRRs (rights, e.g., ownership rights or land use rights, responsibilities, or restrictions) are associated to the whole entity, as included in a land administration system. The administration package's classes are depicted in Figure 2.32.
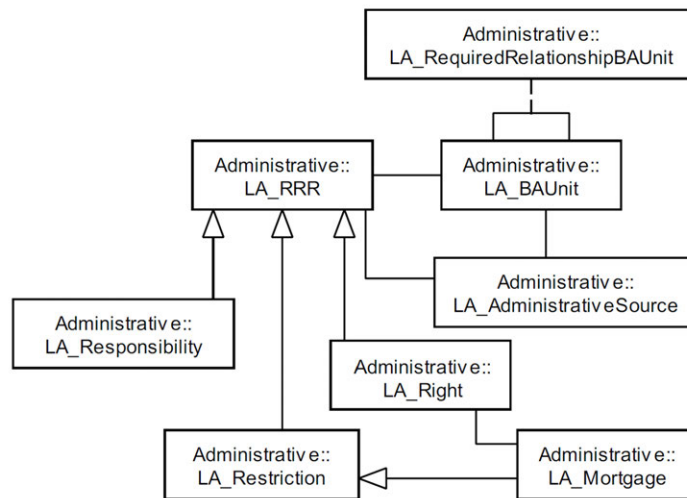
FIG. 2.32 Administrative Package Classes (ISO 19152: 2012)

As illustrated in Figure 2.33, there are many subclasses in the spatial unit package: LA_SpatialUnit, LA_SpatialUnitGroup, LA_Level, LA_LegalSpaceNetwork, LA_LegalSpaceBuildingUnit, and LA_RequiredRelationshipSpatialUnit. A text that explains the geographic unit, such as "From this tree to that river," a point or many points, and a line or multiple lines that indicate a single region or multiple areas are among the attributes that can be used to represent the spatial unit. The LA_SpatialUnitGroup is a collection of spatial units within a planning area or administrative zone. A single area (or several areas) of land and/or water, or a single volume (or many volumes) of space, is referred to as a 'spatial unit' (ISO 19152: 2012).

Textual descriptions and 2D and 3D geometry can be used to describe a spatial unit (Zlatanova et al., 2016). For example, the term "homogeneous" refers to a right,

restriction, or responsibility applicable to the whole basic administrative unit. A right, restriction, or responsibility for the whole fundamental administrative unit is owned by one or more parties (e.g., owners or users). Any increase in the size of the unit would result in a non-homogeneous mix of rights. Making the unit smaller would result in at least two adjacent lots with the same rights combination. Because the spatial units do not need to be visible in the actual world, they are referred to as legal or virtual objects.
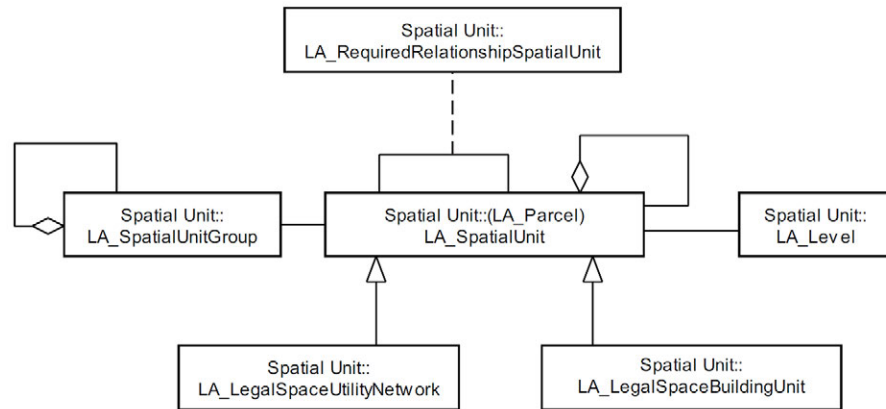
Spatial Unit Package classes (ISO 19152: 2012)

It should be emphasized that the border of a parcel commonly corresponds with a tangible real-world object, such as a fence, wall, or road border. This is even more true in the case of 3D spatial units; for example, the geometries of physical things such as tunnels, buildings (parts), or other structures typically correspond to legal areas with unique and homogenous RRRs attached (Lemmen et al. 2010, Zulkifli et al. 2013). The Surveying and Representation sub-package of the spatial unit package contains four classes: LA_SpatialSource, LA_Point, LA_BoundaryFaceString, and LA_BoundaryFace, as shown in Figure 2.34. LA_SpatialSource is a spatial source that is associated with one or more points. An attribute of LA_SpatialSource is a set of measurements with observations.
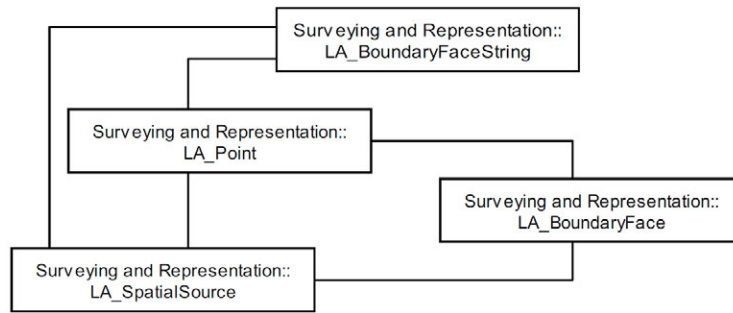
FIG. 2.34 Surveying and Representation Sub-package classes (ISO 19152: 2012)

The party package comprises three classes: LA_Party, LA_GroupParty, and an optional association class LA_PartyMember, as shown in Figure 2.35. A person or an organization that impacts rights transactions is defined as a party according to the LADM standard. LA_GroupParty is defined as several parties that own a particular entity. If a member is a registered party and a constituent of a party group, they will be referred to as a party member.
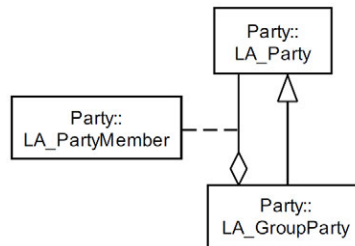
FIG. 2.35 Party Package classes (ISO 19152: 2012)

2.4.2 LADM code lists

LADM provides code lists for various classes to describe and express a long list of potential values, as shown in Figure 2.36. Code lists aim to allow the use of the LADM terminology on a local, regional or national level. During the implementation process, users of the standard have to define and manage the potential values (ISO 19152: 2012). Thus, it is convenient to introduce more code list values as an alternative to adding more classes.

Spatial Unit Package code lists (ISO 19152: 2012)

2.4.3 Relationship between physical and virtual objects

A 3D cadastre is not the same as a 3D building registration. Cadastres are concerned with legal spaces or spaces defined by geometry and topology and which particular RRRs are attached. As a result, while not all architectural elements, such as various rooms/spaces, are legally significant (where the same RRRs apply), they are commonly described while designing a structure. Only when the RRRs differ can a different geometry become necessary. As a result, only a portion of the indoor building model information will likely be applicable in the 3D cadastre context (and maybe that geometry is even implicit, such as a 3D boundary face specified by the 'middle of the wall').

Real-world (physical) objects and legal objects should have consistent geometry, and we should make provision for this, which might be defined using OCL constraints. Rather than being a prescriptive standard, LADM is a conceptual framework that defines concepts and vocabulary. Before changing this into a land administration implementation, a country should first construct an LADM country profile that supports the country's law (and is stated in terms of the international standard).

LADM country profile of malaysia

The land administration organization structure in Malaysia assigns the power to state authorities to manage land, since the land is a state subject based on the Federal Constitution of Malaysia (Zulkifli et al. 2015). Two organizations in Peninsular Malaysia are in charge of managing and maintaining the land administration system: the Department of Survey and Mapping Malaysia (DSMM) and the District Land Offices. Together they are in charge of all cadastral survey and ownership rights. Moreover, there are several policies such as the New Economic Policy (NEP), the National Development Policy (NDP), and the New Economic Model (NEM) that are used to solve land-related issues in Malaysia such as:

— Issues connected to public power over land which includes planning, development control, compulsory purchase, public development and land taxation.

— Issues related to the land market that contain legal and fiscal frameworks for commercial cooperation such as buying, selling, leasing, and mortgaging.

— Issues related to the institutional structures that manage the control of land, including local and central public authorities and the common regulatory framework for decision-making in the field of urban land.

The registration of 3D object rights is not included in the current Malaysian land administration system; only the 2D-based system, which provides essential information about land and property, has been adopted. The development of the Malaysian LADM country profile is based on the eCadastre (in DSMM) and eLand (in District Land Offices) systems; however, these systems are not connected. Thus, 3D property rights and 3D cadastral rights are not available. However, the systems could be expanded and integrated by utilizing the Malaysian LADM country profile to associate important information from both standards. An arrangement of the data content is required.

The administrative data includes the ownership of lots and the level titles for buildings. The spatial data includes a National Digital Cadastral Database (NDCDB), which demonstrated lots, and a level Extensible Markup Language (XML) that shows a building. The Malaysian LADM country profile uses 'MY_' as the prefix that covers spatial and administrative data modelling. The administrative part of the Malaysian LADM country profile includes the party and administrative package. The primary class of the party package is the MY_Party class with its specialization MY_GroupParty. There is an optional association class named MY_PartyMember. The administrative package includes the abstract class MY_RRR, which has three

particular subclasses: MY_Right, MY_Restriction, and MY_Responsibility. The administrative package includes MY_Mortgage, MY_BAUnit (a Basic Administrative Unit), and MY_AdministrativeSource, as shown in Figure 2.37.

FIG. 2.37 Overview of the administrative (legal) portion of the Malaysian LADM country profile (Zulkifli et al. 2015).

The LADM Malaysian country profile applies sID as an administrative source identifier. Essentially, sID is the title number for an administrative source. Aside from source documents, all classes in the LADM are a subclass of VersionedObject and obtain all of the VersionedObject attributes. The class VersionedObject is presented in the LADM to create and maintain historical data. The source documents cannot be changed, and only new source documents can be added.

Malaysia's current land administration system does not maintain complete history management, which is considered a significant change to the current situation. It would be necessary for the land administration system itself and essential for future Malaysian information infrastructure, as others could need the functionality to indicate historical versions of land administration objects. The spatial unit in the Malaysian country profile could be 2D or 3D. Usually, the lots are in 2D, but subsurface lots use 3D volumetric descriptions without 3D topology. There are many abstract classes in the Malaysian country profile: MY_SpatialUnit, MY_Shared3DInfo, and MY_GenericLot.

These classes only maintain the modelling process, describe shared attributes and structures, and not take any instances. Some of the MY classes have a LA class name in the upper right corner with italic font because those classes are obtained from the LA standard, as shown in Figure 2.38. MY_GenericLot contains the attributes of a lot, and it has two specializations, MY_Lot2D and MY_Lot3D, including their attributes and structure. Currently, MY_Lot2D is based on a 2D topology concerning shared boundaries in MY_BoundaryFaceString. The 3D topology is not available for lots in MY_Lot3D and level objects. The model still represents one level object type in 2D using the class MY_LandParcel, but only for buildings with no more than four levels.

The other level objects are suggested to be 3D and therefore derive from an abstract class MY_Shared3DInfo, with level specializations: MY_BuildingUnit, MY_ParcelUnit, MY_AccessoryUnit, MY_CommonPropertyUnit, and MY_ LimitedCommonPropertyUnit. LimitedCommonProperty is designed with a part-of relationship to MY_CommonProperty. A broad range of spatial units is maintained to produce comprehensive and future-proofed models, including legal spaces for utilities, customary areas, and reserved lands such as forests and wildlife areas. The spatial representations of customary areas could be by text or sketches, and they can be measured. MY_Level is utilized to classify several types of spatial units. There is a type of attribute in the MY_Level class that defines the level type of the spatial unit, such as customary, lots (combined land and road), buildings (levels objects), and utilities.

The code list for this attribute can be assigned to MY_LevelContentType. Thus, MY_ Level is a set of spatial units with a geometric or thematic cohesion. The conceptual model offers level 0 for customary, level 1 for reserved land, level 2 for a 2D lot, level 3 for a 3D lot, level 4 for and level 5 for utility. Also, there are links between the spatial units and point tables for spatial source documents: for example, MY_ SpatialSource has an association with MY_SpatialUnit and MY_Point.
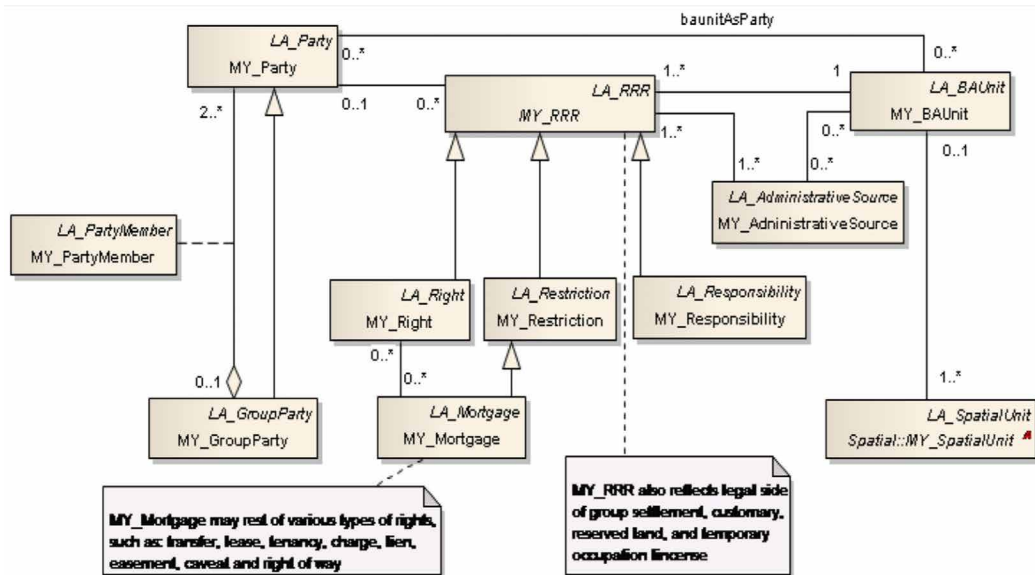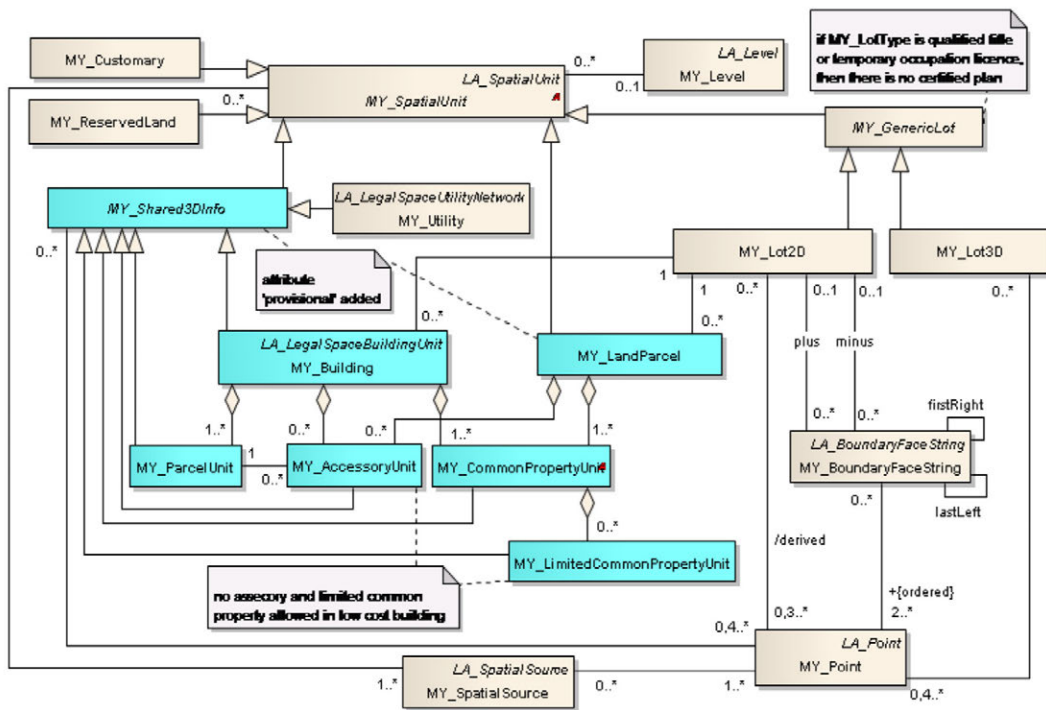
FIG. 2.38 Overview of the spatial part of the Malaysian LADM country profile (Zulkifli et al. 2015).

The LADM Malaysian country profile utilizes suID for the spatial unit identifier and sID for the spatial source identifier. The suID in the Malaysian country profile is based on the Unique Parcel Identifier (UPI). The certified plan number for the spatial source is sID. The development of a Malaysian LADM country profile demands the participation of several departments to direct the fundamental components of the system. Both governmental and private organizations have to be included to combine all aspects of the new system.

The implementation of each part is provided by specific institutions at the national, state, and local levels. This profile presents land ownership and property information and a set of broader land information such as land use, land zoning, infrastructure data, buildings, and properties. The Malaysian LADM country profile also progressively enables regular registration and will overcome the weaknesses of the old system, such as delays in updating registers, high registration costs, and the lack of a detailed overview of current parcels and properties within an area.

Development of a prototype for the assessment of malaysian LADM country profile

Zulkifli et al. (2014) have provided development of a prototype for the assessment of the Malaysian LADM country profile. The Malaysian LADM country profile consists of two parts: administrative and spatial. Modelling tools such as Enterprise Architect provided an automated transformation from the conceptual model, a Unified Modeling Language (UML) class diagram, into a technical model. With the technical model, sample data from JUPEM (spatial) and the Land Office (legal and administrative) could be entered into the database. The authors began by using a UML diagram of the conceptual model that was provided by Zulkifli in 2014 to create a database schema in Oracle Spatial and transpose the land administration system into LADM. Usually, each UML class refers to a table of the same name in the database schema. There are also views with names ending in View, code list tables with names ending in Type, and additional tables, when the relation is multiple-to-multiple between two classes, with names ending in Relationship.

Based on the LADM standard, the Oid data type has two different parts: the namespace and a local ID. However, in the JUPEM system, they do not need to add namespace because it is the same for all objects in the same table. Thus, the local ID is sufficient for the different identifier values. The main characteristic is that the ID must be unique for each object. However, for some objects, there may be several versions with the same ID which can be distinguished by their beginDateTime attributes. For each table in the database, there is a Primary Key (PK) with a set of one or more attributes. Each attribute value of the PK has to be special for each entity.

However, there can be several versions of an object, created by changing some attributes. This means that for one object, there may be several records in the same table with different beginning and ending dates/times. To locate a unique record in the table, the ID and beginDateTime should be included in the PK. The primary key for administrative tables is utilized for physically clustering to improve access without needing an extra indirection of an index. For the geometry, the spatial table is utilized for spatially clustering the records in the table. Moreover, for fast selection of a record according to the ID, the authors have added a B-tree which is a Foreign Key (FK) that is used to indicate attributes that are located within another table to the PK. Then they have stored only the ID in the FK to avoid causing a cascading effect in case of object update. By using this technique, each table can have several FK attributes that refer to several tables.

The authors have also implemented each code list class by its table. The name of the code list table has the extension Type, which occurs after the code list name. Because the code list can be updated, they have beginDateTime and endDateTime attributes. They have referred to the code list by using the ID (cID) attribute of the code list as FK.

There are several types of constraints such as:

— The primary key must be special.
— The endDateTime must be > than beginDateTime.
— The end date of the previous version must be the same as the start of next version.
— The sum of the shares must be equal to 1.
— Each lot must have closed boundaries.
— The boundaries may not intersect.

The authors have chosen to directly utilize the generic solution according to beginDateTime and endDateTime based on the ISO 19152. They have used the Structured Query Language (SQL) create view to realize derived attributes. The LADM Malaysian country profile has various types of area/volume attributes such as surveyed, official, and calculated in MY_Lot2D, MY_Lot3D, and MY_LandParcel, and the multiplicity of these attributes in the profile is great. There are three ways to implement this:

— Additional table for the multiple attributes.
— Vary the usage to represent all values.
— Fix the number of area/volume attributes.

The authors have analysed the specific situation for the best way to realize the multiplicity of attributes. For example, they have used several attributes for different area types in the database schema, as in the case of the area attributes for MY_Lot2D: officalArea_m2, calculatedArea_2m, and surveyedArea_m2. This way was considered the simplest and most efficient solution. In addition, they have created an R-tree index for spatial data and a B-tree index for non-spatial data to enable effective searching based on selected attribute values. To achieve physically organized data in an index organized table, they have used the PK ID attributes in several tables for administrative data. For this method, one B-tree index is kept, making the system more precise and well-organized. The geometry of each spatial class has been used to index spatial objects according to their geometry type with the R-tree index.

They have used the polylines for MY_BoundaryFaceString to avoid redundancy, or they will use the left/right topology information which has to be repeated for each line segment. That will increase the storage size and slow down the system. The end points of edges play a main role in the topology of the model. The intermediate point is defined by two line segments, and the end point is indicated by three or more line segments.

In the next step, they have converted data samples from JUPEM and the Land Office to the data mode and used Oracle Spatial to create the database. They have chosen the World Youth Foundation building as a study area. The building consists of four floors and uses a 3D cadastral registration system but is surrounded by a land parcel that is on a 2D cadastral system based on LADM. Using Bentley Microstation, they have created the database schema and inserted the data to develop their prototype. To use this application, a query is performed by the visual SQL Query Builder, which requires functionality for assessing the model such as:

— Styling specifications (color and line type).
— Styling and drawing specifications for 2D topology.
— Zooming and planning in the 2D displayed map.
— Styling and drawing specifications for 3D simple feature geometry.

The development of the proposed prototype consists of four steps as shown in Figure 2.39:

— Creating the Malaysian LADM country profile (conceptual model).
— Deriving the database schema (technical model).
— Populating Oracle Spatial (converting and inserting the data).
— Developing Bentley MicroStation front-end (viewing and editing the data).
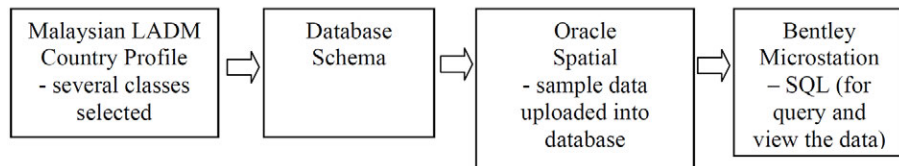
FIG. 2.39 The four steps of the prototype development (Zulkifli et al. 2014).

2.5 Related standards

2.5.1 Industry Foundation Classes (IFC)

The Industry Foundation Classes, or IFC, are an open worldwide standard for exchanging and sharing Building Information Model (BIM) data among software programs used by many users in the construction or facilities management industries. The standard offers data needed throughout the life cycle of buildings and bridges (buildingSMART International Ltd., 1996-2019). Since 1994, IFC has been improved by an industry consortium, and the standardization process has been subjected to a dynamic environment due to the changing industry context, standardization organization, resource availability, and technological advancement. While the primary goal of IFC standardization was to facilitate interoperability amongst AEC/FM software systems, the optimal means to achieve that goal has been evolved over time (Laakso and Kiviniemi, 2012).

In the AEC (Architecture, Engineering, and Construction) industries, BIM (Building Information Modeling) technology is gaining popularity (Eastman et al., 2008). In comparison to traditional CAD technology, BIM can preserve both geometry and rich semantic information of building components, as well as their connections, to facilitate data interchange throughout the lifetime. The IFC (Industry Foundation Classes) standard, developed by the buildingSMART, formerly known as the International Alliance for Interoperability (IAI), is a critical data interchange standard for BIM (BuildingSMART, 2008).

The IFC data model, which provides geometric and rich semantic information on building components, is designed to make the AEC industries more interoperable. It is a vendor-neutral and open specification that is not controlled by a single company or set of companies. The IFC standard is now supported by the majority of BIM software manufacturers. The buildingSMART website provides a list of software applications/utilities that enable IFC import and/or export capability (BuildingSMART, 2011). Several recent research articles have focused on extracting and managing semantic information on building components produced in the form of IFC for a variety of applications, including automatic rule-based checking (Eastman et al., 2009), design solution evaluation (Jeong et al., 2011), construction cost estimating (Zhiliang et al., 2011), construction management (Zhang et al., 2011), and IFC file comparison and metrics (Lee et al., 2011).

The IFC data model was divided into four layers using including the domain, interoperability, core, and resource layers. Figure 2.40 illustrates the relationships between these levels. The layers have rigorous reference hierarchies, with the primary limitation being that referencing can only occur downwards in the hierarchy. This means that data at the resource layer must be self-contained and not relate to any higher-level classes. The data from the resource layer, as well as all other levels below it, may be referenced by the other levels. Only the resource layer allows references inside the same layer. The resource layer provides the resource schema, which includes fundamental specifications for characterizing objects in the levels above.

The kernel and extension modules part of the core layer. The kernel is responsible for determining the model's structure and decomposition, as well as supplying basic concepts such as objects, relationships, type definitions, characteristics, and roles. The core extensions are specialized versions of Kernel classes. The interface for domain models is provided by the interoperability layer, which also serves as an exchange mechanism for facilitating cross-domain interoperability. Domain models for processes in certain AEC domains or types of applications, such as architecture, structural engineering, and HVAC, are contained in the domain layer. (IAI 1999a, 1999b, and 2000).
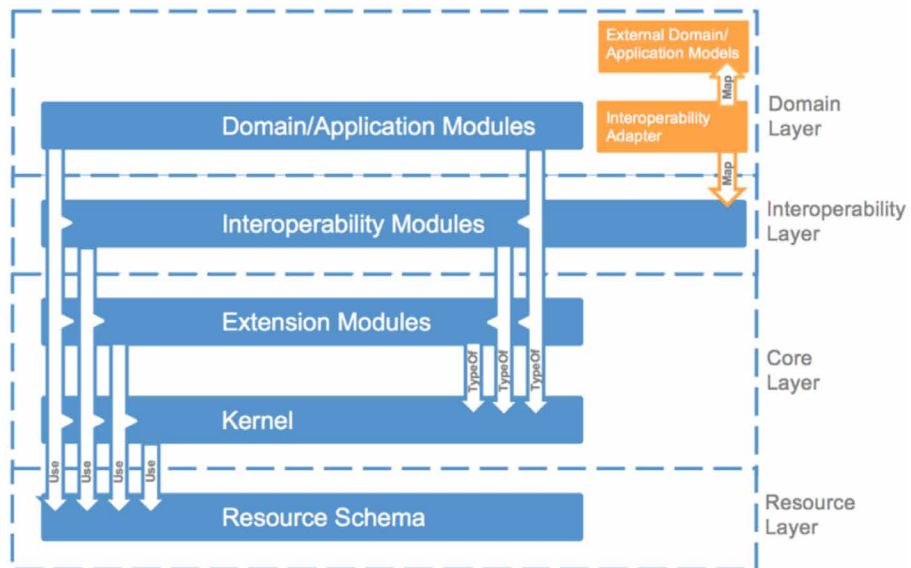
FIG. 2.40 Structure of the IFC data model (IAI 1999a, 1999b, and 2000)

Indoor navigation has been implemented using IFC building models (Isikdag, Zlatanova, and Underwood, 2013; Lin et al., 2013; Boysen et al., 2014; Tang et al., 2015). Lin et al. (2013) used IFC to perform shortest path planning for 3D indoor environments, extracting both geometric and semantic information from building components described inside the IFC file, such as IfcSpace, IfcWall, IfcDoor, etc. In addition to the extendable property sets, the IFC2x3 contains 653 entities and approximately 300 different data types. for this reason, it is required to ensure the accuracy of the information taken from the input IFC file for path planning applications.

The IFC file is fundamentally organized hierarchically. The hierarchical structure of a subset of the IFC standard's currently specified elements, in which all components are derived from the entity IfcProduct. The items processed during indoor navigation are shaded in grey, as shown in Figure 2.41. The diagram illustrates how to use the space and its related components for indoor navigation, with all entity definitions referring to the IFC2x3 specification (Lin et al., 2013):

— **IfcSpace:** Space is an area or volume within a building bounded by particular functions, and it is frequently related to a building story. The spaces in a structure are frequently constructed with some unique or private uses, such as toilets).

— **IfcWall:** The wall is a vertical structure that separates or divides places. IfcWall and its subclass IfcWallStandardCase are both provided by the IFC specification for wall occurrences.

— **IfcDoor:** The door is a structural element primarily used to manage access to people and objects. A door is usually the entrance to a space or room, and the door opening process is specified in the IFC specification as IfcDoorStyle.

— **IfcColumn:** A column is a building's structural elements.

— **IfcStair:** The stair is a vertical pathway that allows people to move from one floor to the next. Stairs or elevators should be regarded as transit nodes of the shortest way in multi-story path design.

— **IfcFurnishingElement:** The IFC standard exchanges instances of IfcFurnishingElement to represent the furnishing items inside a building, such as desks, chairs, and beds.

— **IfcDistributionElement.** Building service element entities are exchanged as instances of subtypes of IfcDistributionElement in the IFC model, where these service elements comprise energy conversion devices such as water heater) and flow moving devices such as pump motor.

The contents mentioned above have discussed the types of the space and its inside components for path planning. Extracting both geometric and semantic information of each building component from the IFC model will be introduced below.
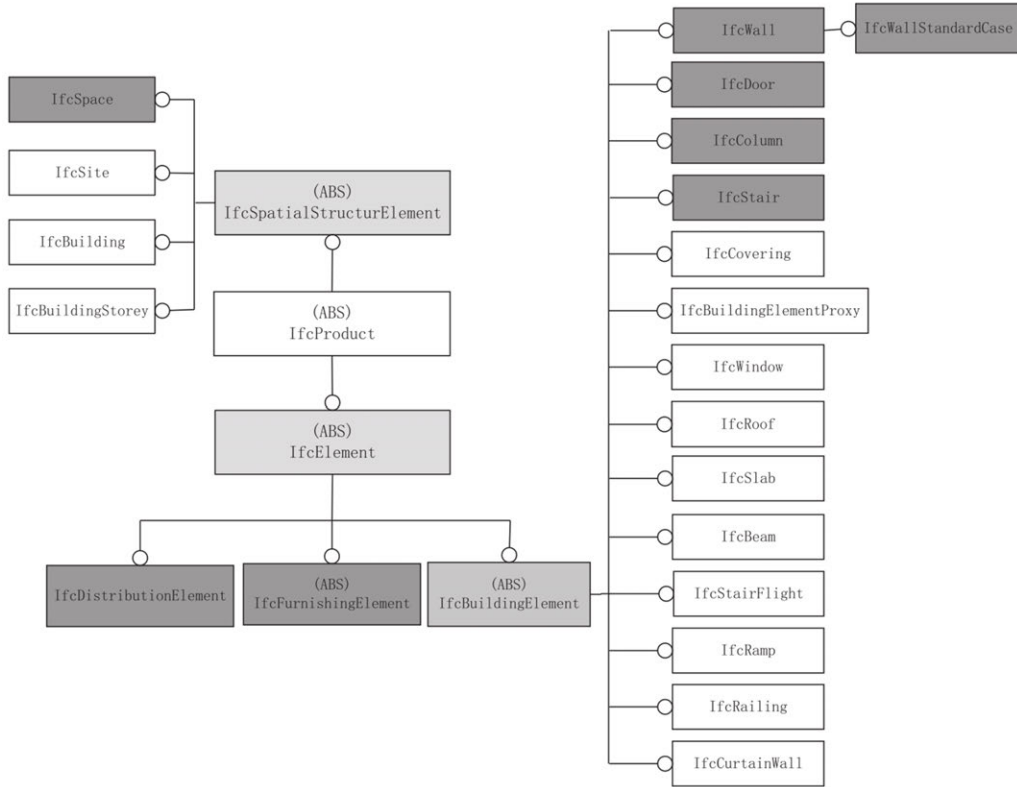
FIG. 2.41 The hierarchy structure of part of the currently defined elements within the IFC architectural model is illustrated, in which all the elements inherit from IfcProduct. Note that the elements processed in path planning are highlighted in the grey background (Lin et al., 2013).

2.5.2 Facility management standard

In today's market, facility management (FM) is a relatively young sector. The International Facility Management Association (IFMA) was founded in the United States in 1978 (Steenhuizen et al., 2014). Facilities management is the process of ensuring that an organization's buildings, systems, and services support core management and operations while also contributing to the achievement of strategic objectives under changing circumstances (Alexander 2013). Nutt (2004) defined facilities management as a tool for achieving a sustainable and operational plan for an organization through time via the management of infrastructure resources and services. Facility management is critical to a building's success since it accounts for more than 80% of the total project cost (Nica and Wodyski, 2016). Pärn et al. (2017) define Facilities management as an integrated strategy to maintain and improving a building in order to enable efficient maintenance and day-to-day operations.

Facilities management concentrates resources on satisfying user demands to support the critical role of people in organizations, and it tries to enhance quality, decrease risks, and assure value for money on a constant basis. It is a critical management function and organization service. It is being used by major corporations worldwide as part of their restructuring plan to get a competitive advantage. It may also guarantee that facilities and support services enhance client response and accomplish its goals.

Increasing expenses of occupying premises, providing services to support corporate operations, and improving working conditions are all significant elements in profitability for organizations of all types in various economies across the world. Reducing the expenses of doing business can be critical to success. User expectations increase as buildings get even more complicated and hold more technology, and the demand for them to perform rises. Increasing regulation to assure health, safety, and welfare, as well as to protect and preserve the environment, has given building managers more significant obligations in terms of workplace management.

Facilities management encompasses all areas of property, space, environmental control, health & security, services, and support, and it necessitates the establishment of appropriate control points inside the organization. These regulations, as well as corporate rules and regulations, will be outlined in the facilities plan. The organization's structure, methods, and tasks will be described. Facilities management rules define how a company responds to critical concerns, including space allocation and pricing, environmental control and protection, and direct and contract workers.

The policies will define the organization's direction as well as the values and principles toward facility users, the organization, its operational units and customers, individual workers, and the general public. Facilities management is essential to organizations in both developed and emerging nations. When supplying the operational environment and services needed for organizational efficiency in a specific setting, distinctions in culture and management style must be considered. Furthermore, several researchers (Maas and Pleunis, 2006; EuroFM, 2011; IFMA-IT1, 2011) indicates that three pillars of FM appear to be significant – the fundamentals of FM:

1 The three FM characteristics:
   a people.
   b place;
   c and process.
2 FM is supportive.
3 There are a variety of fields.

Aside from the three "pillars" described above, the EN 15221 standard is the most essential business model that all FM associations, corporations, and organizations throughout the world follow and promote. CEN produced this standard, which has since become a requirement in every FM-related organization. Its primary purpose is to offer all facility managers a comprehensive understanding of the spectrum of FM, including space and infrastructure and people and organization (CEN, 2006). Furthermore, it attempts to provide a standardized framework so that they may communicate in the same "language":

— Improve cross-communication between stakeholders.
— Boost the efficiency of primary activities and FM processes, as well as the output quality.
— Designed To create systems and tools.

As indicated in Figure 2.42, the standard is divided into six parts. The scope of FM is depicted in Figure 2.43, which includes space and infrastructure and people and organization. The FM agreement is a contract between the supplier and the organization covering facility services and primary activities. This agreement will be implemented at three levels inside the company: strategic, tactical, and operational. The quality of the services given and the deliverables are measured using key performance indicators (KPIs), which must meet the quality standards set out in the service level agreements (SLAs). On a high level of abstraction, FM is the management of internal or external customer/client-supplier relationships and helps differentiate between numerous FM-specific dimensions of benefits and costs," the FM value may be regarded as a multi-dimensional and relationship value (Steenhuizen et al., 2014).

EN 15221 − 1, Part 1	Facility management
EN 15221 − 2, Part 2	FM agreements
EN 15221 − 3, Part 3	Guidance how to achieve/ensure quality in facility management
EN 15221 − 4, Part 4	Classification and structures
EN 15221 − 5, Part 5	Guidance on the development and improvement of processes
EN 15221 − 6, Part 6	Area and space measurement

FIG. 2.42 The standard contains six parts (Steenhuizen et al., 2014)
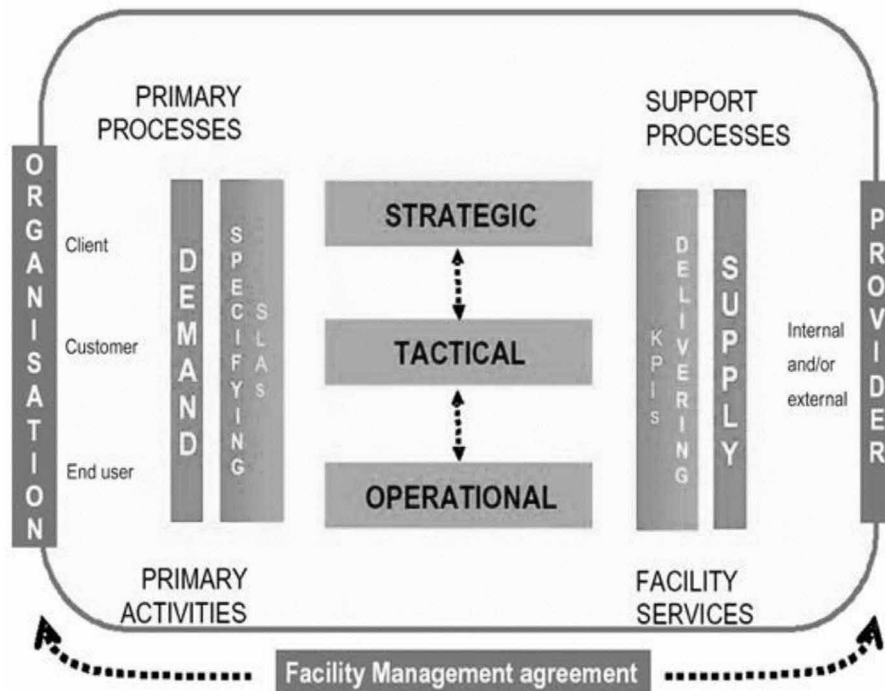
FIG. 2.43 The European FM model (Steenhuizen et al., 2014)

2.6 User profile

In order to support the involvement of different types of users, there is much consideration given to the user profile in the research and development of web-based information systems and mobile telecommunications (Foerster et al. 2012). The modelling of user profiles is aimed at allowing interactive computer systems to improve and adapt to their current users, as well as examining the role of user models in the process of adaptations. The User Modelling System (UMS), provided by Fink and Kobsa in 2002, consists of a dictionary component that contains a user model, usage model, and service model.

The system also includes a user learning component, which supports the acquisition and maintenance of user concerns and priorities from the usage model and updates the individual user model. The architecture of the UMS supports external clients to provide information about the users to the UMS, and to recover existing information about the user from the UMS by using an access control system. The European Telecommunications Standards Institute (ETSI) defines the user profile as the total set of user-related information, priorities, rules and settings that impacts the way that particular user experiences terminals, devices, and services. Standardization of user profiles is important because it ensures that clients and services work well together when implementing user-driven applications. Figure 2.44 shows the general user profile, which is organized as follows:

— Personal information related to the user.

— Human-centered preferences, which provide validation for a broad variety of services.

— Service-related information and preferences, which provide service categories and specific services.

— Device-related information and preferences, which provide device categories and specific devices.

The goal of ETSI framework was to support personalization and profile management. The user profile includes a huge number of settings and performance options. Thus, when the user makes profile specifications from a template, the creation order can be simplified and then further changed by the user to meet their individual requirements.
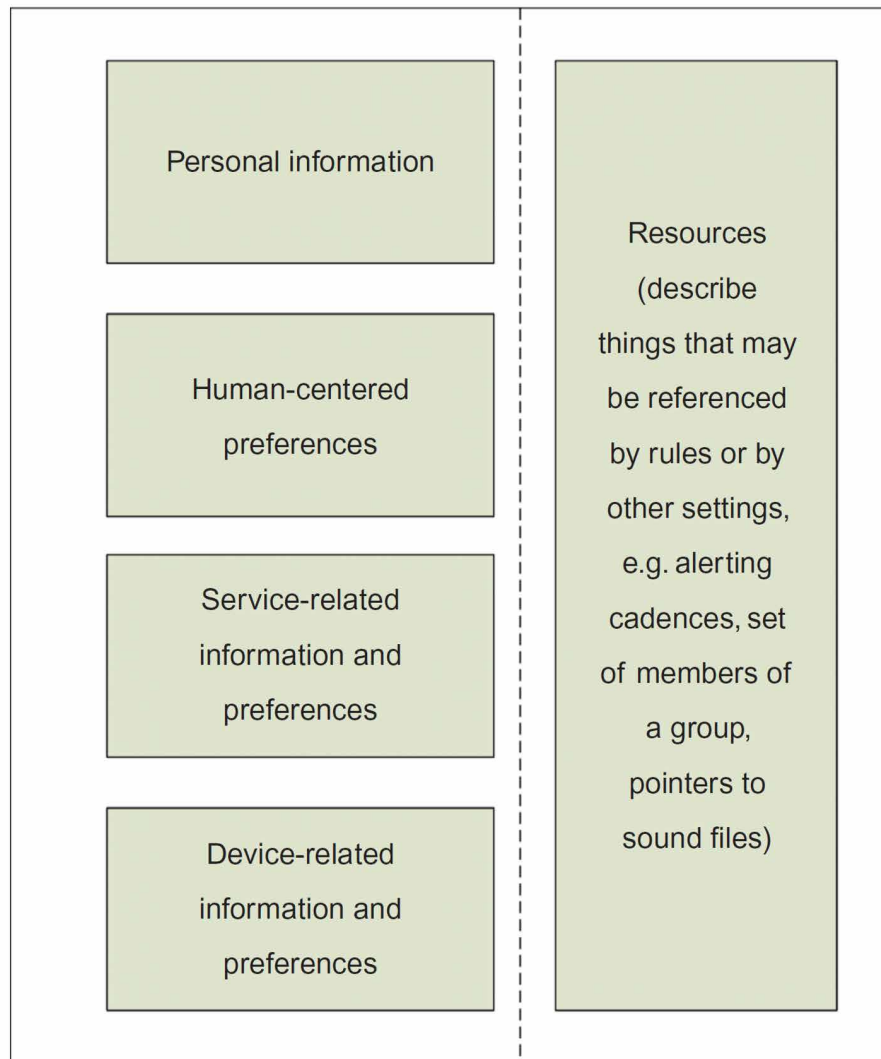
FIG. 2.44 General user profile organization (Foerster et al. 2012).

2.7 **Software**

The software and platform used in this research include:

— **Revit** is a BIM (Building Information Modeling) software that increases efficiency and accuracy across the project lifecycle, from conceptual design, visualization, and analysis to fabrication and construction.

— **AutoCAD** is a computer-aided design (CAD) software is used by architects, engineers, and construction professionals to create precise 2D and 3D drawings.

— **Enterprise Architect** is a UML design and analysis tool that supports UML, SysML, BPMN, and several other technologies. Software development includes everything from gathering requirements through analysis, design models, testing, and maintenance.

— **BIMvision** is an IFC model viewer that is available for free. It enables users to examine virtual models generated by CAD programs like Revit, Archicad, Bentley, etc. BIMvision displays BIM models generated in the IFC 2/3 and 4.0 formats.

— **PostgreSQL** is an advanced, open-source object-relational database system that utilizes and extends the SQL language, as well as several capabilities that allow it to store and handle even the most complex data workloads reliably.

— **PostGIS** is a PostgreSQL spatial database extension. It provides geographic object functionality, allowing SQL location queries.

— **pgRouting** extension adds geographic routing features to the PostGIS / PostgreSQL geospatial database.

— **CesiumJS** is a JavaScript framework that allows the creation of world-class 3D globes and maps with the best performance, accuracy, visual quality, and usability. Developers in various industries, including aerospace, smart cities, and drones, utilize CesiumJS to create interactive web apps for exchanging dynamic geographic data.

TOC

2.8 Summary

This chapter aims to present the state of the art of space subdivision approaches and the related standard to the integration process of LADM and IndoorGML. This chapter started by introducing several definitions of space. Furthermore, defining the space by form or function has been discussed and link to the definition of legal space in LADM. Then, the space subdivision approaches are introduced in section 2.2. The space subdivision approaches have been categorized into three different groups: geometric-based, geometric semantic-based, and semantic geometric based approaches. In each category, several approaches have been presented to reflect their main characteristics and to validate the main concept of the integration model of LADM and IndoorGML. A geometric-based approach is a metric or coordinate-based technique with little or no semantics (Zlatanova et al. 2013, Afyouni et al., 2012). While the geometric-semantics approach is techniques to indoor subdivision utilize the irregular subdivision of space obtained from a network by determining the connection or accessibility between indoor spaces. The third approach of indoor space subdivision focuses on semantics by constructing hierarchical or multi-layered indoor environment concepts. However, none of these approaches considers the user access rights during indoor navigation. Each indoor environment has a different relationship with users, and by defining the relationship, the accessible spaces can be defined to be used during the navigation.

In section 2.3, the IndoorGML standard has been overviewed. IndoorGML is an OGC standard for indoor navigation that provides an elaboration of the indoor space and GML syntax for encoding geoinformation (Zlatanova et al., 2016). IndoorGML generates geometry, topology, and semantics models of indoor environments for use in navigation network components. IndoorGML defines indoor space as space within one or more buildings that include architectural elements. In addition, IndoorGML represents the indoor space semantically and geometrically, as presented in section 2.3. The IndoorGML core module consists of nine classes, and it defines the main concept and components of the multi-layered space model. It is a conceptual model for the representation of the spaces and their topological relationship. The indoor navigation module is presented in section 2.3.4, and it provides support to the indoor navigation applications by providing semantics information for the indoor spaces.

In section 2.4, the LADM standard has been introduced. In LADM, the land administration is defined as the process of identifying, recording, and exchanging information on people's interactions with land or space. LADM is an object-oriented

model, and it has four basic classes: parties, basic administrative units, spatial units, and spatial sources. LADM is a conceptual framework that specifies concepts and terminology. The LADM country profile of Malaysia has been introduced, and it is based on the eCadastre (in Department of Survey and Mapping Malaysia) and eLand (in District Land Offices) systems. As a result, 3D property and cadastral rights are unavailable. However, by using the Malaysian LADM country profile to correlate essential information from both standards, the systems could be expanded and integrated. Malaysia's LADM country profile is divided into two sections: administrative and spatial. Furthermore, a prototype for the assessment of the Malaysian LADM country profile has been developed by (Zulkifli et al. 2014). The development of the proposed prototype consists of four steps: Creating the Malaysian LADM country profile, Deriving the database schema, Populating Oracle Spatial, and Developing the Bentley MicroStation front-end.

Furthermore, the related standards to the integrated model are presented in section 2.5. The Industry Foundation Classes (IFC) are a global open standard for transferring and sharing Building Information Model (BIM) data amongst software programs. The standard establishes data requirements for the entire life cycle of a building. The second standard is Facilities Management (FM), which provides a method for ensuring that an organization's buildings, systems, and services support core management and operations while also contributing to accomplishing strategic goals in a changing environment. Finally, this chapter ends with the user profile. The user profile is used to enhance and adapt interactive computer systems to their current users and investigate the function of user models in the adaptation process.

3 Extending the Conceptual Model of IndoorGML

In chapter 2, the space definition and the space subdivision approach have been discussed. Additionally, an introduction of the integrated standard (LADM and IndoorGML) has been presented to demonstrate the similarities and differences of the standards. This chapter proposes an enhancement of the IndoorGML conceptual model (UML class diagram). The current version of IndoorGML standard (version 1.0) has an incomplete class diagram (incomplete w.r.t. attributes, of which some are appearing in the XML/GML schema), and therefore is incomplete. Furthermore, there are some issues related to the association names, class names, classes that related to the Primal space and the Dual space, code lists, untyped relationships to external object classes, and semantically overlapping classes. Therefore, the aim of this chapter is to provide a more complete conceptual model (in the form of UML class diagram) for IndoorGML.

This chapter is organized as follows, section 3.1 presents the motivation of extending the conceptual model of IndoorGML. In section 3.2, the proposed UML model for IndoorGML is introduced. Section 3.3 summarizes the whole chapter.

3.1 Introduction

Over recent years, the research area of navigation has become very active with an extensive variety of applications. Navigation is essential but also complex human activity. While initially navigation systems have been established for outdoor environments (such as for cars on the road), presently they have subsequently developed to be an essential field of interest for indoors (Makri et al. 2015). According to (Klepeis et al. 2001) around 87% of the people in the USA spend most of their lives inside buildings and the movement of the user of the indoor environment has been affected by the massive size of the indoor environment. The public buildings in our cities such as airports, train stations, hospitals, offices and university buildings, confront users with difficulties to find their destinations, and thus various research has been carried out that has resulted in many navigation models as shown in Figure 3.1. In this chapter, we concentrate on IndoorGML 1.0 (Lee et al. 2015), adopted as a standard by Open Geospatial Consortium (OGC).
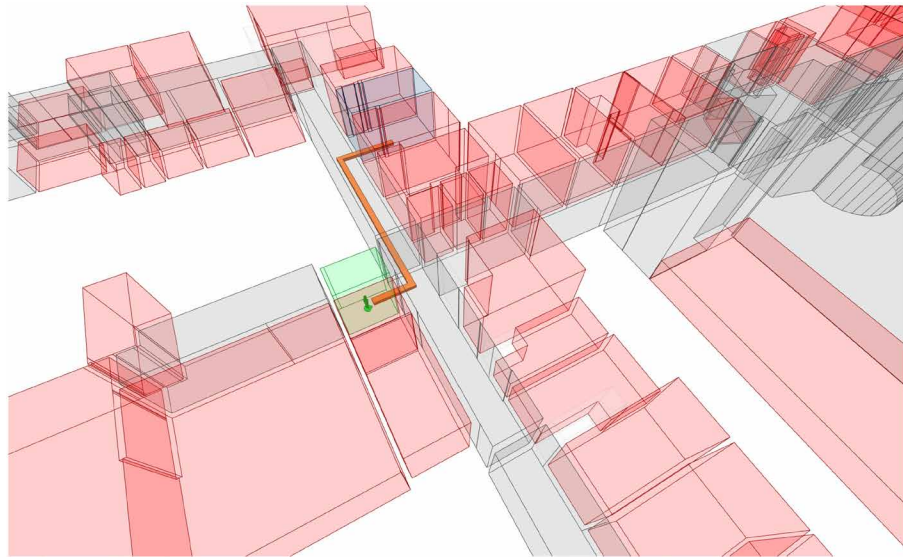
FIG. 3.1 Indoor navigation path.

IndoorGML delivers a framework for indoor navigation systems to offer a description of the indoor space and provide Geography Markup Language (GML) syntax for encoding geoinformation (Zlatanova et al., 2016, Kang and Li 2017). IndoorGML consists of two parts, first the core data model which describes geometry and topology connectivity, and second, a data navigation model that provides semantics for the navigation process (Lee et al., 2015). The main purpose is to establish a methodology to classify spaces (rooms, corridors, etc.) and their indoor characteristics rather than representing architectural elements (Li, 2016). However, the version 1.0 of IndoorGML has an incomplete UML model and that affects the quality of applications that depend on it. In this chapter we propose an enhancement for a new version of the standard. We have also discussed alternatives in several cases and provided arguments pro and con to each option and based on this selected best option. We classify some critical aspects that we have considered in this process:

— Complete attributes and code list for all classes.
— Better representation for the Primal space and Dual space.
— Clear terminology (vocabulary).
— Introducing geometry as attribute of classes (making the model clearer).

The methodology of this research is based on the following research phases: 1. Analyzing current version of IndoorGML and finding missing and weak parts, 2. Proposing options for solutions, 3. Discussion the pros and cons of the various options, 4. Selection the best option and make this part of improved IndoorGML proposal.

As mentioned in chapter 2, the current IndoorGML UML model contains the classes and their relationships as shown Figure 3.2. It has four different types of classes (GML, IndoorCore, IndoorNavi, and Not implemented). Most of the classes do not have attributes: no attribute names, no attribute data types. Further, the associations that link the classes have names that bring some confusion to the user. The GeneralSpace and the TransferSpace classes have attributes that contain the same code list values. But, if code lists have equal values, it is unclear what has to distinct the code lists. The SpaceLayer class has a relationship with the CellSpace, State, and Transition classes and that creates misunderstanding for the user of the standard (as it is not directly clear from the model that CellSpace/ State represents primal space and that Transition represents dual space).

FIG. 3.2 The current UML model of IndoorGML

Furthermore, including the AbstractFeature class to the UML class diagram is not the best way for illustration, because it has many relationships with other classes, as shown in Figure 3.2. Furthermore, the type of the link is a generalization with lines in the illustration to nearly all other classes: spaghetti drawing. The standard represents the geometry data as separate classes and that allows mixing of the geometries to different objects (which could have been sharper typed). In addition, having geometry as separated classes in the model increases the implementation complexity. This chapter studies and evaluates several issues that relate to the UML class diagram and proposes several enhancements of the standard.

3.2 Proposed UML model for IndoorGML

3.2.1 From classes to attributes

Solid, Surface, Point, and Curve are geometry classes (as defined in ISO 19107) in the current version of IndoorGML with associations to classes that have geometric representations. Although this approach might be beneficial for keeping topological consistency, it is rather complex for implementation. Therefore, we propose to convert the classes into attributes. The CellSpace class has two additional attributes to represent the geometry data types as shown in Figure 3.3.
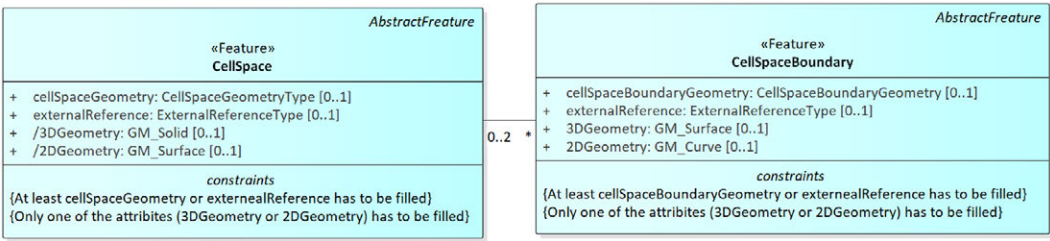
FIG. 3.3 Additional geometry attributes for CellSpace class and CellSpaceBoundary and their constraints

The 3DGeometry attributes are proposed to have the GM_Solid value, and the 2DGeometry attributes are proposed to have the GM_Surface value. The CellSpace class is proposed to have a constraint that only one of the attributes (3DGeometry or 2DGeometry) has to be filled. The CellSpaceBoundary is proposed to have two additional attributes, first 3DGeometry attribute that has the value GM_Surface, and second 2D Geometry attribute that has the value GM_Curve. The CellSpaceBoundary class is proposed to have a constraint that only one of the attributes (3DGeometry or 2DGeometry) has to be filled based on the application. Because the geometry of the CellSpace can (conceptually) be derived from the geometry of the associated boundaries, this is indicated with a forward slash before attribute name, e.g. /2DGeometry.

The Point Geometry type is proposed to be added as an attribute to the NodeInDualSpace class and the RouteNode class as an attribute that call Location and has the value GM_Point as shown in Figure 3.4. The curve geometry type is proposed to be added to EdgeInDualSpace class and RouteSegment class (for route parts) as an attribute that call Geometry and has the value GM_Curve as shown in Figure 3.5.
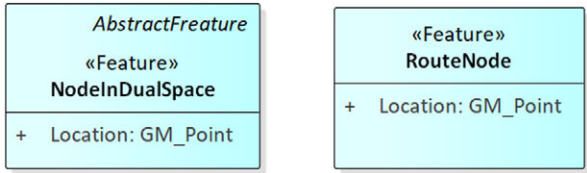
FIG. 3.4 New attributes for NodeInDualSpace class and RouteNode class.
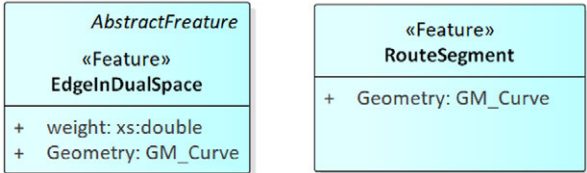
FIG. 3.5 New attribute for EdgeInDualSpace class and RouteSegment class.

TOC

Developing the concept of ExternalObject class

The current UML model contains ExternalObject class that has an association with Cell- Space class and CellSpaceBoundary as shown in Figure 3.2. We propose that the current ExternalObject class has two external object classes because the information about the CellSpace and the CellSpaceBoundary could be obtained from different sources. The new two classes are proposed to have associations with the current ExternalObject class (as superclass), the new subclasses are also more precise typed. This method will bring more flexibility to the representation space and boundary as shown in Figure 3.6.

The CellSpace class is proposed to have an association with a new class that call "ExternalCellSpaceObjec", and it is responsible for providing the object reference of the Space from the ExternalObject class. Also, the CellSpaceBoundary class is proposed to have an association with a new class that is called "ExternalCellSpaceBoundaryObject", and it is responsible for providing the object reference of the boundary from the ExternalObject class. Also, the type of the class of the ExternalObject is proposed to be changed from Feature type to the Stereotype «BluePrint» because this class represents a reference that is not included in the model.
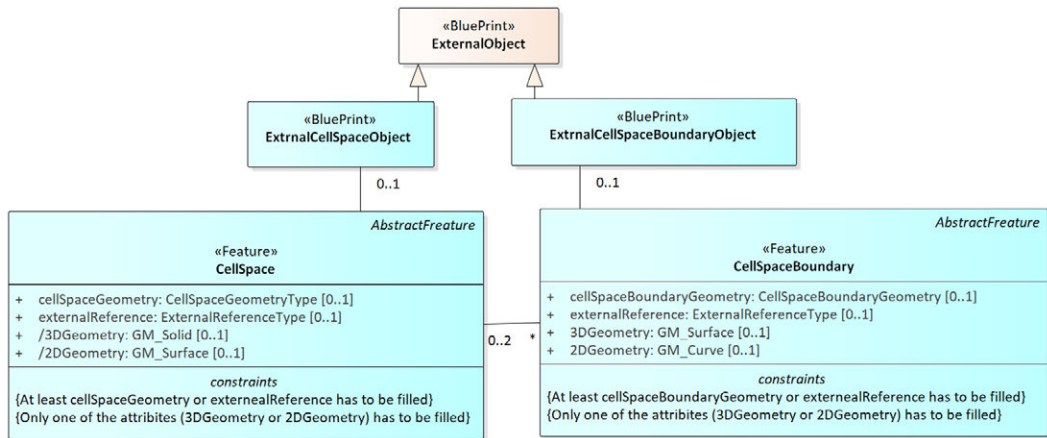
FIG. 3.6 The proposed ExternalObject classes.

3.2.3 Association multiplicity of CellSpace and CellSpaceBoundary

The association multiplicity between CellSpace and CellSpaceBoundary in the current version of the standard shows that each CellSpace has many Boundaries, and each CellSpaceBoundary has zero or one CellSpace as shown in Figure 3.2. However, in reality each CellSpaceBoundary could have one or two (or zero if boundary not used) CellSpace as shown in Figure 3.6. Furthermore, in case of so called functional areas or virtual spaces, the neighbor cells do share a one boundary. The multiplicity is proposed to be modified as shown in Figure 3.7.
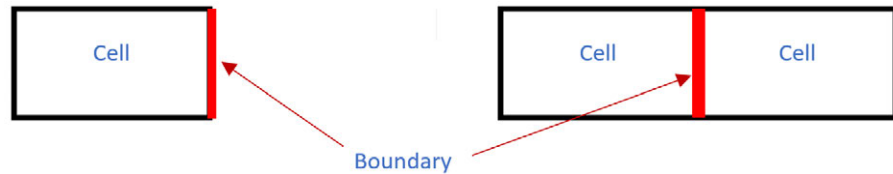
FIG. 3.7 CellSpaceBoundary could have one or two CellSpace

3.2.4 The terms State and Transition

We propose to change the names of the classes State and Transition into the more intuitive terms Node and Edge, because it is easier for general users. Moreover, the terms State and Transition are more related to navigation and could be confusing for CellSpaces based on sensor coverages. In addition, we suggest adding 'Dual' to each class to make clear they belong to the Dual space. The term State has been changed to NodeInDualSpace and the term Transition has been changed to EdgeInDualSpace as shown in Figure 3.8.
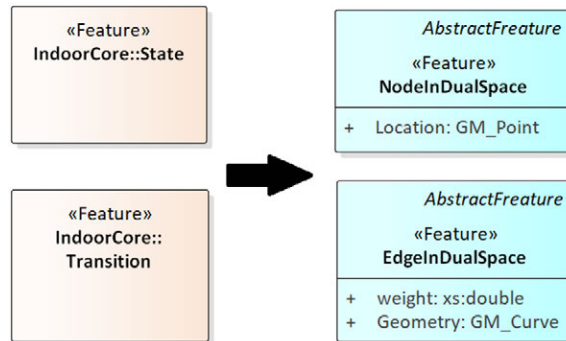
FIG. 3.8 Proposed terms for State and Transition classes.

TOC

3.2.5 Code Lists

The current version of the standard has the same code list values for GeneralSpace class and TransferSpace class (gml:CodeType). We have changed that by adding different names for the code list as shown in Figure 3.9 (in total 7 different code lists) to introduce clarity The GeneralSpace class has three attributes (function, usage, and class) and each attribute has a code list value, with example code list values as shown in Figure 3.10. The Usage attributes have a code list values that represent the user groups of the space such as student group, employee group, and visitor group.

The ConnectionSpace class is a subclass of the TransferSpace, and it has three attributes (function, usage, and class), and each attribute has a code list value, as shown in Figure 3.11. The AnchorSpace class is a subclass of the TransferSpace, and it has three attributes (function, usage, and class), and each attribute has a code list value, as shown in Figure 3.12. The SpaceLayer class has five attributes (usage, terminationDate, function, creationDate, and class). The usage attribute represents the type of building, for example, hospital, shopping mall, etc. The terminationDate attribute provides the date of the termination of the space layer. The function attribute provides specific information about the user (types of users), for example, children, adults, etc. The creationDate attribute provides the date of the creation of the space layer. Finally, the class attribute has a code list type value which is the SpaceLayerClassType, as shown in Figure 3.13. Note that the values of an enumeration type are fixed (and cannot be extended as for code lists).
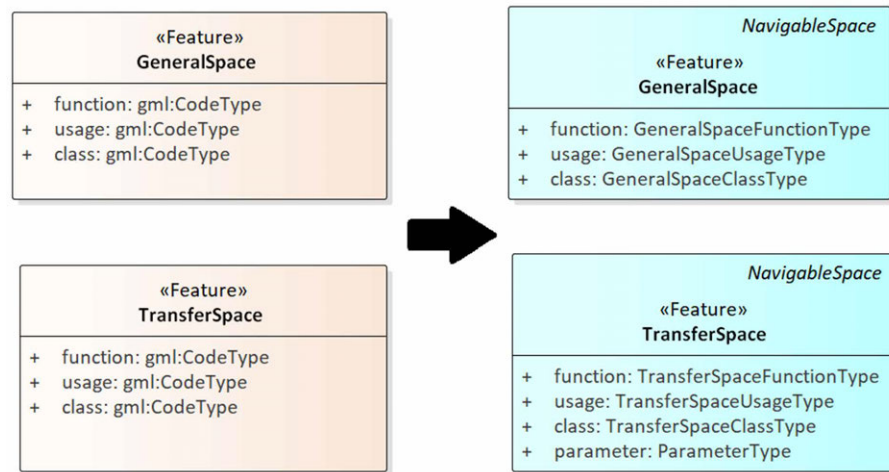
FIG. 3.9 New code list names for GeneralSpace and TransferSpace classes.

TOC

FIG. 3.10 Code list for the attributes of the GeneralSpace class (with example values).

FIG. 3.11 Code list for the attributes of the ConnectionSpace class.

FIG. 3.12 Code list for the attributes of the AnchorSpace class.

FIG. 3.13 Code list values for the attributes of the SpaceLayer class.

The InterLayerConnection class has two attributes (typeOfTopoExpression and comment). The typeOfTopoExpression attribute contains the types of relationships, which are given by an enumeration. The comment attribute is reserved for providing additional information about the relationship. The typeOfTopoExpression attributes has an enumeration value which is the typeOfTopoEx- pressionCodeType and it consists of two enumeration values (typeOfTopoExpressionCodeE- numerationType and typeOfTopoExpressionCodeOtherType), however, we propose to replace these 3 «enumeration» types with a single «codeList» that has the name TopoExpressionType as shown in Figure 3.14.
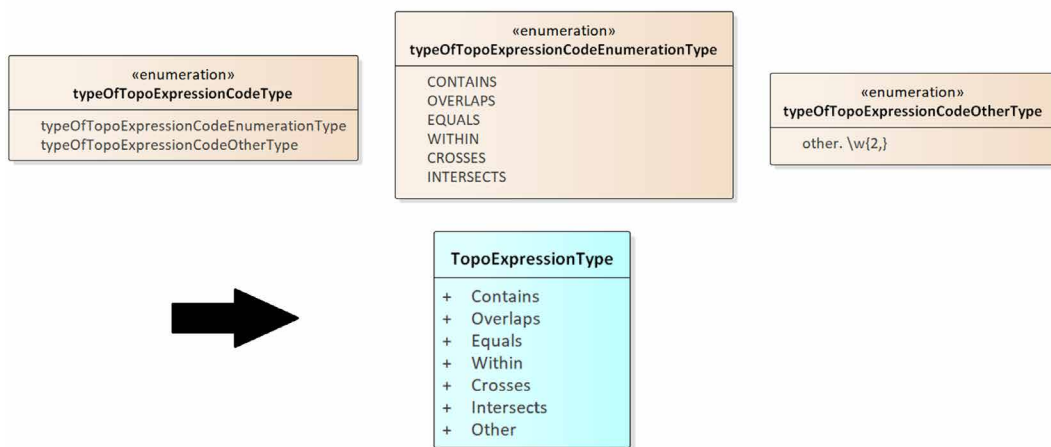
FIG. 3.14 Enumeration values for the attributes of the InterLayerConnection class.

3.2.6 Classes and associations

The current UML model contains an association between the SpaceLayer class and the NodeInDualSpace (State) class and EdgeInDualSpace (Transition) class have been defined as Composition association as shown in Figure 3.2. However, instead of connecting these two classes to the SpaceLayer, we have proposed a new feature class called DualSpaceNetworkLayer that will be as a collecting class for the Node and the Edge of the Dual space. We want to emphasize that the layers can be used for both: the Primal and Dual Spaces.

The SpaceLayer class is proposed to have an association with the CellSpace class and the SpaceLayer will be collecting class for the spaces of the primal space. The name of MultiLayerGraph class has changed to MultiLayerNetwork because a graph does not need to have geometry and in the case of IndoorGML there is a need for geometries at least for the Nodes. The MultiLayerNetwork is proposed to have an association with the NodeInDualSpace and EdgeInDualSpace instead of the association with the SpaceLayer because it deals with the Dual space as shown in Figure 3.15.
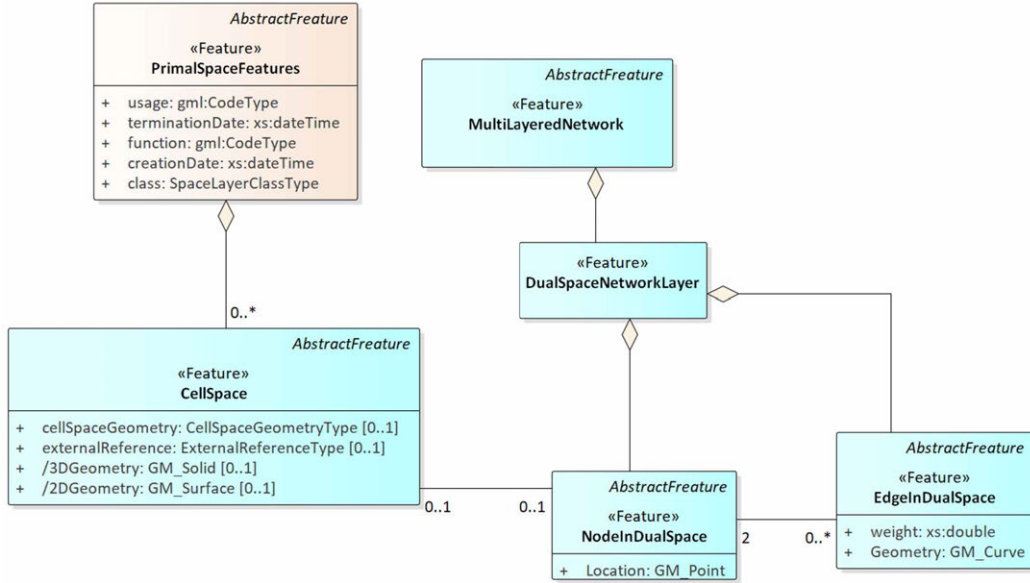
FIG. 3.15 New DualSpaceNetworkLayer class and their associations with the NodeInDualSpace class and EdgeInDualSpace class.

Also, the current UML model of the IndoorGML standard has defined names for the associations between the classes such as duality, edges, nodes, geometry, and partialBoundaryBy which are dedicated for the XML implementation. For the SQL implementation the naming of the relationship is not needed.

The proposed UML model does not include all the defined names of the associations to avoid confusing as shown in Figure 3.2. Additionally, the TransferSpace class and CellSpaceBoundary has parameter attributes that have a type (virtual, real) to allowing aggregation and subdivision of CellSpaces. Furthermore, the TransitionSpace class has been removed from the UML class diagram because it is difficult to semantically distinguish this class from the ConnectionSpace class.

The transition space could be a large hall that could be considered as corridor or a room, and it is difficult to decide how to classify them.
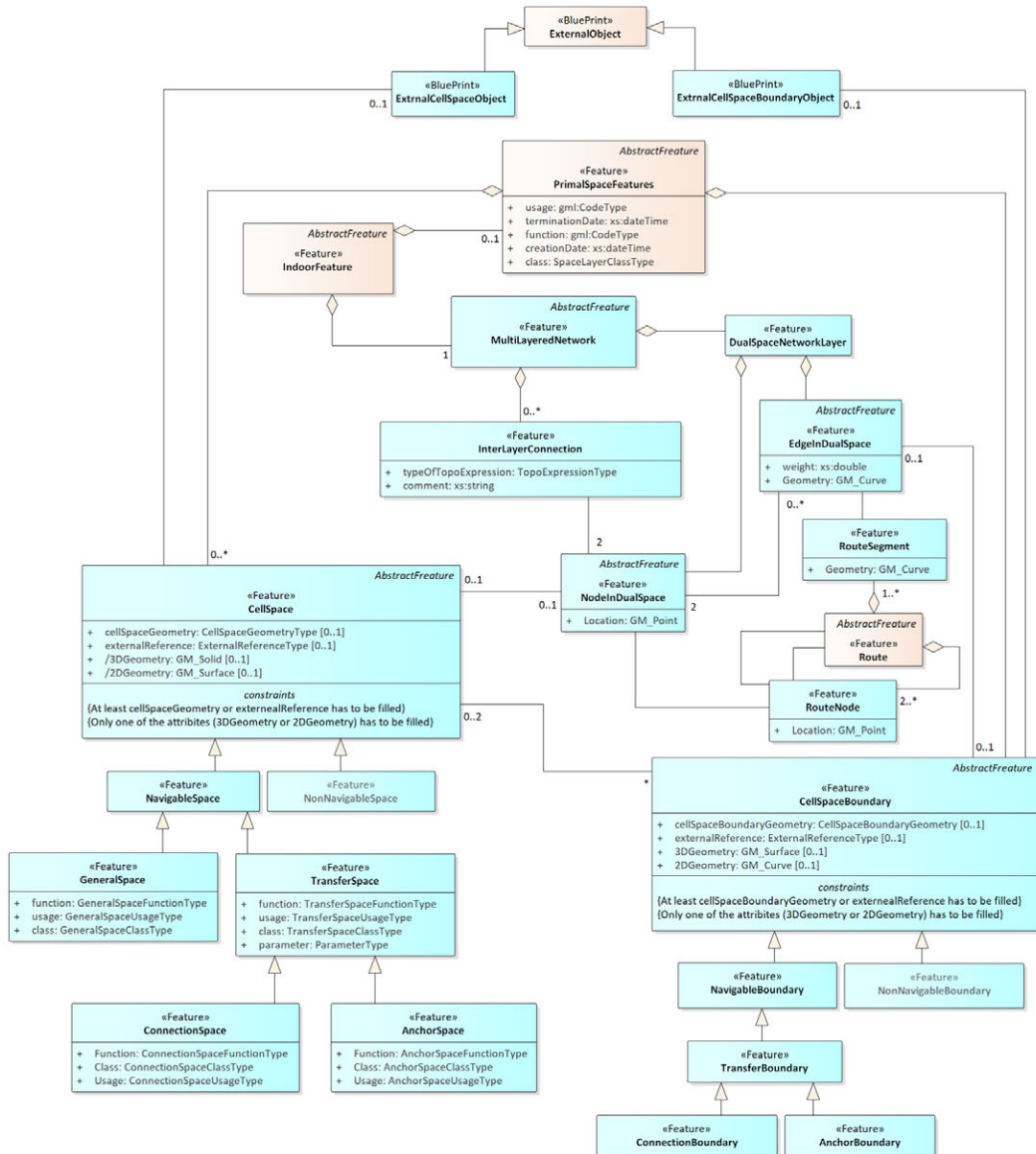
FIG. 3.16 Proposed conceptual model of IndoorGML.

3.3 Summary

This chapter proposed an enhancement for the UML class diagram of IndoorGML standard. It suggested the following amendments of the conceptual model:

— The ExternalObject class has two subclasses (ExternalCellSpaceObject and ExternalCellSpaceBoundaryObject). The CellSpace has an association with the ExternalCellSpaceObject and the CellSpaceBoundary have an association with ExternalCellSpaceBoundaryObject to improve the concept behind the ExternalObject class.

— Association multiplicity of CellSpace and CellSpaceBoundary is corrected.

— The terms State and Transition are changed into NodeInDualSpace and EdgeInDualSpace because they better represent the nature of these classes and improve the perception.

— The geometry classes are converted into attributes of the classes that need them to ensure better understanding during the implementation from the user.

— GeneralSpace class and TransferSpace class have different names for the code lists, and we have created code list classes to define the values for each attribute.

— DualSpaceNetworkLayer is introduced as a collecting class for the node and the edge of the dual space. The SpaceLayer has an association with the CellSpace class only and is a collecting class for the spaces in the primal space.

— TransferSpace class and CellSpaceBoundary have additional attributes that have the value (virtual, real) to allow aggregation and subdivision of CellSpaces.

Additional investigation is required to define attributes for all classes. This chapter reflects the initial developments of a more complete and more enhanced conceptual model for IndoorGML. This chapter has covered the sub-question "Q1. What is the UML class diagram in IndoorGML, and how it should be improved?". Furthermore, the changes that have been proposed in this chapter will be taken into account in the new version 2.0 of the conceptual model of the IndoorGML standard in order to provide a better comprehension of the UML diagram.

TOC

4 2D Country Profile based on LADM

In the previous chapter, the proposed amendments for the IndoorGML standard have been presented. In this section, the development of the 2D LADM country profile is introduced. The goal of the development of the country profile is to define the rights, restrictions, and responsibilities for the indoor spaces based on the ownership regulations of Saudi Arabia. The chapter aims to build a better communication system between all the stakeholders to secure the registration of property ownership.

This chapter is structured as follows; the land administration in Saudi Arabia is presented in Section 4.1. Section 4.2 presents the current land administration system in Saudi Arabia. The development of the initial 2D country profile is illustrated in section 4.3. Section 4.4 presents a way to improve the initial country profile. The development of the improved 2D country profile is presented in Section 4.5. Section 4.6 summarizes the whole chapter.

4.1 Land administration in Saudi Arabia

Land is the most valuable natural resource for every country, and it forms the core of its cultural, social, and economic development. The rapid growth of cities and their infrastructure requires an efficient integration between planning and management of land resources. Therefore, the LADM country profile is important to understand the current land registration of the country (that usually involves several stakeholders) and establish a uniform standard terminology, which will allow for better interoperability between the stakeholders. The property registration system in the Kingdom of Saudi Arabia has many stakeholders in obtaining and maintaining land records, which leads to a complex system, which is challenging to maintain.

The Ministry of Justice is currently responsible for the registration of legal ownership of parcels and buildings. However, the registrations of the spatial information and their regulations for lands and buildings are under the responsibilities of the municipalities. The Ministry of Municipal and Rural Affairs is responsible for the administration of the municipalities throughout the Kingdom, which was established in 1975. The primary duties of the Ministry of Municipal and Rural Affairs are the city and town planning and the development and maintenance of the infrastructure. The Real Estate General Authority has recently been established to manage, supervise, and improve the non-governmental real estate activity to raise its efficiency and encourage investment in it. Additionally, it is responsible for developing the transformation from deed registration to title registration.

Each of the stakeholders mentioned above has its own system and regulations, and there is no shared database between the stakeholders. The lack of a unified and comprehensive land registration system has resulted in many struggles over access rights and ownership rights. Therefore, it is critical to develop and achieve a sustainable and productive land registration system that would provide a basis for conflict resolution and participatory decision-making process.

The Kingdom of Saudi Arabia is around 2,000,000 km^2, and its population exceeded 29.8 million in 2014. 90% of its population lives in urban areas. Urbanization will continue and is expected to reach up to 97.6 % by 2030 (Alrajhi et al., 2010). In order to achieve efficient access, sharing land and cadastral data between all the stakeholders that are involved in the process of recording the legal rights for the land in the Kingdom of Saudi Arabia, it is required to create a model that covers the current domain according to the standards and recommendations in the field of spatial data. Thus, an effective land administration system is necessitated

to represent the high dynamics in people to land relationships of Saudi Arabia cities. Furthermore, a stable land registration system is essential to guarantee the protection of property rights.

As discussed in previous chapter, since the release of LADM, countries such as Turkey, Malaysia, South Korea, The Netherlands, Croatia, and the Czech Republic have developed country-profiles. This chapter presents the first ideas for a country profile of Saudi Arabia based on the LADM. The proposed profile attempts to cover both legal and spatial components of the current registration system. Two types of spatial units are discussed, namely private and public land. The development of the LADM profile for the Kingdom of Saudi Arabia followed three steps:

— Conducting interviews with the stakeholders to collect information about the regulations of the land/building ownership.

— Analyzing the current land registration system and its requirement for both spatial and non-spatial data.

— Developing the initial LADM country profile based on the local regulations.

The proposed model aims to build a better communication system between all the stockholders to secure the land registration.

4.2 The current land administration system in Saudi Arabia

The land administration system is under the responsibilities of four different stakeholders (Ministry of Municipal and Rural Affairs, Ministry of Justice, Real Estate General Authority, and Ministry of Housing). They are responsible for all types of information related to ownership registration, such as technical data and legal data. The land administration system in Saudi Arabia covers two main parcels: public parcels and private parcels. The current system does not register the public parcels, and they are considered under the ownership of the government. On the other hand, private parcels could have different owners, such as government ownership, ownership related to the business industry, or induvial ownership (a group of private parties). Therefore, the four stakeholders have different tasks during the ownership registration.

	Residential Apartments Buildings		Residential villas
	Residential villa or two-storey apartments		Residential certified
	Commercial Street second class		Commercial Street first class
	Local Commercial Street		Main Commercial Street
	Government area		Integral projects and villages
	Marine areas		Educational services
	Religious Services		Health Services
	Regional Services		Government services
	streets and squares Sidewalk		Parks and Sports Clubs
	Rain and drainage channels		Existing business centers
	Warehouses, light industries and workshops		Sea and lakes
	Petroleum Industries		Intermediate Industries

FIG. 4.1 Land use map of Jeddah, Saudi Arabia

The Ministry of Municipal and Rural Affairs is responsible for planning the cities and define the land use for each district and parcel, as shown in Figure 4.1. Also, it is responsible for providing the construction code and regulations for all types of buildings and infrastructure. Furthermore, the Ministry of Municipal and Rural Affairs creates and maintains all public areas such as Gardens, squares, and parks by defining the regulation for each type (https://www.momra.gov.sa). Additionally, licensing all business activities is under their responsibilities by defining the rights, restrictions, and responsibilities based on the type of activity. Furthermore, the Ministry of Municipal and Rural Affairs is the source of all types of technical data related to the planning of the cities, such as survey data, land use, and building requirements and regulations.

The Ministry of Housing is responsible for the housing market in Saudi Arabia by defining the regulation to provide a well structure market. It has many initiatives to support its goals, such as unit subdivision, owner's association, rent program, white land regulations, and Building Technology Initiative (https://www.housing.gov.sa/ar/initiatives). The ministry has defined the unit subdivision regulation to improve the registration of the ownership of each property (https://www.housing.gov.sa). The ministry has issued the System of procedures that include all the requirements to registrar each unit and that by applying through an architecture firm to ensure meeting all the requirements.

The third stakeholder responsible for the land registration system is the Real Estate General Authority, and it is under the Ministry of Housing authority. It is responsible for issuing and maintaining all the regulations related to the real estate market. Additionally, it is responsible for issuing the title registration documents for all property types (https://rega.gov.sa).

The Ministry of Justice is considered the last stakeholder involved in the property registration, and their responsibility is to provide the deed registration to the owner after receiving all the required information from the other stakeholders (https://www.moj.gov.sa). Figure 4.2 shows an example of the deed registration. Issuing the deed registration document has a different process based on the type of property. For example, transferring the ownership of a parcel or a unit with a deed registration document will start by applying the transfer request from the owner and the buyer to the Ministry of Justice. Then the Ministry of Justice will check the status of the deed registration document and that the Ministry of Justice has the right of contacting the Ministry of Municipal and Rural Affairs for additional information or issuing the new deed documents directly at the same time as shown in Figure 4.3.

FIG. 4.2 Deed registration

FIG. 4.3 Process of transfer the ownership (deed registration)

The second type of property registration is related to units subdivision. This type of property registration starts by applying a request to the Ministry of Housing through an architecture firm. The architecture firm checks all the technical data based on the available data from the Ministry of Municipal and Rural Affairs. Then the request is sent to the Ministry of Housing to apply and check all the required information for this type of request. If all the requests have passed all the requirements, the Ministry of Justice is informed to issue new deed registration documents for each unit of the building, as shown in Figure 4.4.
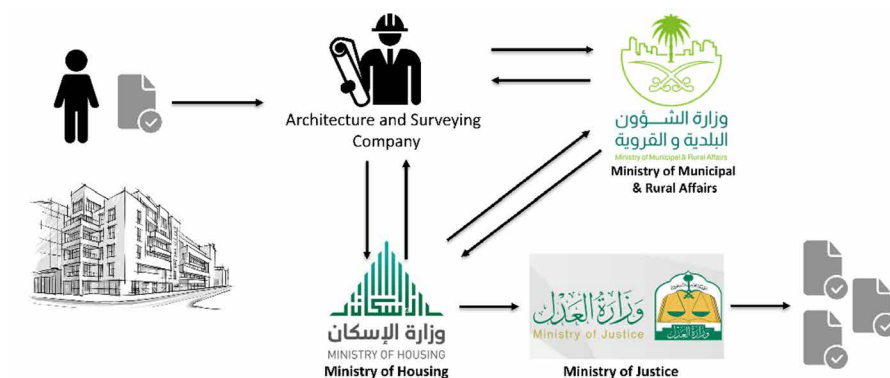
Process of unit subdivision (deed registration)

The third type of property registration is related to the land subdivision into several parcels, and it has two different cases, first, if the land has deed registration documents (for example own by an individual or company), and second if the land does not have a deed registration document (public land own by the government). In the case there is a deed registration document, the owner should start the request by hiring a certified architecture and surveying firm to subdivide the land into several parcels (create the master plan) based on the regulations of the Ministry of Municipal and Rural Affairs. Then, by having the master plan, the Architecture and surveying firm has to apply to the Ministry of Municipal and Rural Affairs for their approval. Next, the Ministry of Justice receives the required data from the Ministry of Municipal and Rural Affairs to issuing the deeds registration documents for each parcel, as shown in Figure 4.5.

In the second case, when the land is owned by the government, the Ministry of Municipal and Rural Affairs hires a certified architecture and surveying firm to subdivide the land into several parcels (create the master plan) based on the regulations of the Ministry of Municipal and Rural Affairs. Then, the Ministry approves the master plan for the land to issue the deeds registration documents for each parcel through the Ministry of Justice, as shown in Figure 4.5.
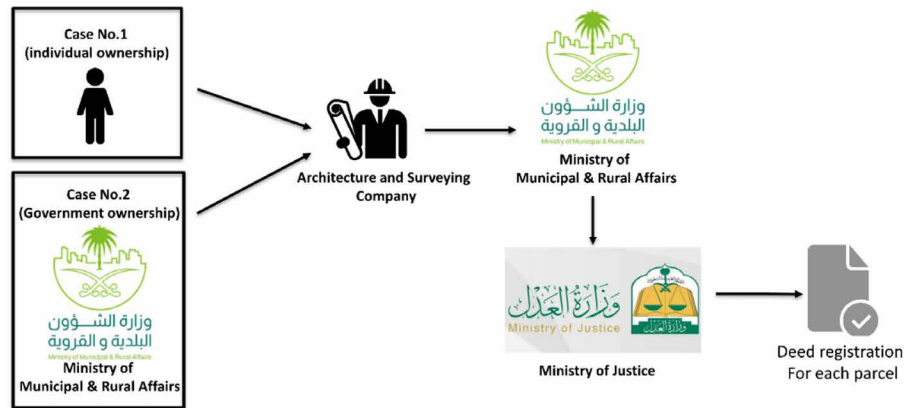
FIG. 4.5 Process of land subdivision into several parcels (deed registration)

The last type of Property registration is the title registration, and it is under the responsibility of the Real Estate General Authority. The process of issuing the title starts by applying a registration request to the Real Estate General Authority to convert the deed registration documents into a title registration. Next, the Real Estate General Authority will communicate with all the stakeholders to collect and check the deed documents information and then issuing the title document as shown in Figure 4.6.
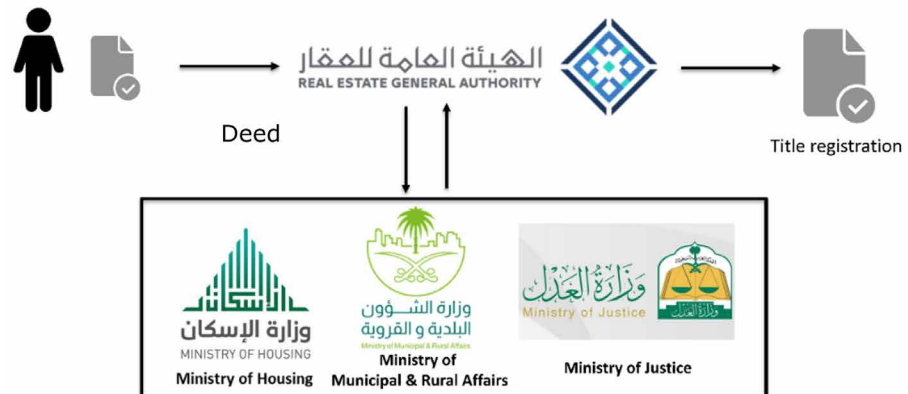
FIG. 4.6 Process of issuing title documents

The Property ownership system and subdivision have been defined in Act (M/5 2002), and it is under the responsibility of the Ministry of Municipal and Rural Affairs and Ministry of Housing, and it defines the following terms:

— **Land:** The land allocated for constructing a building and the construction of its facilities and services, according to the engineering plan that the building permit has approved.

— **Real estate unit:** It is the house, the floor, the apartment, the garage, the shop, or any part of the building that can be sorted, and the property rights are placed and disposed of separately from other parts of the building.

— **Owner**: The owner of an independent real estate unit, and the owner could be one or a group of owners.

— **Maintenance and restoration:** it is the necessary work to maintain the benefit, whether for an independent unit or for what is included in the common property, such as elevator, ladder, and garden.

— **Common Parts:** it is the footprint of the building, gardens, rebounds, the structure of the building, the roof, the entrances, the stairs, and all other parts of the building that are intended for common use.

Additionally, based on the Act (M/5 2002), each owner has the rights to build on his or her land within the limits of regulations and instructions one or more floors or buildings and subdivide them into independent real estate units according to the approved design in the original plans and license. Some or all these units are considered separate from each other. All the independent real estate units have to be numbered sequentially without repeating the same number. Also, the shape and boundaries of the land, its lengths, construction, and dimensions shall be according to the approved design plan. In addition, the contents of the ownership registration shall remain in similarity with the descriptions of the land, its boundaries and shape, and the descriptions of the real estate unit, its boundaries, and its geometric form.

The Act (M/5 2002) provides more regulations about if there several owners for one entity or in one building. Owners of real estate units in a single building shall be partners in the common areas of the building unless otherwise agreed. The construction elements (such as walls) located between two adjacent units in one building are owned by the owners of the two units. Neither of the owners can use his/her share in a way that harms the other. Any common areas that benefit only some of the building owners are considered common ownership between them. The common

area that cannot be divided between the owners is common ownership from the total area of the building and the land for the owners. Each owner will own share of the common areas in proportion to the part-owned separately by him/her.

Each owner of one or more real estate units should participate in the costs of maintaining, managing and renovating the common parts in proportion to the value of the part that is owned separately. Any owner may improve the use of the common area or part of it after getting the owners' association's approval at his own expense without changing the function or cause any harm to others. The owner has the right to change the use of his/her property after obtaining the approval from the owners' association and issuing the necessary license to approve the amendment from the responsible municipality.

For transferring ownership, the owner should submit an application for subdividing the real estate unit to the municipality, accompanied by a copy of the deed and a copy of the approved plans for the building and the building permit. The buildings that do not have a building permit should submit a sketch drawing specifying the location and surveying of the real estate unit to be sorted. Then, after completing all the requirements for the subdivision, the municipality should verify the submitted documents and make sure that all data related to the total real estate unit and its neighbors are correct. Finally, the municipality refers the application of the subdivision to the Ministry of Justice to complete the necessary steps towards issuing the property document.

The Ministry of Municipal and Rural Affairs has spatial records for all types of lands. However, the Ministry of Justice does not register the ownership rights for roads, rivers, green areas, mountains, and deserts. Additionally, the Ministry of Justice registers the time management for ownership registrations.

4.3 Initial 2D country profile of Saudi Arabia

LADM has proven already it helps to improve, develop, implement, and maintain the ownership registration more efficiently and therefore it has been used to develop the first ideas for a Saudi Arabia country profile. LADM makes the data model more transparent by including the source documents, the owner's information and includes their rights, restrictions, and responsibilities (Zulkifli et al., 2014 & Amalina et al., 2013).

As mentioned previously, the main goal of the standard is to identify, register and validate several types of information such as parcels, documents, persons, control points etc. This section presents the initial steps towards a Saudi Arabia Country profile. The 'SA_' is the prefix for the Saudi Arabia country profile. Both, the spatial and non-spatial data are covered in the initial country profile. The non-spatial part is adopted directly from the LADM standard. The spatial part includes additional classes in order to reflect the regulations in Saudi Arabia. The land registration system in Saudi Arabia is based on 2D data, therefore, the proposed model only covers the 2D geometric descriptions. Figure 4.7 and Figure 4.8 show spatial and non-spatial classes of the Saudi Arabia Country Profile.

The development of the Saudi country profile started with conducting interviews with responsible organizations. The General Commission for survey was the subject of the first interview because it is representing the country in the LADM community. The experts described the relationship between all the sectors, and they open a communication channel for us with the Ministry of Municipal and Rural Affairs and the Real Estate General Authority. By understanding the relationships, the work started by analyzing the Property ownership system and subdivision to understand how the land registration system works in Saudi Arabia.

The connection between all tasks of the four organizations was the foundation to create the initial LADM country profile of Saudi Arabia. All the classes of the country profile are inherited from the main classes of LADM. The SA_Party, the SA_BAUnit, and the SA_Mortgage classes are under the responsibility of the Ministry of Justice. The Ministry of Justice registers the information represented by these classes. The rest of the classes are under the responsibilities of the Ministry of Municipal and Rural Affairs, Ministry of Housing, and Real Estate General Authority, because they are responsible for the spatial information. Also, they are related to the RRR classes. The spatial and non-spatial data modeling have several classes with new code lists for the Saudi Arabia country profile as shown in Figure 4.9.

FIG. 4.7 The non-spatial classes of the initial country profile of Saudi Arabia

FIG. 4.8 The spatial classes of the initial country profile of Saudi Arabia

TOC

«CodeList»
SA_landUseType

+ Residential Apartments Buildings
+ Residential villa or two-storey apartment
+ Commercial Street second class
+ Local Commercial Street
+ Government area
+ Marine areas
+ others

«CodeList»
SA_ParcelUnitType

+ Office
+ Apartment
+ Shop
+ Clinic
+ Others

«CodeList»
SA_BuildingType

+ Residential
+ Commercial
+ Industrial
+ Others

«CodeList»
SA_AmenitiesUnitType

+ Storage
+ Parking
+ Others

SA_ShareAreaUnitType

+ Stairs
+ Lifts
+ Corridors
+ Entrance
+ Swimming pool
+ Others

FIG. 4.9 The code lists of the initial country profile of Saudi Arabia

4.4 Way to improve the initial LADM country profile

As discussed in the previous chapter, several countries have developed their LADM country profile by following different approaches without a specific roadmap or methodology. This has increased the need to create a more formal outline to guide countries when developing a country profile (Kalogianni et al., 2019). The Annex D of ISO 19152 LADM Edition II includes such a methodology (Lemmen et al., 2019). According to it a list of principles has been identified in support to the development of the initial country profile of Saudi Arabia, such as:

— Analyzing the law and regulations of the land administration system.
— Describing the current situation of the land administration system according to the current registration system.
— Mapping the main elements between the local land administration system and LADM.

The Initial country profile has been developed based on the relationship between all the stakeholders to represent the land administration system in Saudi Arabia. Therefore, all the information in Section 4.3 has been taken into consideration during the process of development of the initial country profile. As a result of the development process, the initial profile represents the basic information of the current land administration system.

The Spatial classes have include the SA_SpatialUnit, and it has two subclasses SA_LandParcel and SA_BuildingUnit, to represent the parcel and building. The SA_BuildingUnit has three subclasses SA_InnerUnit (to represent the unit such as

an apartment, an office, clinic, etc.), SA_AmenitiesUnit (to represent services unit such as storage unit), and SA_SharedAreaUnit (to represent all the areas that have shared ownership between the owners such as corridor). All the three classes have an association relationship with SA_BoundaryFaceString for the representation of the 2D boundary information (in current land administration system in Saudi Arabia, the representation of all the inner units is in 2D by including all the 2D floor plans to subdivision request). On the other hand, the SA_LandParcel has one subclass SA_AmenitiesUnit. The SA_BoundaryFaceString has an association relationship with SA_Point in order to have zero, three, or more points for each unit. Furthermore, the SA_SpatialSource has an association relationship with each of SA_SpatialUnit and the SA_Point.

The Non-Spatial classes have included the party package, which consists of SA_Party, SA_GroupParty, and SA_PartyMember. The SA_Party class has one additional attribute to represent the nationality of the party. Furthermore, the administrative package consists of SA_RRR, and it has three subclasses SA_Right, SA_Responsibility, and SA_Restriction. The SA_Mortgage is a subclass of SA_Restriction, and an association relationship with SA_Right. As mentioned before, the initial country profile has covered only the basic information for the current land administration system after conducting many interviews with different stakeholders. However, the amount of data that has been collected is not sufficient for a complete representation of the current system. Therefore, another approach has been used to collect all the information that has to be documented in the registration process from all the stakeholders.

This new approach has focused on collecting several deed documents for different types of properties, such as land parcels, buildings, apartments units. Each type of deed registration documents that belong to one type of property is be used to extract all the information that has been included by the stakeholders during the registration. Then, a complete list of the information that has been extracted is grouped under the type of property. By doing the same for all types of properties, several lists that include unique attributes for each type of property are created.

The next step is to compare all the lists to extract the repeated (common) attributes and define them as non-optional attributes, and they have to be listed in a new list called registration of deed information for Saudi Arabia. The other attributes that not have been duplicated are defined as an optional attribute based on the type of property registration, and they are added to the new list registration of deed information for Saudi Arabia. The attributes of the new list are analyzed to assign each attribute to the correct class in the country profile.

4.5 Improving country profile of Saudi Arabia based on LADM

The improvement process for the country profile started by collecting several deed registrations documents for various types of pf properties. There are three types of properties are included in this process: apartment property, single house property, and land parcel property, and they are considered as the most common types of properties in the land administration system of Saudi Arabia. The deed registrations documents that belong to apartment unit property type have been analyzed in order to extract the essential information that has to be used during the registration, and 35 attributes have been extracted, as shown in Figure 4.10.

This process has been repeated for the house property, which resulted in 34 attributes. In the case of land parcel property, there were 16 attributes. Furthermore, there are 16 attributes duplicated in all the three lists, and they were considered as non-optional attributes, such as parcel No., district No., district name, city, ownership boundary, etc. The other attributes have been considered as optional attributes based on the condition of the property registration.

The next step is to list all the attributes to the new list Registration of deed information for Saudi Arabia, as shown in Figure 4.10. All attributes have been analyzed, and they represent three different types of information: party information, spatial information, and administrative information. Then, each attribute has been assigned to the related class in the country profile, as shown in Figure 4.11. Additionally, the data type of each attribute has been defined based on the input information type, and for the attributes that have a code list, the possible values of the code list has been defined.

Apartment registration Deed information

- Apartment number
- Floor number
- parcel number
- district plan number
- district plan name
- city name
- Ownership boundary
- Apartment area (Sq.M)
- Technical report number
- Date of theTechnical report
- Technical report source
- Notaries registration number
- Notaries registration date
- Percentage of the apartment area to the parcel area
- Apartment share from the parcel area(Sq.M)
- Registration deed number of the previous owner
- Date of the Deed registration of the previous owner
- Name of the owner
- Nationality of the owner
- Id Type
- Id number
- Mortgage loan source
- Commercial Registration No for Mortgage loan source
- Mortgage loan letter number
- Mortgage loan date
- Notaries registration number for the letter of mortgage loan
- Notaries registration date for the letter of mortgage loan
- Property value
- Duration installment (No.of months)
- installment value
- Starting date of installment
- Shariah Board authorization number
- Date shariah Board authorization number
- Registration deed number
- Registration deed date

House registration Deed information

- parcel number
- district plan number
- district plan name
- city name
- Ownership boundary
- Parcel area (Sq.M)
- Technical report number
- Date of theTechnical report
- Technical report source
- Notaries registration number
- Notaries registration date
- Registration deed number of the previous owner
- Date of the Deed registration of the previous owner
- Name of the owner
- Nationality of the owner
- Id Type
- Id number
- Mortgage loan source number 1
- Commercial Registration No for Mortgage loan source number 1
- Mortgage loan letter number from source number 1
- Mortgage loan date from source number 1
- Notaries registration number for the letter of mortgage loan from source number 1
- Notaries registration date for the letter of mortgage loan from source number 1
- Mortgage loan value from source number 1
- Mortgage loan source number 2
- Commercial Registration No for Mortgage loan source number 2
- Mortgage loan letter number from source number 2
- Mortgage loan date from source number 2
- Notaries registration number for the letter of mortgage loan from source number 2
- Notaries registration date for the letter of mortgage loan from source number 2
- Mortgage loan value from source number 2
- Property total value
- Registration deed number
- Registration deed date

Land parcel registration Deed information

- parcel number
- district plan number
- district plan name
- city name
- Ownership boundary
- Parcel area (Sq.M)
- Registration deed number of the previous owner
- Folder number
- Date of the Deed registration of the previous owner
- Name of the owner
- Nationality of the owner
- Id Type
- Id number
- Property total value
- Registration deed number
- Registration deed date

Those are all the information that is required to issuing the deed certificate for the main three types of property in SA

FIG. 4.10 Deed registration information

Registration Deed information FOR SA	LADM classes	Datatype	Code list	Code list value
property Type	SA_SpatialUnit	integer	SA_TypeOfProperty	parcel, buiding
Property No.	SA_InnerUnit	integer		
Floor No.	SA_InnerUnit	integer		
parcel No.	SA_LandParcel-SA_InnerUnit	varchar		
district No.	SA_SpatialUnit	varchar		
district name	SA_SpatialUnit	varchar		
city	SA_SpatialUnit	varchar		
ownership boundary	SA_LandParcel-SA_InnerUnit	varchar		
property area (Sq.M) / area (Sq.M)	SA_LandParcel-SA_InnerUnit	double		
Technical report No.	SA_AdministrativeSource	varchar		
Date of theTechnical report	SA_AdministrativeSource	date		
Technical report source	SA_AdministrativeSource	varchar		
Notaries registration No.	SA_AdministrativeSource	varchar		
Notaries registration date	SA_AdministrativeSource	date		
percentage of the property area to the parcel area	SA_InnerUnit	varchar		
property share from the parcel area (Sq.M)	SA_InnerUnit	varchar		
Registration deed number of the previous owner/ previous registration deed number	SA_AdministrativeSource	varchar		
Floder No.	SA_AdministrativeSource	varchar		
Date of the Deed registration of the previous owner/ previous registration deed date	SA_AdministrativeSource	date		
Name	SA_Party	varchar		
Nationality	SA_Party		SA_nationalityType	saudi, Gulf country,others
Type	SA_Party		SA_IdType	national ID, passport
Id No.	SA_Party	varchar		
mortgage source	SA_MortgageSourceOne	varchar		
commercial Registration	SA_MortgageSourceOne	varchar		
registration number for mortgage letter	SA_MortgageSourceOne	varchar		
registration date for mortgage letter	SA_MortgageSourceOne	date		
notaries registration number for mortgage letter	SA_MortgageSourceOne	varchar		
notaries registration date for mortgage letter	SA_MortgageSourceOne	date		
mortgage amount from source	SA_MortgageSourceOne	double		
mortgage source	SA_MortgageSourceTwo	varchar		
commercial Registration	SA_MortgageSourceTwo	varchar		
registration number for mortgage letter	SA_MortgageSourceTwo	varchar		
registration date for mortgage letter	SA_MortgageSourceTwo	date		
notaries registration number for mortgage letter	SA_MortgageSourceTwo	varchar		
notaries registration date for mortgage letter	SA_MortgageSourceTwo	date		
mortgage amount from source	SA_MortgageSourceTwo	double		
property total mortgage	SA_Mortgage	double		
duration installment (No.of months)	SA_Mortgage	integer		
installment amount	SA_Mortgage	double		
installment starting date	SA_Mortgage	date		
shariah Board authorization No.	SA_Mortgage	varchar		
shariah Board authorization date	SA_Mortgage	date		
registration deed No.	SA_AdministrativeSource	varchar		
registration deed date	SA_AdministrativeSource	date		
The New attributes for the classes of the country profile of SA				

FIG. 4.11 New attributes for the country profile

TOC

By having all the new attributes, the earlier proposed UML class diagram has been updated in Enterprise Architect (EA). The non-spatial classes consist of the Party package and the administrative package, as shown in Figure 4.12. The Party package consists of SA_Party class, and it has three additional attributes: nationalID, Nationality, and type (represents the ID type). The attributes of SA_Party are non-optional. The SA_GroupParty and SA_PartyMember inherit the same attributes from LA_PartyMember and LA_GroupParty. The administrative package consists of the SA_BAUnit, SA_RRR (Including SA_Right, SA_Responsibility, and SA_Restriction as subclasses), SA_AdministativeSource, and SA_Mortgage. The SA_AdministativeSource contains additional attributes to the inherited attributes from the LA_AdministativeSource.

The deed No. and deed date attributes are non-optional, and the rest of the attributes are considered as optional attributes based on the conditions of the property registration. The SA_Mortgage class has additional attributes, and only the shariah Board authorization No. and shariah Board authorization date are optional attributes. Furthermore, the SA_Mortgage abstract class has two subclasses SA_MortgageSourceOne and SA_MortgageSourceTwo, to represent different mortgage sources. The current land administration system in Saudi Arabia registers all mortgage sources, such as bank mortgage, government mortgage or both. Only the attributes of SA_MortgageSourceOne are non-optional, and the SA_MortgageSourceTwo is optional when there is only one source of mortgage.

The spatial classes consist of SA_SpatialUnit abstract class, and it has four additional attributes (property Type, district No., district name, and city), and all of them are considered as non-optional attributes, as shown in Figure 4.13. The SA_LandParcel and SA_BuildingUnit are subclasses of the SA_SpatialUnit, and they have additional attributes that are non-optional attributes. The SA_LandParcel has five attributes (parcel No., area, ownership boundary, type (to represent the type of parcel) and reference) to represents primary information about the parcel.

The SA_BuildingUnit has four attributes (parcel No., reference, type (to represent the type of the building) and numberOfFloor) to represents the primary information about the building. The SA_InnerUnit (to represent the unit such as an apartment), SA_AmenitiesUnit (to represent services unit such as storage unit), and SA_SharedAreaUnit (to represent all the areas that have shared ownership between the owners such as corridor) are subclasses of SA_BuildingUnit. Each of these classes has several attributes that are considered as non-optional attributes. The rest of the spatial classes are inherited from the original classes of LADM. Figure 4.14 has shown the values of the code lists.

FIG. 4.12 Non-spatial classes of the country profile of Saudi Arabia
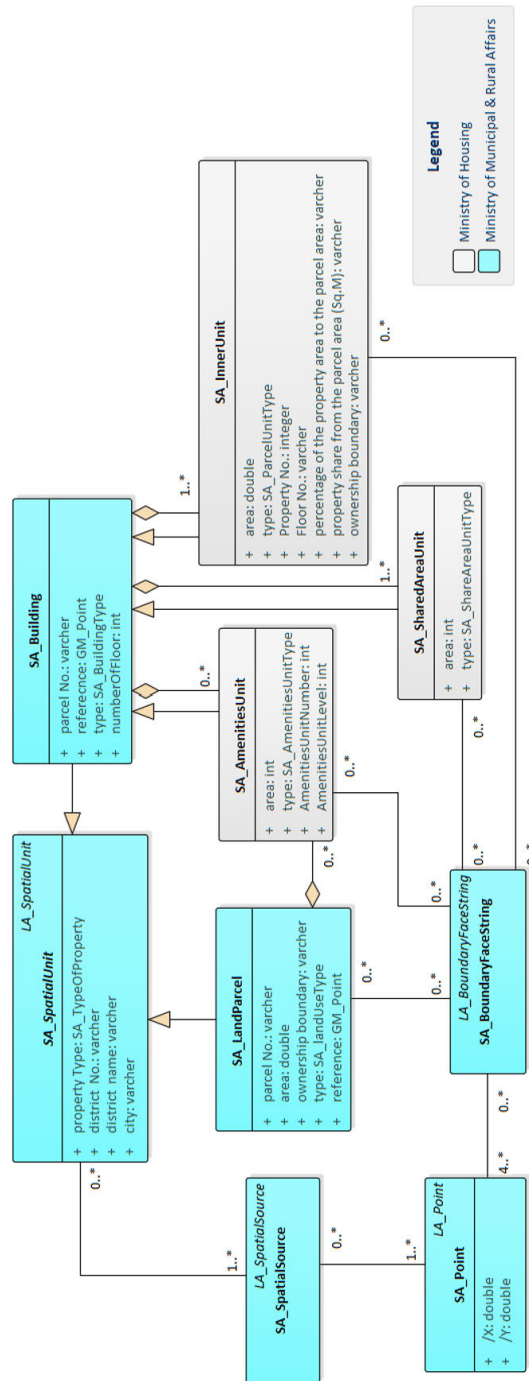
FIG. 4.13 Spatial classes of the country profile of Saudi Arabia
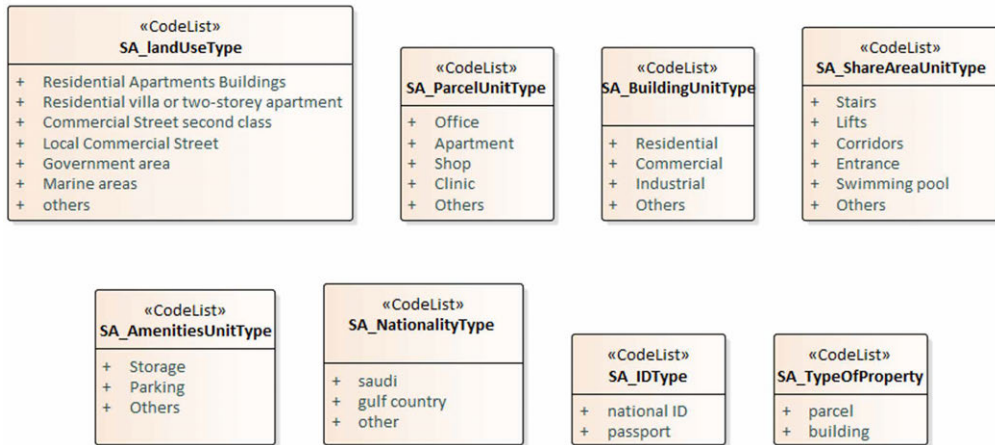
FIG. 4.14 Code lists of the country profile of Saudi Arabia

4.6 Summary

The land administration system in Saudi Arabia is under the responsibility of four stakeholders, and each of them has several tasks during the registration of property. These tasks require communications between all the stakeholders to provide the ownership documents. For this reason, the initial 2D country profile has been developed to improve the interoperability between all the stakeholders and to represent the land administration system in Saudi Arabia based on LADM.

However, by testing and validating the initial country profile, the result has shown that only the basic information of the land administration system has been represented. Therefore, a new approach has been used to extract all the essential information from the land administration system by collecting several deed registrations for different types of properties and compare between them to extract the optional and non-optional attributes. Then, all attributes have been grouped into three different categories based on their types (spatial information, party information, and administrative information). These categories have been used later to assign each attribute to the related class in the country profile UML class diagram in EA. By having additional attributes, the initial country profile has been extended to reflect the land administration system in Saudi Arabia. As described in

this chapter, a methodology for developing Saudi Arabia's 2D country profile has been developed, and other countries could adopt the same approach to develop their own 2D country profiles. This chapter also provides an answer to the sub-question "Q2. What is the status of Land Administration in 3D indoor environment in Saudi Arabia?". The sub-question has been answered by giving all of the information on the relationship between all of the stakeholders who are engaged in land registration, as well as presenting a new method that has been utilized to extract all of the essential information from the land administration system.

5 3D country profile for buildings based on LADM

The development of the 2D LADM country profile was introduced in chapter 4. In this chapter, the development of the 3D country profile of Saudi Arabia based on LADM is presented. The development of the 3D country profile is based on the building subdivision procedures that focus on the indoor rights, restrictions, and responsibilities. This chapter shows the process of mapping from the BIM/IFC 3D model to LADM for both conceptual modelling and at the level of the individual data instances with their geometry and topology. This mapping requires that the BIM/IFC file contains sufficient information to identify the different spaces being part of a property. Three different primary types of spaces are identified: private, common, and exclusive common spaces. Additionally, the rights are attached to the indoor spaces and to the construction elements, such as walls, slabs, and columns.

The chapter is structured as follows: the introduction of the importance of 3D is presented in Section 5.1. Section 5.2 presents an extensive overview of the building unit's subdivision regulations in Saudi Arabia, while Section 5.3 contains the 3D representation of building unit's subdivision procedures. Based on those, the initial 3D LADM-based country profile for Saudi Arabia is presented in Section 5.4. Section 5.5 summarizes the whole chapter.

The importance of 3D

Much of the current research in land administration focuses on issues related to 3D representations: techniques for data collection, optimizing processes, 3D web-based data dissemination and visualization, standardization, and interoperability of solutions. As the world is increasingly migrating towards integration, the need to combine independent systems and procedures associated with different disciplines and scales of the built environment is becoming pertinent. In this context, both systems' communication and data interoperability matters. In this respect, standards have a crucial role.

In this lifecycle thinking approach, the reuse of information between the various stages of an object's lifecycle seems to be cost and time effective. This also applies to the land administration domain, where, traditionally, the source of information is data acquisition via surveying equipment, existing cadastral databases, and related maps. Today, there is much interest at an international level in reusing information from the design phase of buildings and infrastructures for cadastral registrations, also embodying the concept of the lifecycle of information.

Moreover, today, land administration systems (LAS) are facing new challenges for managing ownership rights in complex urban environments with the growing dominance of high-rise building structures and complex infrastructure. Therefore, they are seeking to adopt 3D digital approaches for managing and representing complex ownership rights. Such 3D approaches and 3D information can be derived from the design phase by the Architecture, Engineering, and Construction (AEC) industry. In this domain, there has been a significant leap in the development of Building Information Modelling (BIM), as an integrated, 3D digital information repository, facilitating collaboration among different AEC actors throughout the development cycle of buildings (Rajabifard, 2019).

Hence, BIM models, and specifically, Industry Foundation Class (IFC) files are considered promising source for land administration, as they provide a rich amount of 3D geometric, topological and semantic information about buildings. Such source data is expected to have capabilities to specify semantics, which can identify property units accurately, represent cadastral boundaries better, and visualise complex buildings in more detail (Rajabifard, 2019).

What is more, as national governments and jurisdictions around the world begin to mandate the use of BIM in various procedures, they play a key-role in significantly

accelerating the early stages of BIM adaptation and implementation worldwide. This fact will lead to the availability of numerous BIM models of complex buildings and infrastructures in the near future, which underscores the rationale of exploring BIM for land administration purposes. In this context, Liu et al. (2017) underlined that although BIM can provide much detailed information for LAS purposes, this information can sometimes be too detailed, and a simplification process may be required, while information concerning ownership and transaction history, is not available in BIM. Similarly, not all the IFC files may be suitable as a source for cadastral registration, as each time their richness in content and structure (IFC classes) depends on the purpose for which they have been created. Last but not least, the regulations that apply in each country influence the workflow followed for the creation of the IFC file.

The property registration system in Saudi Arabia has entered a new era with new ownership and subdivision regulations that have been issued, and thus, together with the availability of IFC files, it was decided to base this research on Saudi Arabia's reality and needs. Hence, the main part of this research is country-specific and at an initial stage, as it is investigated how different types of spaces can be mapped from IFC to LADM, using real-world data for Saudi Arabia (both spatial and administrative). This mapping builds on existing knowledge and experience and introduces a novel approach of refining models with the buildings' spaces, taking into account three main types of spaces: private spaces, common spaces, and exclusive common spaces.

5.2 Building unit's subdivision procedures

The property registration system in Saudi Arabia entered a new era with the approval of the Real Estate ownership and subdivision regulations from the Council of Ministers of Saudi Arabia. The Real Estate ownership and subdivision regulations have been issued by Decision No. 40 from the Council of Ministers of Saudi Arabia dated 22/04/2002 and approved by Royal Decree No. M / 5 dated 24/04/2002 (Ministry of Housing, 2002). The new regulation includes several articles that have to be considered during the property subdivision, namely:

1   Each building could be subdivided based on the architecture floor plans that have been approved and licensed by the Municipality.

2   The owner may subdivide one or more real estate units from the main deed registration of the land to have a separate deed registration for each unit, including all the information that is related to the location of the property, property number, floor number, and the shared area from the land and the building area.

3   The owner has the right to use the property without changing the function of that area.

4   The units' owners share the common spaces based on the proportion of the value of their units.

5   The owners could use the common spaces without changing the main function of those spaces.

6   The owners do not have the right to apply any changes that could threaten the building's safety or influence the shape of the building.

7   The owner has the right to change the property's function after obtaining written approval from the owner's association of the building and obtaining the necessary license from the Municipality.

8   The maintenance cost of the common spaces has to be covered by all the owners according to the percentage of the owned spaces.

9   The common spaces include the parcel, the garden, the setback of the building, the construction elements, the roof area, the entrance, the stairs, and all other parts that have been defined as common areas such as corridors, parking, elevators, and the external facades of the buildings unless there is another agreement.

10   The side barriers and the walls between two contiguous units in the building are defined as exclusive common ownership between the owners of the units unless they are proven otherwise, and neither of them has the right to use its share in a way that harms the other.

11   The common parts that have limited benefit to some owners are considered as exclusive common ownership between them unless they are proven otherwise.

12   To transfer the property ownership after the initial construction of the building:
- The owner should submit a subdivision unit request to the Municipality, including the deed registration document, architecture floor plans (AutoCAD and PDF 2D Files), and construction license. If the building does not have a construction license, a sketch drawing must be submitted to determine the location and survey for the real estate unit to be sorted.
- Then, the Municipality has to check all the documents to validate that all the requirements are met.
- If the request meets all the requirements, the Municipality transfers the request to the Ministry of Justice to issue the deed registration document for the real estate unit.

The supervision of the building unit's subdivision duty in Saudi Arabia, has been placed under the Ministry of Housing responsibility according to Royal Decree No. 7262 on 21/11/2015. The goal of moving the responsibility for the building unit's subdivision from the Ministry of Municipal and Rural Affairs to the Ministry of Housing was to develop, regulate, and standardize the procedures of building unit subdivision to ensure better representation of the property boundaries. The goals and benefits of the building's subdivision procedures are: 1) standardizing the building's subdivision procedures, 2) developing and organizing the systems, 3) automating the processes, 4) preserving and guaranteeing the unit owner's rights, 5) activating the role of the building owner union, and 6) reducing procedures time.

5.2.1   Conditions and requirements for the subdivision of the real estate units

Some conditions have to be available in the property to apply the subdivision procedures after the building's initial construction. Those conditions have been defined by the Ministry of Housing to ensure complete ownership for the property after issuing the deed registration documents (Ministry of Housing, 2020). The following conditions must be met for each real estate unit that has an independent deed registration document from the primary deed registration documents of the building:

1. Each property must have a separate entrance.
2. Each property should have an electricity meter.
3. The common spaces and shared facilities must have a service meter.
4. The building of the property should have a common space from the roof to serve all properties.

5   Each property should have at least one car parking spot located in the building.

After having all the conditions met in the property, several documents have to be collected to submit the request for a subdivision procedures:

– Deed registration documents.	– Building completion certificate.
– Construction license.	– Certificate of correction of status: If there is a conflict in nature (the current condition of the building) with the building permit, the owner must bring a license to correct the situation.
– Authorization from the owner to the architecture firm.	– Building safety certificate
– The approved building floors plans from municipality.	– Location coordinates file
– The as-built floor plans.	– Photos for the real estate

The approved building floors plans from the Municipality usually consist of all the 2D floor plans and one or more sections plans to represent the height of the floors, as shown in Figure 5.1.

FIG. 5.1 Example of one of the required documents by the Ministry of Housing: the approved building floors plans from municipality (in the request of the subdivision).

Types of real estate and sub-dividable units

The Ministry of Housing has defined the main types of real estate that could be subdivided into several units based on the subdivision procedures (Ministry of Housing, 2020). Furthermore, the Ministry has specified the units that could be obtained as a result of subdivision procedures. The *first category* represents the main types of real estate properties that could be subdivided into several units:

1   **Tower:** It is a building that could have different types of units such as residential, commercial, or multi-use units, and has common areas that have different rights of use based on the user type unit.

2   **Mall:** It is a commercial building that has either connected or separate commercial units and common areas.

3   **Residential complex:** It is a residential community that has connected or separate units and common areas.

4   **Residential Commercial Complex:** t is a mixed-use building that has connected or separate units and common areas.

5   **Building (storey building):** It is a building that contains more than one unit and common areas and consists of several floors.

6   **Villa:** It is a separate building consisting of one or more floors, and it has an external wall from all sides.

Additionally, according to the regulations, the main difference between the Tower and Building (storey building) is that the tower could have more than one type of property, while the building only has one type of property. The *second category* represents the units that could be obtained as a result of subdivision procedures and could have individual deed registrations documents:

1   **Building:** It is a separate building with its setbacks and contains several floors.

2   **Connected building:** It is a non-detached connected building without setbacks and containing several floors.

3   **Tower:** It is a separate building with its setbacks and has several floors.

4 **Connected tower:** It is a non-detached connected building without setbacks and containing several floors.

5 **Apartment:** It is an independent unit considered part of one floor.

6 **Two-floor apartment:** It is an independent unit consisting of two floors, with an internal staircase and part of a building.

7 **Flat and loft extension:** It is an independent unit that is part of a floor and contains an upper extension that is not connected by an internal staircase.

8 **Floor and loft extension:** A floor within a building has an upper extension that is not connected by an internal staircase.

9 **Floor:** A floor in a building.

10 **Hotel:** A building or part of a building that contains multiple floors and features its own services.

11 **Mall:** A building consists of several shops or administrative offices.

12 **Connected commercial complex:** It is a commercial building with either connected or separate commercial units and common areas.

13 **Residential complex:** It is a residential community that has connected or separate units and common areas.

14 **Two floors commercial unit:** A commercial unit consists of two connecting floors by an internal staircase.

15 **Store:** A commercial unit that is part of a building and has a separate entrance.

16 **Studio:** It is a housing unit with no more than 3 components.

17 **Villa:** It is an independent villa with its setbacks, and the width of the street should not be less than 12 meters, and their area not less than 200 m^2.

18 **Connected villa:** It is a villa structurally connected with several units.

19 **Connected duplex villa:** It is structurally connected villa to another villa and is connected to another villa, or there is a shaft between them, or the width of the street is less than 10m, or it has a separated structure, and its area is less than 200 m², or the street width is less than 12m.

20 **Vertical duplex villa:** It is adjacent to another villa and has a separate structure. There is no Shaft between them, and the street's width is not less than 10 meters. The villa area is not less than 200 m², and the width of the street is not less than 12 meters.

21 **Roof villa:** It is an independent unit consisting of two or more floors, and there is a separate internal staircase, and it is located in the last floor of the building.

22 **Office:** It is a unit located inside the property for office use.

23 **Mosque A:** It is the mosque that is located inside a complex and has a separate piece of the parcel.

24 **Mosque B:** It is the mosque that is located inside a complex and does not have a separate piece of the parcel.

25 **Floor and lower extension:** A floor in a building that has a lower extension and not connected by an internal staircase.

26 **Apartment and lower extension:** It is an independent unit that is part of a floor and contains a lower extension that is not connected by an internal staircase.

27 **Two vertical apartments:** It is a residential unit that contains two vertical apartments, and they are not connected by an internal staircase.

The following table shows the unit types that could be subdivided from the main types of real estate properties (first category):

TABLE 5.1 The subdivided units from the main types of real estate properties

Functional unit types	Construction types					
	1-Tower	2-Mall	3-Residential complex	4-Residential Commercial Complex	5-Building	6-Villa
1-Building						
2-Connected building						
3-Tower						
4-Connected tower						
5-Apartment						
6-Two-floor apartment						
7-Flat and loft extension						
8-Floor and loft extension						
9-Floor						
10-Hotel						
11-Mall						
12-Connected commercial complex						
13-Residential complex						
14-Two floors commercial unit						
15-Store						
16-Studio						
17-Villa						
18-Connected villa						
19-Connected duplex villa						
20-Vertical duplex villa						
21-Roof villa						
22-Office						
23-Mosque A						
24-Mosque B						
25-Floor and lower extension						
26-Apartment and lower extension						
27- Two vertical apartments						

5.2.3   **Property unit numbering approach**

The approach that has been used by the Ministry of Housing to assign a number to the property unit is based on the approved numbering system by the National Address. Each building obtains a number that consists of building number, postal code, and an additional number, as shown in Figure 5.2 (Ministry of Housing, 2020).
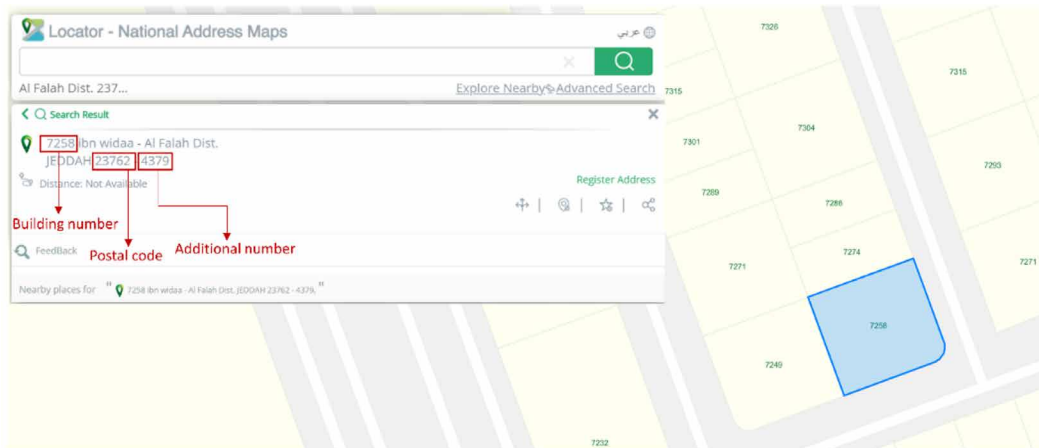
FIG. 5.2 The numbering approach system of the national address

The building number is a dedicated number for each building located in the same street and consists of four-digits. The postal code indicates a specific region and consists of five digits. The additional number allows to distinguish between buildings that have the same building number and are located in different streets and consist of four digits. If the building has several property units that have separate deed registration documents such as apartments or offices, all units of the building will be numbered sequentially. They will be refereed by a number that consist of the unit number and the floor number (unit /floor number). Table 5.2 shows an example of the numbering system for a building consisting of three units. Additionally, the related spaces to the units, such as parking spot, storage, or driver room, will be linked to the main unit (such as an apartment) by the unit number as shown in Table 5.3. Numbering the main units of the building and the service spaces (parking spot, storages, and driver rooms) are under the architecture firms' responsibilities by following the national address's numbering approach.

TABLE 5.2 Numbering units' approach

Property Unit	Floor number	Unit/Floor number	Building number	Postal code	Additional number
1	Ground floor	1/G	7258	23762	4379
2	First floor	2/1	7258	23762	4379
3	Second floor	3/2	7258	23762	4379

TABLE 5.3 Linking the main units with their related spaces

Property Unit	Part	Part role
1	1/G	Main
1	1/G	Parking
1	2/G	Parking
1	1/B	Storage
1	1/G	Driver
2	2/1	Main
2	3/G	Parking
2	2/B	Storage
2	2/G	Driver
3	3/2	main
3	Etc.	

In the case of merging two units in the same building, such as unit/floor number 11/1 and unit/floor number 12/1 (units 11 and 12 both on the first floor), the merged unit will take the lower number, hence 11/1. The merged units have to be horizontally or vertically adjacent, and each unit must have an individual deed registration document. Additionally, the integrated units' usage has to be identical (residential or commercial) (Ministry of Housing, 2020). The subdivision procedures will not be applied to any property that does not have a unique unit number. Therefore, the numbering approach is critical to ensure which property will have a separate deed registration.

5.2.4 Common and private areas/parts

The common areas serve one or more (groups of) units, and they have several types, such as common spaces, exclusive common spaces, and private spaces. Below a list of the different building parts:

- **Private spaces** have been defined as a part that belongs to only one unit, and it does not have any common services. Furthermore, the private part cannot be used to pass to another unit or a common area or has shared services.

- **Exclusive common spaces:** The common areas and services that have exclusive use for some units only.

- **Common spaces:** The areas and services that all units are sharing the use of them, for example, shaft, roof, elevator, stair area, setbacks, parking, and exterior façades of the building.

According to the subdivision regulation, if a building contains less parking than the number of units, the parking spots have to be numbered and added to the deed registration during the subdivision procedures. In this case, the owner of the unit will have exclusive common ownership for the parking spot. While if the number of parking is similar or higher than the unit numbers, then assigning a number to each parking is optional during the subdivision process, and the deed registration document will not include it. In this case, the parking spots will have common ownership for all the owners.

5.2.5 Procedures for calculating the unit's area and their boundaries

All areas in the building must be divided by drawing the boundaries of all units, common spaces, exclusive common spaces, and private spaces so that there are no areas that have not been calculated, i.e., a planar partition (per floor). The areas of setbacks and roof must be calculated and determine by their use as a private or common space. The boundaries should be drawn from the middle of the wall on the borders of units, common and private spaces in all cases regardless of whether it is bordered by common spaces, unit, or private space as shown in Figure 5.3.

Each unit's area is calculated from the middle of the walls and windows by using the boundaries of the unit (Ministry of Hosing, 2020) and the balcony area is included in the unit calculated area. The areas of the shaft and common spaces are not part of the unit area. In the case of private spaces related to specific unit, these private spaces should be added as part of the unit and do not enter within the unit's calculated area, such as parking, storage, and driver's room. The building's external façades are considered as common space that is defined as half of the thickness of the outer wall of all the units, as shown in Figure 5.4. All the elements of the façades are considered under common ownership.
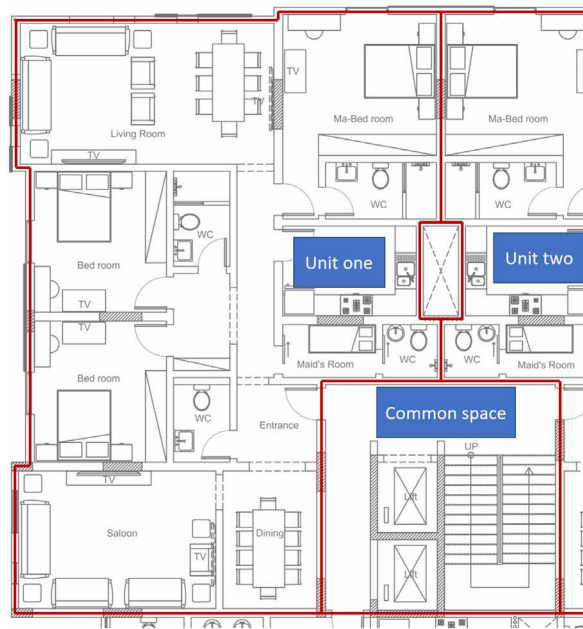
FIG. 5.3 Unit boundaries in middle of the walls

The external façades of the building

FIG. 5.4 External façades of the building

5.2.6 Construction elements

According to the building unit's subdivision procedures, the building's construction elements of have common ownership, including walls (located on the boundary of the property unit), columns, and slabs. The following applies to the construction elements:

— The walls located within property unit boundary will have private ownership and can be modified without approval of the owners' union council.

— The walls located in-between two private units or private units and exclusive common spaces will have exclusive common ownership.

— The walls located between private ownership and common ownership spaces will have common ownership.

— The columns located within property boundary will have common ownership even if their areas have been added to the calculated area of the property, as shown in Figure 5.5.

— The building's slabs have two different ownership rights, common or exclusive common based on their location.

— The slabs located between two private ownership spaces, or one private and one common will have exclusive common rights.

— The slabs located between two common spaces will have common ownership.

— All construction elements that have common or exclusive common ownership have a restriction of use or change.
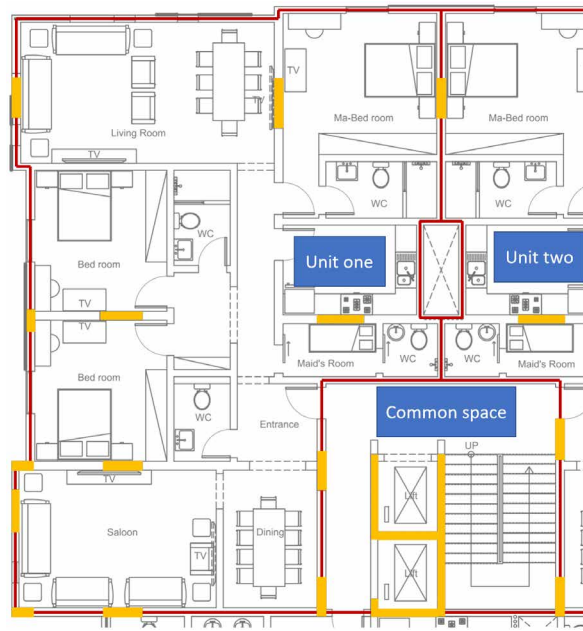
FIG. 5.5 The common ownership of columns

5.3 Private, common, and exclusive common 3D building units

The traditional building unit's subdivision procedures in Saudi Arabia are based on the 2D representation of the legal space ownership, as described in the previous section. However, the 3D representation of the legal space ownership will bring a more accurate description of the spaces for better registration. Therefore, this section introduces the 3D representation of the legal space ownership by using the same rules and regulations of the current building unit's subdivision procedures of Saudi Arabia. A local Saudi Arabia architecture firm has created a real-world 3D model for a complex architecture project, and it is used in the context of this research to apply the current regulation, which was translated into 3D. It is an apartment building located in Jeddah, Saudi Arabia, consisting of 13 apartments, as presented in Figure 5.6. Each unit (apartment) has it owns car parking, driver room, and water tank. This is a single use real estate (so no divisions such as in case of mixed-use real estate), showing Private spaces, Exclusive common spaces, and Common spaces.

Modifying the 3D model based on the building unit's subdivision procedures

A brief study had revealed that most of the architecture firms in Saudi Arabia create 3D models for most of their complex projects, but they use them mostly for marketing purposes. They create 3D perspective views to get the Municipality's approval. Therefore, the building's 3D models are currently not being used for defining the legal space of each ownership. In this context, when following the proposed approach, the 3D model that will be used shall be evaluated and examined in terms of completeness and correctness, i.e., check if there any missing parts or elements that should be included; improve the model accordingly before applying the current unit's subdivision procedures.

The method that has been used to evaluate the 3D model is described as follows. The first step was to check if the 3D model, as received from the architecture firm, follows the same design of the building as the paper-based floor plans. After that, all the architectural elements such as walls, doors, and windows had to be checked again to ensure that every apartment is enclosed by walls and doors and there is no overlap between apartments. Next, the height of each floor had to be measured to ensure a correct height of the building. These steps revealed several issues such as missing 3D spaces, overlap between the slabs and missing windows and doors. Additionally, the construction elements of the building have some issues such as the columns that have been created as one element and they will have the same information. The discovered errors were corrected 'manually' in the IFC model.

During the evaluation of the 3D model of this complex building several issues arise that need to be fixed before applying the current the unit's subdivision procedures. Firstly, missing 3D spaces as shown in Figure 5.7. The spaces are used to define the ownership unit's legal boundary, and without them there will be no 3D representation of the legal spaces. Secondly, each floor slab has been initially created as one element for all apartments located on the same floor, and this does not allow assignment the ownership for each part that covers the units (apartment) located above and under the slab as shown in Figure 5.8a. Similarly, the columns that have been created as a single object for the entire building, and that do not allow to add different ownership rights to each induvial column as shown in Figure 5.8b. Thirdly, due to the marketing purpose of the 3D model, it does not contain some elements at the underground spaces, such as the water tanks. Lastly, some walls have to be modified to represent the condition of the ownership of each unit.

FIG. 5.6 A 3D model of an apartment building

Spaces are missing
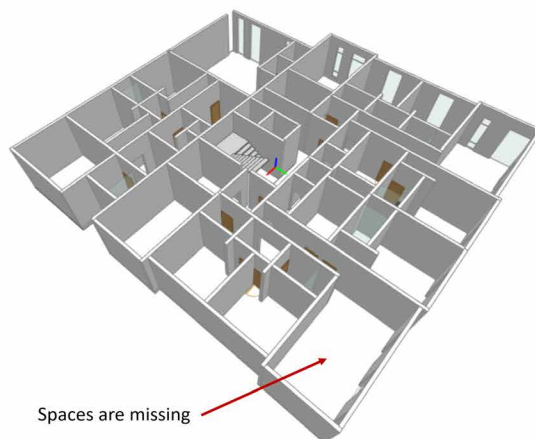
IFC Structure
Type
⊞ Building Storey
⊞ Building Storey
⊞ Building Storey
⊞ Building Storey
⊟ Building Storey
⊞ Walls
⊞ Annotations
⊞ Slabs
⊞ Doors
⊞ Curtain Walls
⊞ Others
⊞ Columns
⊞ Stairs

The content of the first floor

FIG. 5.7 Missing Spaces from the 3D model
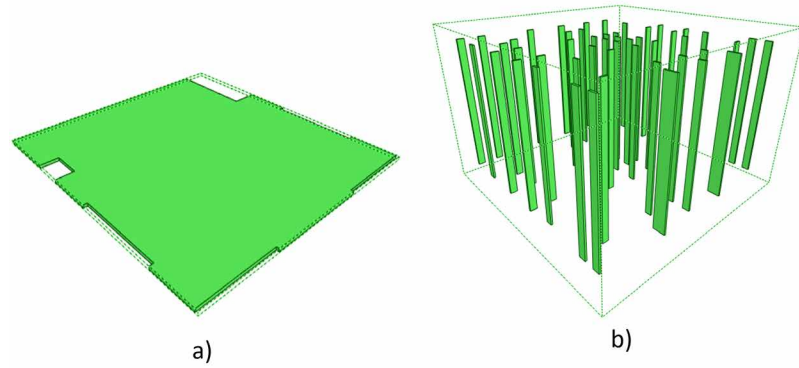
FIG. 5.8 The Slab and columns have been created as single object
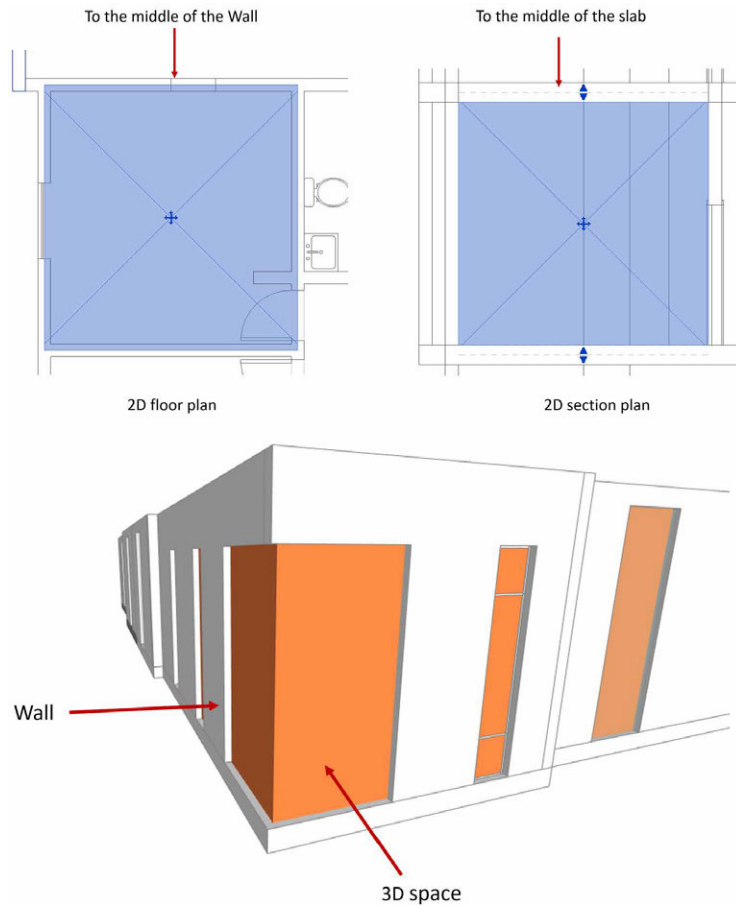
FIG. 5.9 Space representation

As a next step, the 3D spaces have been added to the 3D model. Each space has covered the room from/to the middle of the walls and the slab, to follow the current building unit's subdivision procedures, as shown in Figure 5.9. The software does not support creating one space for the entire apartment. Thus, it was decided that each apartment will consist of several spaces equal to the number of its rooms.

5.3.2 The private building units

Each building's space has included additional information to represent the ownership of the space such as private, common part, or exclusive common part. Several attributes and associations have been added to the model for this purpose, as shown in Table 5.4, which will be included accordingly in each building's space based on its type/ function.

TABLE 5.4 The attributes and their description for the SA_BuildingSpaces

Attributes	Description
Property Type	The type of the property (Apartment, Office)
Property No.	Number of the Property
Ownership Type	Represents the ownership type such as private
Service Area Type	Represents the function services area such as entrance, parking, etc..
ZoneName	It is used as an ID to attach the services areas to their properties such as parking or driver room that are related to the apartment
Associations	**Description**
Exclusive Common Ownership +	Name or number of the property or area that located in the right side of the Exclusive Common space
Exclusive Common Ownership -	Name or number of the property or area that located in the left side of the Exclusive Common space

By adding the attributes to each space's type, several types of space ownership are defined. Figure 5.10 shows the private ownership of the apartments located on the first floor. For example, the ownership type for apartment one is private ownership, and it has included the property number to distinguish the related space of apartment one from the rest of the spaces of other apartments. Additionally, for each space, the 'ZoneName' attribute has been added to create IfcZone in the BIM file, which works as a collector for all the spaces that belong to single ownership. In the case of representing all the spaces that belong to apartment one, the 'ZoneName' attribute gets the value 'Apartment One' for each area that belongs to apartment one, as shown in Figure 5.11.
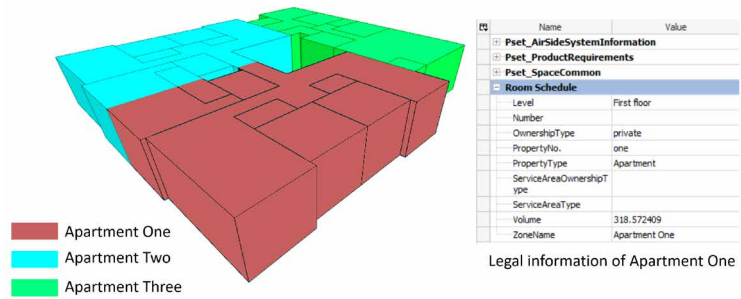
FIG. 5.10 The private ownership of apartment one
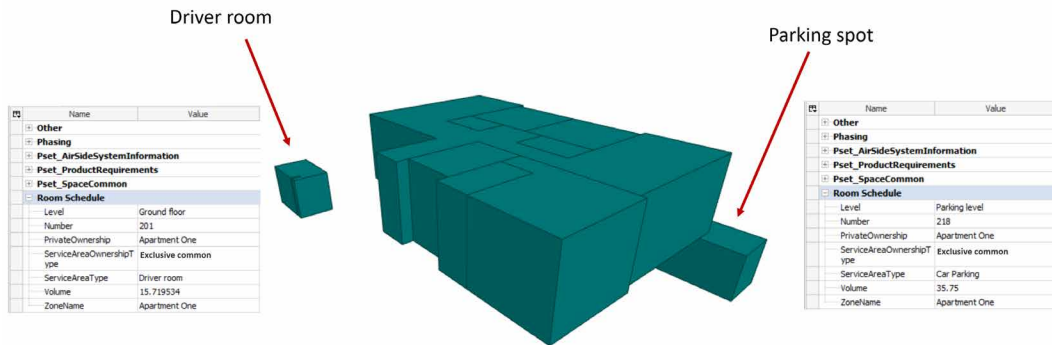
FIG. 5.11 The representation of the service spaces for apartment one (one zone of which the main one has many spaces, and the other two, driver room and parking spot, each have just one space)

Apartment one has the following amenity/service spaces a parking spot and a driver's room, and all of them have the same value ('Apartment One') for the attribute 'ZoneName'. Each service space has Exclusive common ownership for the 'ServiceAreaOwnershipType' attribute, while the 'ServiceAreaType' represents the space's function. However, if the service spaces are not registered as Exclusive common ownership spaces for Apartment One (which is also an option in the Saudi-Arabia legislation), they will have a common ownership based on the building unit's subdivision procedures, and the representation of the Apartment one will be without the service spaces. The 'ZoneName' attribute will have the value 'parking spot' for the parking space and 'driver room' for the driver's room space. Figure 5.12 shows the representation of the private spaces of apartment one without the service spaces.

Name	Value
⊞ **Pset_AirSideSystemInformation**	
⊞ **Pset_ProductRequirements**	
⊞ **Pset_SpaceCommon**	
⊟ **Room Schedule**	
Level	First floor
Number	27
OwnershipType	private
PropertyNo.	one
PropertyType	Apartment
ServiceAreaOwnershipType	
ServiceAreaType	
Volume	71.336
ZoneName	Apartment One
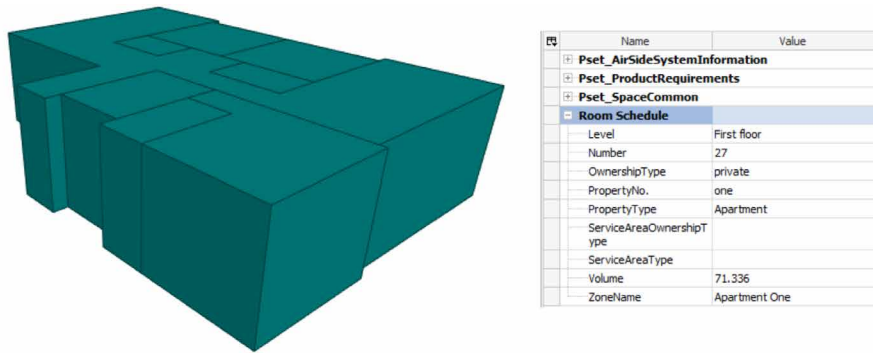
FIG. 5.12 The representation of the private spaces for apartment one (as driver rooms and parking spots are common spaces in this option)

The common building units

Furthermore, the building has other spaces of common ownership, such as the entrance, entrance hall, corridors, stairs, elevator, and service floor, and these spaces can be used by all owners of the building, as shown in Figure 5.13. On the other hand, if the parking spaces, drivers' rooms, and the water tank are also in common ownership, then the representation of the common spaces will include the parking floor and the underground water tank, as presented in Figure 5.14.

Name	Value
⊞ **Identity Data**	
⊞ **Other**	
⊞ **Phasing**	
⊞ **Pset_AirSideSystemInformation**	
⊞ **Pset_ProductRequirements**	
⊞ **Pset_SpaceCommon**	
⊟ **Room Schedule**	
Level	Ground floor
Number	195
ServiceAreaOwnershipType	Common
ServiceAreaType	Entrance hall
Volume	142.807737
ZoneName	Entrance Hall

- Service floor
- Corridor, stairs, elevator
- Entrance

Legal information for the entrance
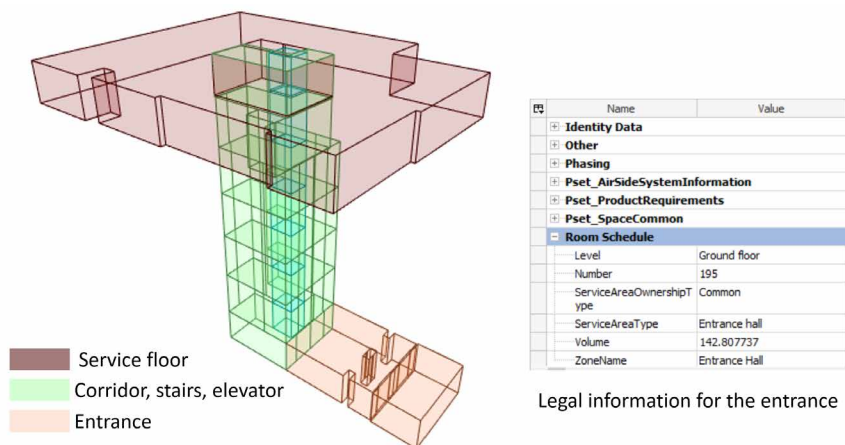
FIG. 5.13 The common spaces of the building

Service floor
Corridor, stairs, elevator
Entrance
Drivers' rooms
Water tanks

5.3.4 The exclusive common building units

The last type of space ownership is the exclusive common ownership. There are two spaces with this type of ownership: shaft number one, and shaft number two. Both have this type of ownership because they serve only a part of the building. Specifically, shaft number one is located on the front side of the building and is surrounded by apartment one and two on the first floor, apartment four and five on the second floor, apartment seven and eight on the third floor, apartment eleven and twelve on the fourth floor, and apartment thirteen on the fifth floor. The shaft number one and shaft number two have other associations, as previously described in Table 5.2, to represent the spaces sharing the use of the shafts. The 'Exclusive Common Ownership +' and 'Exclusive Common Ownership – 'associations have been used to represent for the right and left units, respectively. The model will only register the neighbouring units located on the same floor; however, all units on the other floors adjacent to the shaft will share the same rights, as shown in Figure 5.15.
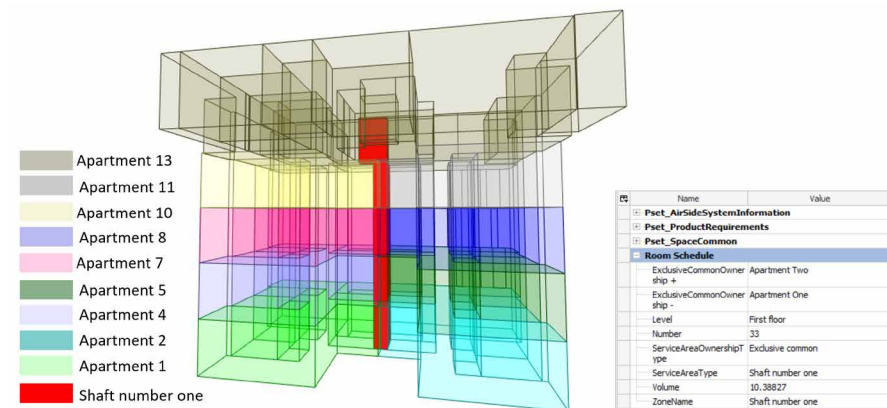
FIG. 5.15 3D section of the building to represent the exclusive common ownership of the shaft

5.3.5   ## Construction elements of the building: walls

The construction elements of the building have different ownership based on the location of each element. Therefore, each type of construction element contains additional attributes to represent ownership. Table 5.5 shows the additional attributes that have been added to the walls of the 3D model.

TABLE 5.5 The attributes and their description for the SA_ConstructionElement

Attributes	Description
Construction Element Type	To represents the construction element type
Ownership Type	Represents the ownership type such as private, common, etc.
ZoneName	It is used as an ID to attach the construction element to their properties

Associations	Description
Common Ownership +	Boolean, true if right side is common property
Common Ownership	Boolean, true if left side is common property
Exclusive Common Ownership +	Boolean, true if right side is exclusive common property
Exclusive Common Ownership -	Boolean, true if left side is exclusive common property

The walls have six types of ownership based on their location. The *first type* of ownership refers to the façade walls. Based on the current procedures of the building unit's subdivision, the boundary of the ownership for an apartment will start from the center of the wall by drawing a polyline around the property. Therefore, the façade wall will have common ownership. The unit owner will use the wall's inner face, and the outer face of the wall will have common ownership based on the building unit's subdivision procedures, as shown in Figure 5.16a.

The *second type* of ownership is related to a wall located inside the boundary of one apartment. The wall will have private ownership, as shown in Figure 5.16b. The owner could modify all the walls located within the unit's boundary without obtaining any approval from the owners' union council. The *third type* refers to a wall located on the edge of two different private ownerships (between two apartments). The wall will have common ownership, as shown in Figure 5.16c. The two units have the rights to use the wall, but without causing any damage that will harm the other unit.

The *fourth type* of wall ownership is related to a wall located between private space and exclusive common space. The ownership type of the wall will be exclusive common, as shown in Figure 5.16d. The *fifth type* of wall ownership related to a wall located between private space and common space. The ownership type of the wall will be common ownership, as shown in Figure 5.16e. The *last type* of wall ownership related to a wall located between two common spaces and the ownership type will be common ownership.

a) Façade wall has common ownership:

Name	Value
⊞ Phasing	
⊞ Pset_ElementShading	
⊞ Pset_ProductRequirements	
⊞ Pset_QuantityTakeOff	
⊞ Pset_ReinforcementBarPitchOfWall	
⊞ Pset_WallCommon	
⊞ Structural	
⊟ Wall Schedule	
CommonOwnership	Facade
CommonOwnership +	Apartment One
PrivateOwnership	
WallOwnershipType	Common
WallType	Facade
ZoneName	Facade

Center of the wall

Inner face of the wall

Outer face of the Façade wall

b) A wall is located inside a unit and has private ownership:

Name	Value
⊞ Materials and Finishes	
⊞ Other	
⊞ Phasing	
⊞ Pset_ElementShading	
⊞ Pset_ProductRequirements	
⊞ Pset_QuantityTakeOff	
⊞ Pset_ReinforcementBarPitchOfWall	
⊞ Pset_WallCommon	
⊞ Structural	
⊟ Wall Schedule	
PrivateOwnership	Apartment One
WallOwnershipType	Private
WallType	Inner
ZoneName	Wall Apartment one

■ Inner wall
■ Apartment One
■ Apartment Two
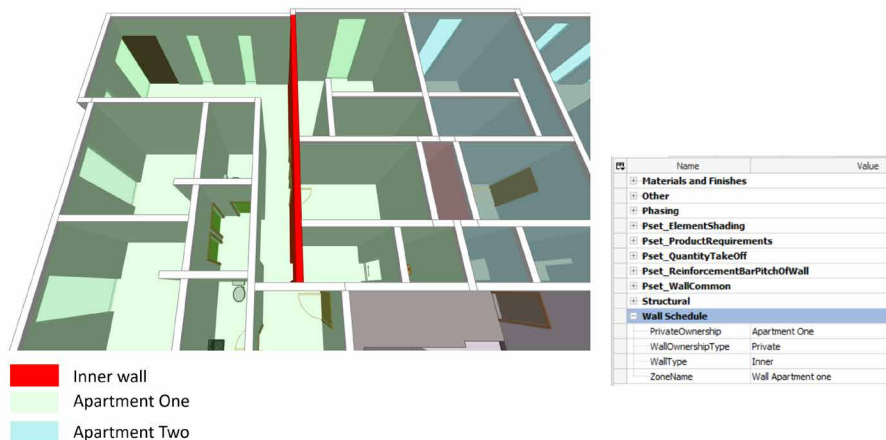
FIG. 5.16 The ownership types of the walls

c) A wall is located between two private units and has an exclusive common ownership

	Name	Value
⊞	**Pset_ElementShading**	
⊞	**Pset_ProductRequirements**	
⊞	**Pset_QuantityTakeOff**	
⊞	**Pset_ReinforcementBarPitchOfWall**	
⊞	**Pset_WallCommon**	
⊞	**Structural**	
⊟	**Wall Schedule**	
	ExclusivecommonOwnership	Apartment One
	ExclusiveCommonOwnership -	Apartment Two
	PrivateOwnership	Apartment Two
	WallOwnershipType	Exclusive Common
	WallType	Inner
	ZoneName	Wall Apartment One and Two

■ Inner wall
▢ Apartment One
▢ Apartment Two

d) A wall is located between private unit and exclusive common ownership space, and has an exclusive common ownership

	Name	Value
⊞	**Pset_ElementShading**	
⊞	**Pset_ProductRequirements**	
⊞	**Pset_QuantityTakeOff**	
⊞	**Pset_ReinforcementBarPitchOfWall**	
⊞	**Pset_WallCommon**	
⊞	**Structural**	
⊟	**Wall Schedule**	
	ExclusivecommonOwnership	Shaft Number One
	ExclusiveCommonOwnership -	Apartment One
	PrivateOwnership	
	WallOwnershipType	Exclusive Common
	WallType	Inner
	ZoneName	Wall Apartment One and Shaft Number One

■ Inner wall
▢ Apartment One
▢ Apartment Two

FIG. 5.16 The ownership types of the walls

e) A wall is located between private unit and common ownership space, and has common ownership

Inner wall
Apartment One
Corridor and stairs
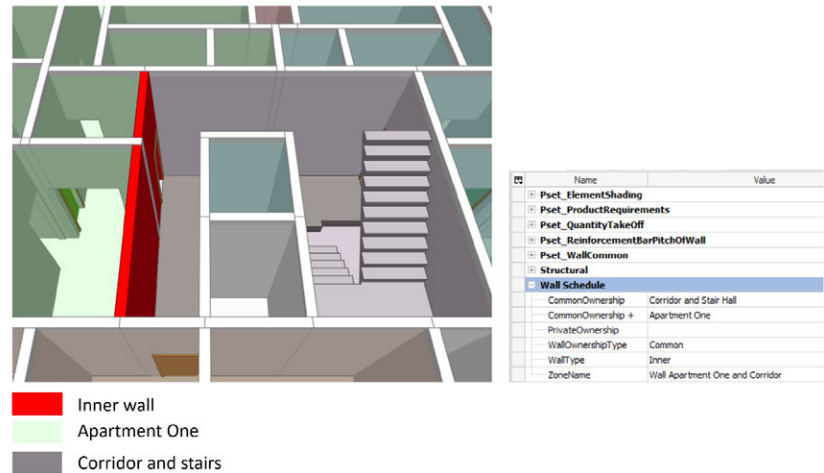
FIG. 5.16 The ownership types of the walls

5.3.6   ## Construction elements of the building: columns

The second type of construction element is the columns. They have common ownership rights. Additional attributes have been added to the columns to define the ownership, as shown in Table 5.5. Accordingly, the columns have to be created as detached columns to assign these attributes to each column separately, as shown in Figure 5.17. Adding these attributes to the columns is to distinguish between the columns that are located on the boundary of the unit and the columns that are located within the boundary of the unit. The columns that are located within the unit will be added to the calculated area of the unit.

Column common ownership information

Common Ownership

Apartment One
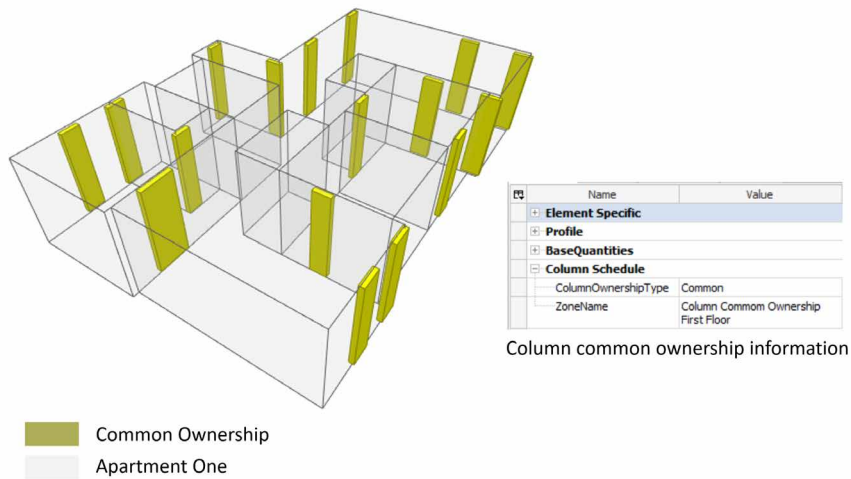
FIG. 5.17 The ownership types of the columns

5.3.7 Construction elements of the building: slabs

The last construction element is the slabs, which have different ownership rights based on their locations. Based on the current regulation of the subdivision procedures, the slabs follow the same regulations for the walls located on the boundary of units. Therefore, there are two types of ownership rights for the slabs: common ownership and exclusive common ownership. Figure 5.18 shows a slab with exclusive common ownership because it is located between two private ownership apartments.
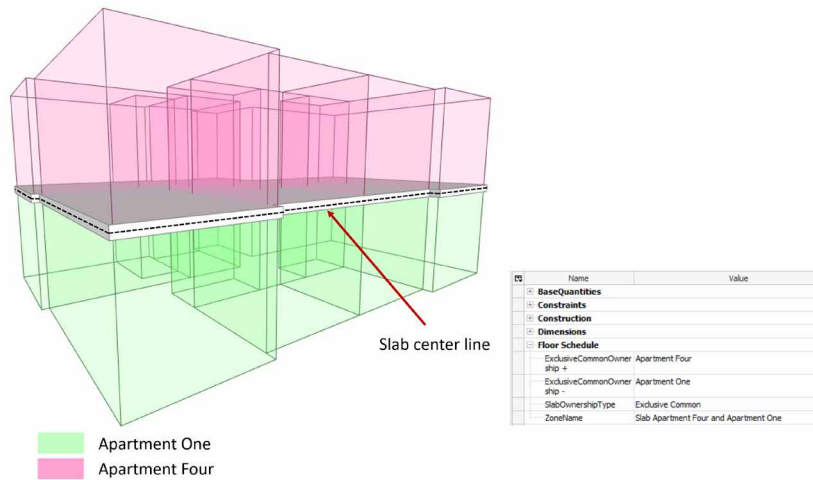
FIG. 5.18 The ownership type of the slab

<div style="text-align:center">

5.4 3D country profile for apartment units

</div>

The development of the 3D country profile of Saudi Arabia started by updating the 2D country profile that has been proposed by (Alattas et al. 2020). The development of the 2D country profile emphasized the relationship between the involved stakeholders in property registration in Saudi Arabia. There are four stakeholders (Ministry of Municipal and Rural Affairs, Ministry of Justice, Real Estate General Authority, and Ministry of Housing) with different responsibilities during the registration procedure. Therefore, several steps have been followed to develop the 2D country profile based on their relation.

5.4.1 Extending the 2D country profile to the 3D country profile

The authors have developed the 3D country profile based on the update of the earlier developed 2D profile (see Chapter 4) and added classes, associations and code lists to meet the needs for 3D volume registration. According to the draft methodology of developing country profiles (Kalogianni et al., 2020) based on ISO19152, one of the

initial steps is the mapping of the classes of the existing land administration system in Saudi Arabia with the LADM concept. Based on this mapping, it was selected which classes shall be used, which are not relevant for this country profile and others that should be added to address the needs of the country. Therefore, Table 5.6 represents the main classes of LADM that have been used for the development of the 3D country profile.

TABLE 5.6 The LADM classes that have been used for the development of the 3D country profile

LADM package	LADM class	Included or not Included
	VersionedObject	Included
	LA_Source	Included
Party Package	LA_Party	Included
	LA_GroupParty	Included
	LA_PartyMember	Included
Administrative Package	LA_RRR	Included
	LA_Right	Included
	LA Restriction	Included
	LA_Responsibility	Included
	LA_BAUnit	Included
	LA_Mortgage	Included
	LA_AdministrativeSource	Included
	LA_RequiredReIationshipBAUnit	Not Included
Spatial unit Package	LA_SpatialUnit	Included
	LA_SpatialUnitGroup	Not Included
	LA_LegaISpaceBuiIdingUnit	Not Included
	LA_LegalSpaceJtilityNetwork	Not Included
	LA Level	Included
	LA_RequiredRelationshipSpatialUnit	Not Included
Surveying and Representation Subpackage	LA_Point	Included
	LA_SpatialSource	Included
	LA_BoundaryFaceString	Included
	LA_BoundaryFace	Included

According to the new attributes that have been proposed in Section 5.3 to define the ownership of the spaces and the construction elements, the SA_BAUnit, SA_Right, and SA_Party classes of the administrative package have new attributes, as shown in Figure 5.19. At the class SA_Right, the attribute 'type' takes values from the code list LA_RightType, which has three values: private ownership, common ownership, and exclusive common ownership. The SA_Party class has four additional attributes: name, nationalID, nationality, and IDType. The attribute 'Nationality' takes values from the code list SA_NationalityType, representing different nationalities such as Saudi and Gulf countries.

The SA_SpatialUnit is an abstract class, and it has three additional attributes, from those defined in the ISO 19152:2012 UML: districtNo, districtName, and city. The SA_Level class is used to present the three levels of property representation: level zero for the parcels, level one for the building units, and level two for the construction elements, as shown in Figure 5.20. The SA_ConstructionElement is an abstract class, and it has a generalization association with the SA_SpatialUnit class. What is more, it has a constraint associated with the property representation level, thus representing level two of the SA_Level class. The SA_ConstructionElement has three subclasses: SA_Wall, SA_Column, and SA_Slab.

Furthermore, the SA_Building class has a generalization association with the SA_SpatialUnit, and it has three additional attributes from those stated in the ISO UML: reference, type, and numberOfFloor. The reference attribute has the value of GM_Point, and the attribute 'type' takes values from the code list SA_BuildingType, representing several types of buildings, such as residential, commercial, and industrial. Additionally, the SA_Building class has a composition association with SA_ConstructionElement. The SA_BuildingUnit class is an abstract class, and it represents the spaces of the building; it has three subclasses: SA_MainUnit, SA_AmenitiesUnit, and SA_SharedAreaUnit, and two additional attributes are added: floorNo, and area. The SA_MainUnit class represents the main type of spaces, and has five attributes: type, propertyNo, percentageOfThePropertyAreaToTheParcelArea, propertyShareFromTheParcelArea (Sq.M), ownershipBoundary. The attribute 'type' takes values from the code list SA_UnitType, representing several types of units such as office, apartment, shop, and clinic. The SA_AmenitiesUnit class represents the services spaces, and it has three attributes: type, AmenitiesUnitNumber, and AmenitiesUnitLevel.

The SA_SharedAreaUnit class has one attribute 'type', which takes values from the code list SA_ShareAreaType. The attribute 'type' has the value SA_ShareAreaType, representing the services area type such as stairs, lifts, corridors, entrance, and parking.

Moreover, the SA_BuildingUnit class has two associations '+/-' with the classes SA_Wall, SA_Column, and SA_Slab to represent the spaces located right and left of the construction element to define the right type of use for the construction element. The SA_LandParcel class has a generalization association with the SA_SpatialUnit class, and it has five attributes: parcelNo, area, ownershipBoundary, type, reference. The attribute 'type' takes value from the code list SA_landUseType, representing the land's use type, such as residential apartment buildings and government areas. Figure 5.21 presents the code lists of the 3D country profile.
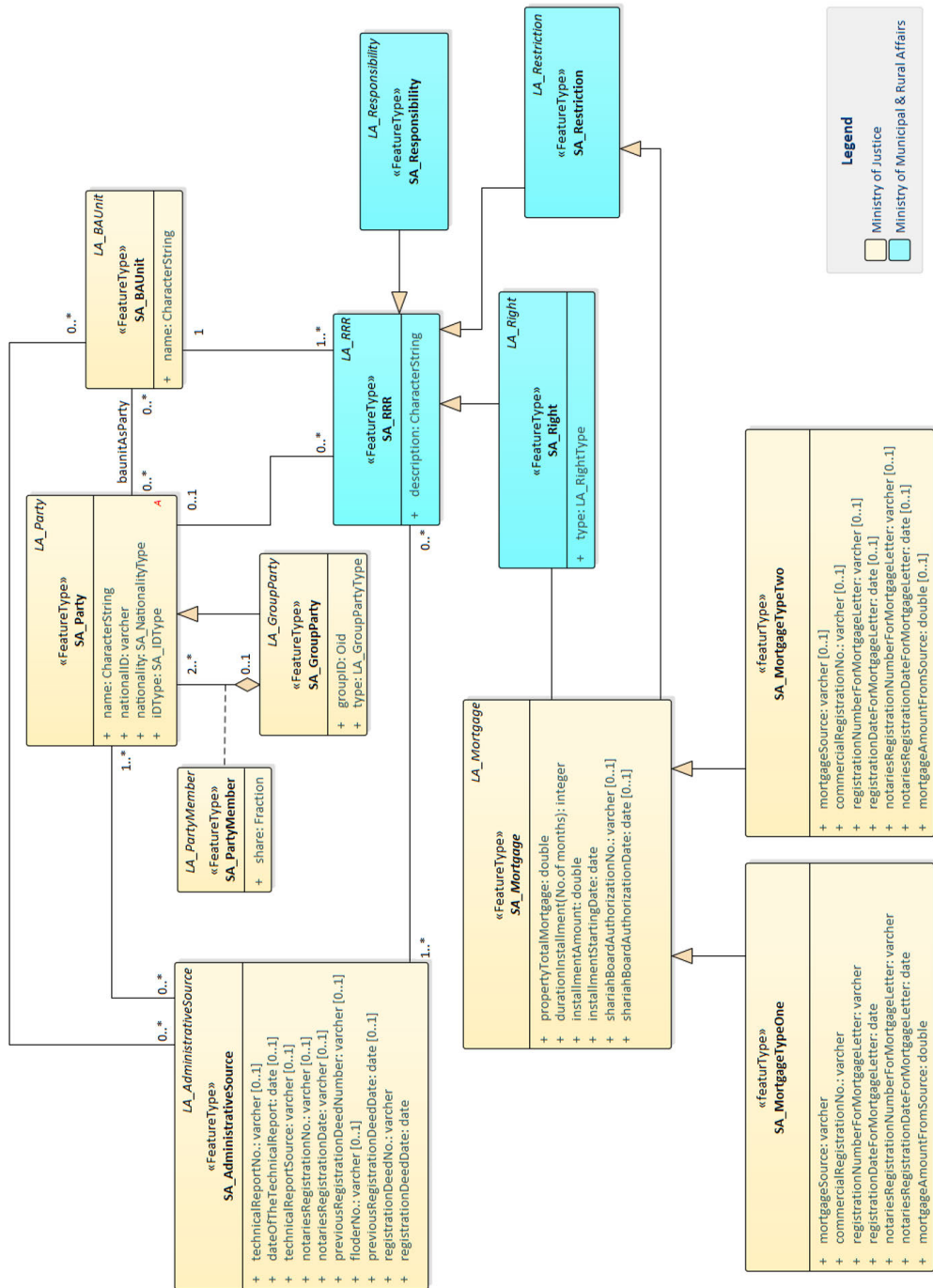
FIG. 5.19 Party and administrative package of the 3D LADM-based country profile

FIG. 5.20 Spatial package of the 3D LADM–based country profile
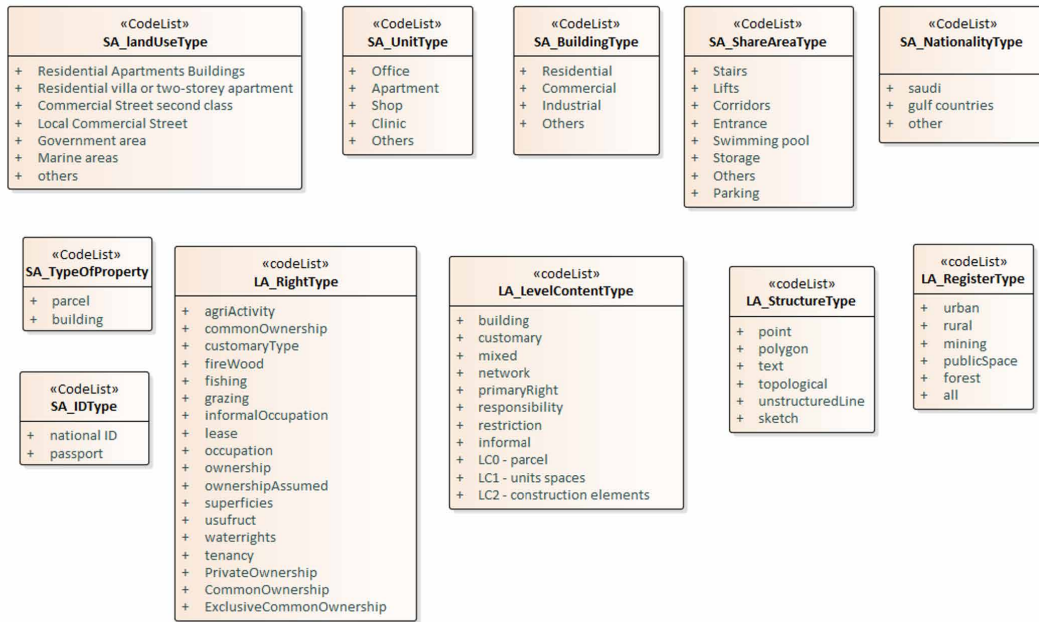
FIG. 5.21 Code lists of the 3D LADM–based country profile

5.4.2 Instance-level diagrams for the 3D country profile

The first instance level diagram represents private ownership for apartment one and their amenities unit, as shown in Figure 5.22. The diagram shows that the party has the right of private ownership for apartment one and the parking lot. The SA_BAUnit has associations with the SA_MainUnit and the SA_AmenitiesUnit classes to attach the private right of the ownership. The SA_MainUnit and the SA_AmenitiesUnit have a composition association with the SA_Building to represent the relationship between the apartment and the amenities and the building. Additionally, the SA_Level class is defining the level of this diagram as level one type for building unit.
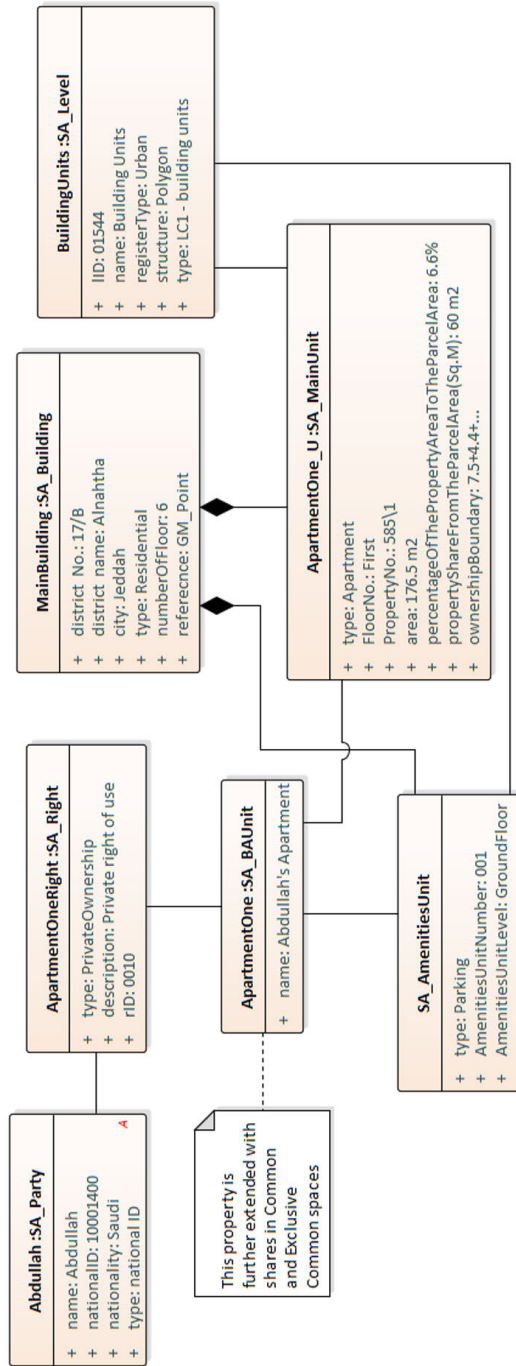
FIG. 5.22 Instance level diagram for private ownership for apartment one
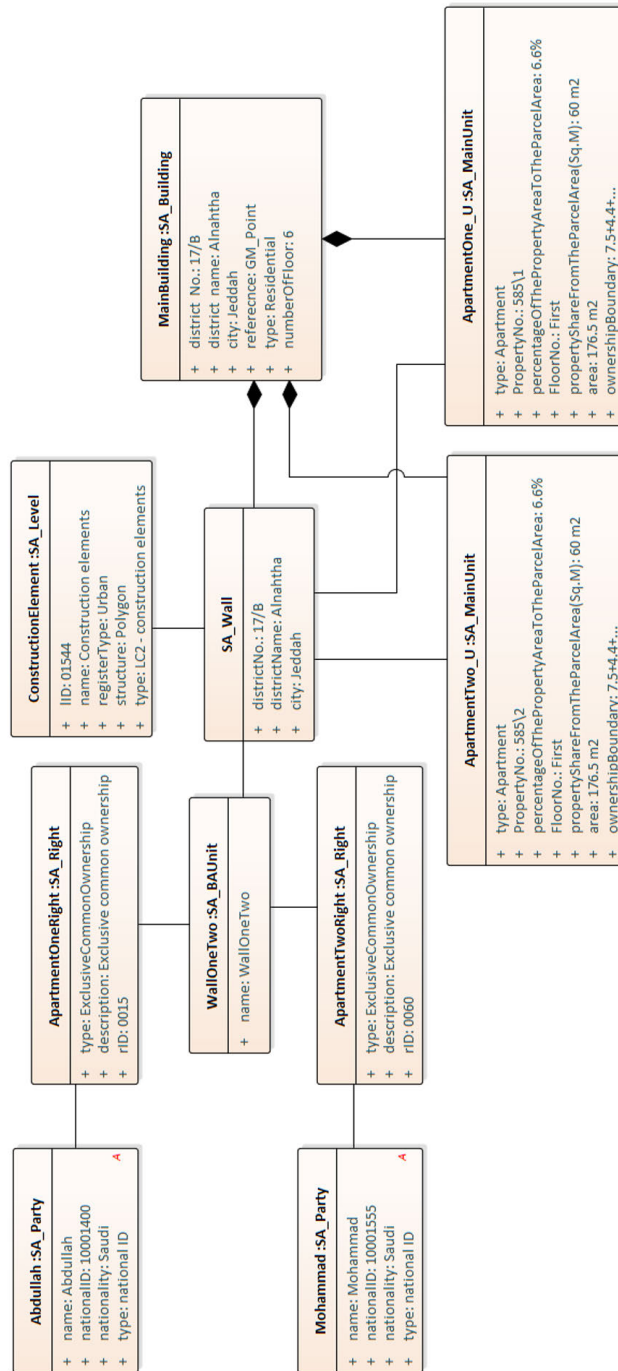
FIG. 5.23 Instance level diagram for exclusive common ownership for wall

The second instance level diagram shows the exclusive common ownership for the wall located between two private units, as shown in Figure 5.23. Each party has induvial exclusive common ownership right to the wall, and these rights are registered in the SA_BAUnit. The SA_BAUnit has an association with the SA_Wall to attach the right. Then the wall has associations to the apartment one and two to represent the two private units that are neighboring the wall form each side. The two SA_MainUnit classes and the SA_Wall have a composition association with the SA_Building to show that the main units and the wall are part of the building. Then, the SA_Level has an association with the SA_Wall to represent the level type which is, in this case, a construction elements level.

Two options are presented through instance level diagrams representing common ownership for a shared parcel for several parties: 1. Parties having common ownership to the parcel or 2. Common ownership of parcels attached to the apartments (SA_BAUnit), which are in turn owned by parties. In the first option, the parties have direct common ownership to the parcel, as shown in Figure 5.24. Each party has a private ownership right to an apartment, and this right is registered in a separate SA_BAUnit class. All the parties have an association with SA_GroupParty to represent them as group that have common ownership right for the parcel by having an association with the SA_Right class. Then, the SA_Right has an association with the SA_BAUnit to register the right. Moreover, The SA_BAUnit has associations to the SA_LandParcel and the SA_Building to attach the common ownership right.

The second option to register common ownership for a parcel where each BaUnit (apartment) is a party, is depicted in Figure 5.25. The SA_BAUnit class for each apartment has an association with SA_Party that represents a baunit as a party such as BauApartmentOne, then each of the SA_Party has an association with the SA_GroupParty class. The group of parties has common ownership right for the parcel by having an association between the SA_GroupParty and the SA_Right. Then, the Right is registered in the SA_BAUnit class. The SA_BAUnit has associations to the SA_LandParcel and the SA_Building to attach the common ownership right.
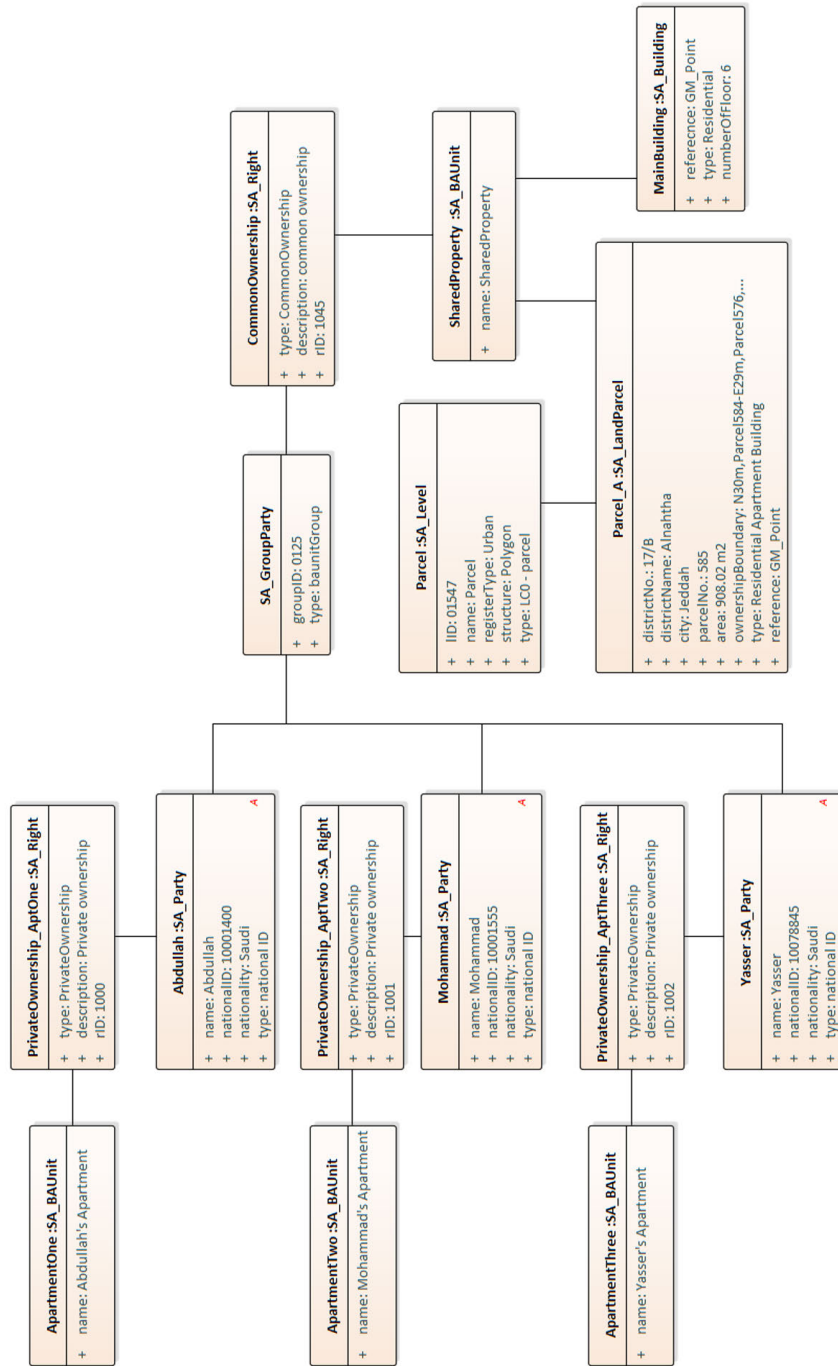
FIG. 5.24 Instance level diagram for direct common ownership for a shared parcel for multiple parties
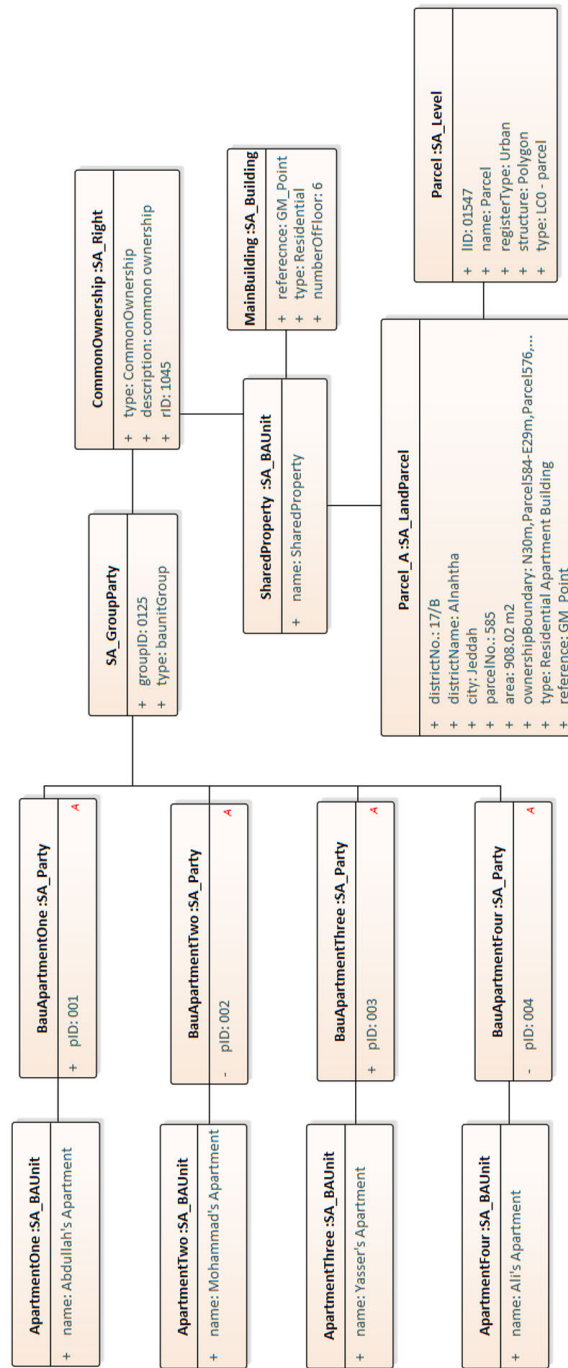
FIG. 5.25 Instance level diagram for a common ownership for a parcel where the BAUnit is a party

5.5 Summary

This chapter deals with mapping the 3D representation of the building unit's subdivision procedures (from a case study in Saudi Arabia) to the LADM concept. The mapping from IFC to LADM builds on existing knowledge and experience, as presented in Section 5.3. In addition, it introduces a novel approach for refining models with the buildings' spaces, highlighting three main types of spaces: private spaces, common spaces, and exclusive common spaces.

Considering the wide recognition and the adoption pace of BIM, this chapter reflects on the recent research on the potential role of reusing BIM/ IFC files in buildings' lifecycle and specifically on exploring the use of IFC files as input to 3D cadastral solutions to support the registration of multi-level properties and apartments (Kalogianni et al., 2020). Therefore, two general approaches have been observed: enriching IFC files with legal information or extending LADM with physical counterparts. The work presented in this chapter is a hybrid approach of the two aforementioned ones, as the 3D model (IFC) is being structured in such a way to be able to provide also the legal information, while the LADM-based country profile has been extended with physical counterparts.

The approach is based on the current regulations of the subdivision procedures, which include different regulations about the unit subdivision rules, such as the building type, calculating the unit's area and their boundaries, and the ownership types of the private, common, and exclusive common spaces. However, applying these procedures on 2D models does not provide a better understanding of the relationship between the subdivided units and the common spaces in all directions (horizontal and vertical).

The current regulations do not describe the relationships between the units in detail, affecting the quality of the subdivision procedures. Therefore, the 3D representation of the building unit's subdivision procedures has been developed to cover more information during the registration of the building's legal spaces and mapped to LADM concepts. In this scene, the first step was to assess and analyze a 3D IFC model for a real-world complex building to implement the current subdivision procedures.

It is underlined that according to the regulations, several issues that arise related to the 3D IFC model have been addressed to apply the building unit's subdivision procedures:

— The first issue was related to the spaces of the building. In the IFC model used in the use case, only the building's construction elements were modelled, while the spaces of the building were not included and were added to provide the volume of the spaces.

— The second issue was related to the floor slabs of the building. Each floor had one slab covering the entire floor without considering the boundary of the private units and the common spaces.

— Additionally, the 3D model did not include the underground water tanks, which need to be added, as in Saudi Arabia, every water tank is related to a specific private unit.

Furthermore, additional attributes and associations were introduced to attach the ownership rights to the spaces, such as 'property type,' 'property No,' 'ownership type,' 'service area type,' and the 'ZoneName.' Furthermore, the spaces of the building had been included in associations to define the adjacent units. At the building's construction elements, new attributes have been included, such as 'type,' 'ownership type,' and 'ZoneName' to define the ownership of each element based on their location. Other associations were also introduced to define the adjacent spaces of the construction elements. The additional attributes and associations that have been introduced to the spaces and the construction elements allow defining several ownership types for the walls and the slabs in both directions. Therefore, it is concluded that with the representation of the current regulation of the subdivision procedures in 3D, the ownership rights can now be better defined, as they include more information about each space of the building. Finally, following the developed 3D profile, the approach is validated by creating instance-level diagrams for different ownership types. This chapter has answered the sub-question "Q2. What is the status of Land Administration in 3D indoor environment in Saudi Arabia?". The content of this chapter has provided a methodology that can be used for other countries to develop their 3D country profile. In this chapter, a complete description of how to use BIM models for the registration of the ownership has been introduced to provide a better representation of the legal spaces of the building based on LADM.

6 Combined LADM and IndoorGML conceptual model

In chapters 4 and 5, the development of the 2D and 3D country profiles to define ownership/relationship of indoor spaces based on the rights, restrictions, and responsibilities of parties were presented. This chapter investigates the development of the combined use of IndoorGML and the LADM to define the accessibility of the indoor spaces based on the ownership and/or the functional right for use. The relationship between the user and the indoor space depends on the type of the building and the function of the spaces. The indoor spaces of each building have different usage functions and associated users. By defining the user types of the indoor spaces, LADM makes it possible to establish a relationship between the indoor spaces and the users. Navigation path computation should take into account the access rights of a specific person at a given time. Each user of the indoor environment may have different access rights that affect the navigation path. Further, the same user could have different access rights if the time of navigation has changed. The accessibility of the spaces depends on the user's RRR and time.

The chapter is structured as follows: Section 6.1 presents the accessibility of the space. The similarities and differences of LADM and IndoorGML are presented in section 6.2. Section 6.3 illustrates the development of the integration model. Section 6.4 introduces the developments of the LA_Party package. Section 6.5 shows a case study for two different university buildings based on the integrated model. Navigation examples using the Rights, Restrictions, and responsibilities are illustrated in section 6.6. Finally, section 6.7 summarizes the whole chapter.

6.1 Space accessibility

There are many types of buildings, such as educational, shopping centers, public transportation, residential, and hospitals, where each has different types of users. The indoor environment of each type of building is unique and has many relationships between spaces and users. The indoor space for each building is defined according to physical boundaries, such as floors, walls, and ceilings. However, the indoor spaces are not subdivided according to their accessibility for different users. As mentioned in chapter 2, there are many approaches to subdivide the indoor spaces and none of these approaches have considered the accessibility of the indoor spaces based on the user type.

Currently, navigation inside buildings is performed to reach different destinations based on the user's desire. However, in reality, each indoor environment has indicators that are based on the rights, restrictions, and responsibilities of the user and space. In each indoor environment, there are spaces are accessible for all types of users, and there are spaces are accessible for some of the users. Therefore, to provide an effective navigation for different types of users, the indoor environment, and the space-user RRRs must be considered. Thus, when space subdivision process according to the effect of RRR, the result will enhance the navigation based on the actual user access to spaces.

Each space has different usability characteristics, which leads to different relations between users and spaces. According to these relationships, the NavigableSpace has different rights, restrictions, and responsibilities, based on an individual or group of users. To be able to define the rights, restrictions, and responsibilities based on the users and the spaces, it is important to find a method that is based on a well-known standard that has the ability to assess the relationship between the user and the space to define access rights for each user.

Therefore, the integration between LADM and IndoorGML will provide indoor navigations route for the users according to their relationship with the indoor spaces. LADM defines the relationships between the users and the spaces by defining the rights, restrictions, and responsibilities for each space based on the relationship between the users and the spaces. Then, according to the access rights, IndoorGML generates the indoor navigation routes based on the user's accessibility.

LADM can cover a wide scope of information that is related to our daily life activity in educational or medical institutions, transportation hubs, shopping malls, etc.

This includes a great deal of information that is relevant for navigation access rights for specific types of buildings. For example, for educational buildings, such as universities, it can be related to: student groups/cohorts, staff groups/departments, on individuals (staff, students, visitors), on lecture schedules, on room/desk assignments, on opening/access hours for various parties, on meeting room reservation, etc. Thus, this is very broad, but, in reality, it is already used in practice (perhaps not in one system, but it is good that there is a conceptual model including all of these aspects). We assessed the conceptual model, by adding instance level (real) data to the model for a number of real-world cases. We further showed how data from this model can be used to do routing, which takes into account the access rights of a specific user. Furthermore, this chapter shows how data from this model can be used to do routing, which takes into account the access rights of a specific user.

6.2 Similarities and differences of LADM and IndoorGML

The two standards have been developed for different purposes (navigation vs. land administration) and have different scope (indoor vs. indoor/outdoor, above/below surface). The two standards have many differences and similarities (Zlatanova et al., 2016). The similarities between the two models are:

— Both models (can) deal with semantically annotated 3D spaces, which have properties.

— Both models operate with abstract spaces. Abstract spaces in IndoorGML can be defined on the basis of user or environment properties. Abstract spaces in LADM are based on legal regulations. Similarly, IndoorGML allows subdivision and aggregations of spaces, such as accessibility, security, etc. The same is true in LADM: legal spaces can be grouped in LA_BAUnit or LA_SpatialUnit and organized in a hierarchy.

— Both models have a notion of primal space with geometry and topology. The 3D partitioning of LADM can be seen as primal space. LADM maintains links to external classes, of which some are mentioned in annex K of the standard: building units, utility networks. IndoorGML provides links to CityGML, IFC, and KML.

— Both models can support several subdivisions of space. The mechanism in IndoorGML is by defining specific space layers. LADM abstract subdivisions are embedded in the conceptual schema (and called LA_Level).

— Both models maintain relationships between objects. LADM supports extensive set of relationships and constrains. Spatial relationships can be based on topology but could be also without topology (just geometry or even textual descriptions). IndoorGML does not have specific notions of constraints between objects, but rather topological relationships (i.e., adjacency and connectivity) are used to derive the dual space.

There are also a number of significant differences:

— LADM is only a conceptual schema, while IndoorGML has XML implementation.

— IndoorGML requires non-overlapping subdivision of spaces, LADM may have overlapping abstract spaces, but spatial units that are related to full ownership may not overlap with each other (but these might overlap with a spatial unit related to a certain restriction; e.g., because of an environmental protection zone).

— IndoorGML maintains primal and dual space, while LADM has only primal space.

— LADM models legal and administrative concepts, such as ownership rights of spaces that are related to certain (group) parties. IndoorGML might use such rights to specify subdivision, but no explicit space layer has been developed so far.

According to the similarities and differences of the standards, LADM could be applied to determine a framework for space subdivision. As discussed in Chapter 5, LADM is not only about ownership rights, but also about rights to cover various relationships between spaces and parties, including those that cover the function rights of indoor spaces to determine the accessibility for the parties based on RRRs for the IndoorGML. The topological spatial units do not have gaps or overlaps in the partition in LADM.

The rights, restrictions, and responsibilities, and the administrative unit play a critical part during this process. We explore the combined use IndoorGML and the LADM by creating a link that connects each navigable space of IndoorGML to the corresponding LA_SpatialUnit of the LADM without adjusting IndoorGML and LADM. As a navigable space in IndoorGML can correspond to various spatial units of the LADM (and vice versa), a many-to-many association is needed. In this way, it is possible to model or to subdivide the spatial units in the LADM. Via LA_BAUnit, the

associated rights and parties can be obtained (for navigable spaces linked with a LA_SpatialUnit). Note that in order to be able to use one-to-one correspondence, each space of IndoorGML would need to be defined based on the constraint terms of the spatial unit of the LADM (and vice versa), which is considered as less convenient. The combined use model will determine indoor space rights, and that will perform efficient navigation.

6.3 Methodology to develop the combined model

To illustrate the concepts, this chapter concentrates on an educational building that has different types of users, such as students, employees, and visitors, and they have functional rights to use the spaces of the building. These rights do not have a legal foundation, but they are still based on the classes of the LADM, representing rights, restrictions, and responsibilities.

The rights, restrictions, and responsibilities affect the motion of users (use, manage, transfer, add, receive) in indoor spaces by regulating the access and use of space. Figure 6.1 represent a general overview of the combined use model of the LADM, IndoorGML, and an external party database. IndoorGML associates spatial data that contains information about primal space and the external database associates information about users. The LADM associates the subdivision of the indoor space to IndoorGML, based on the rights, restrictions, and responsibilities.
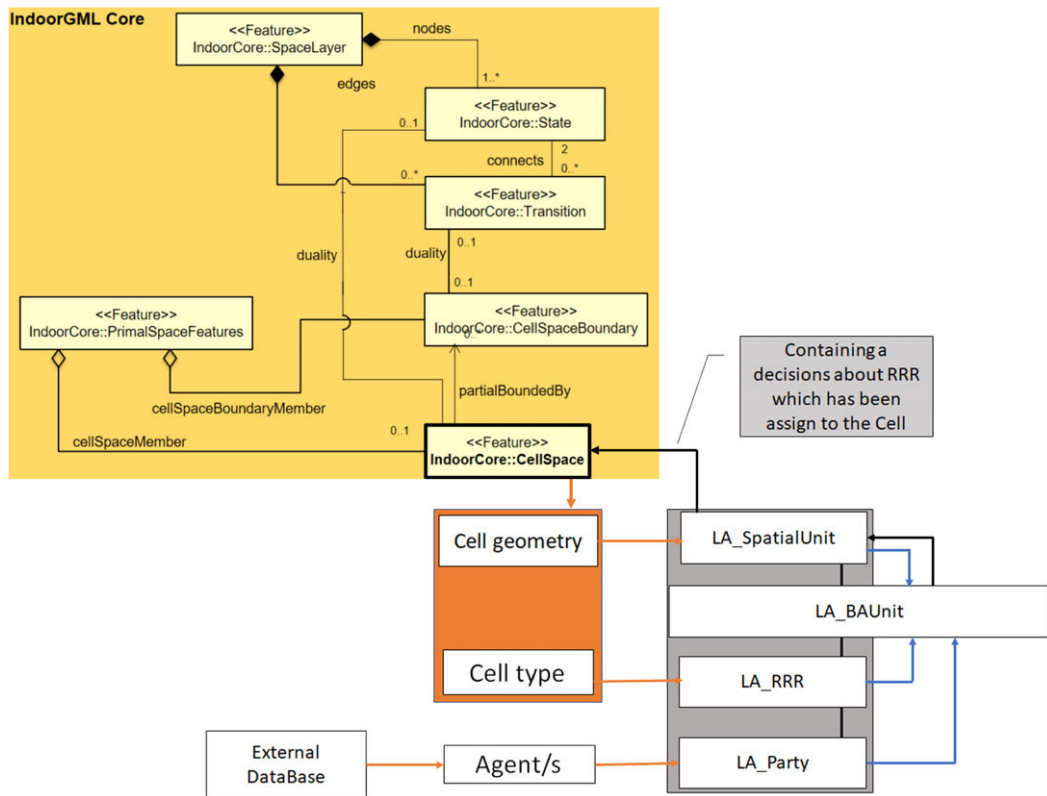
FIG. 6.1 The combined use process for IndoorGML and the LADM.

The major link between the spatial features of indoor space from the CellSpace class in the IndoorGML to the Spatial Unit Package in the LADM is modelled as an association. The association provides the identification (cell number) and the function of the cell. The spatial information of the cell collected by LA_SpatialUnit and the cell function information gathered by the LA_RRR. The user's information is associated from an external database (with person information) to the Party Package. The LA_BAUnit, collects the information that is to be registered based on the LA_Right class information and LA_SpatialUnit. Based on the registration of information, the LA_BAUnit and LA_SpatialUnit associate the subdivision of indoor spaces (NavigableSpaces) to the cell space in IndoorGML.

Each type of building has a unique indoor space, which is represented by a variety of cells in IndoorGML. Each cell has a unique ID and a type of function that is used during the navigation process. IndoorGML provides this information with the cell geometry to the LADM to create a subdivision of the indoor space (NavigableSpaces),

according to the RRRs. To apply a subdivision of the indoor spaces, an analysis has to be performed of the indoor space (NavigableSpaces), based on the type of building (hospital, educational, shopping mall, institutional building, etc.) and the type of users (doctors, nurse, students, visitors, customers, etc.). The relationship between the indoor space and the users defines the functional use rights.

The LADM classifies the GeneralSpaces and the TransferSpaces into categories that are based on the RRR of each cell. LADM uses the LA_RightType (with possible values in a code list) and the associated parties to classify the indoor space to a different type of cells, each type having different functional rights, as shown in Figure 6.2.
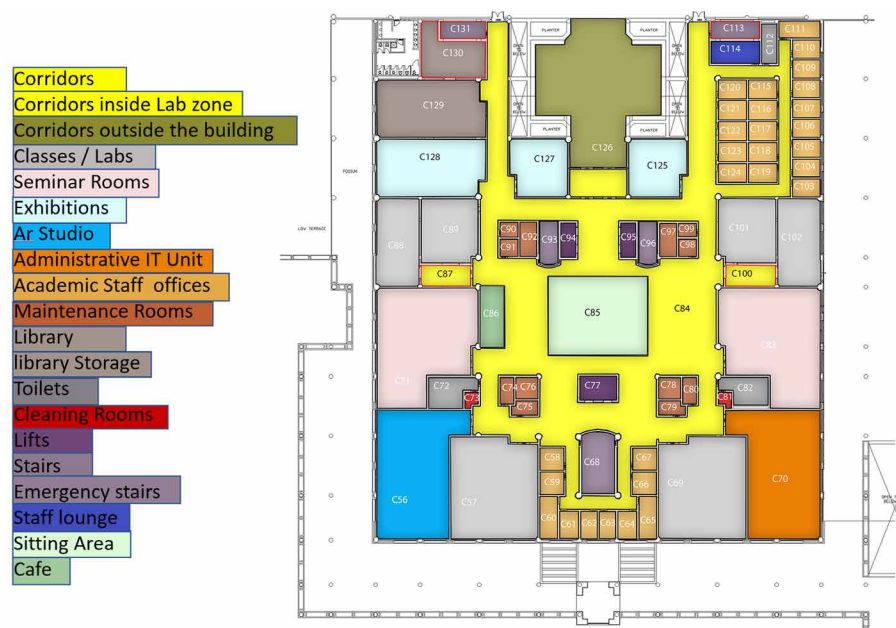
FIG. 6.2 Classification of different types of cells based on rights, restrictions, and responsibilities and the usage function of the space.

According to the parties' rights, there are two type of cells that are categorized as (1) cells that have private rights for individual, or groups of, parties, and (2) cells that have common rights for individual, or groups of, parties. The first category means that a specific individual or group of a party has the right to use the cell, while the second category shows a common right may exist between the users. The LADM uses the same method to subdivide each cell into smaller cells that contain private rights for the individual party. For example, LADM divides an administrative

department into offices, and each office held some certain rights for individual, or groups of, parties, and then divide the office into smaller cells representing each desk space and their rights based on the party, as shown in Figure 6.3. The result of the classification represents the relation between private rights cells and common rights cells, based on the user's activity. The LADM requires the information about the party, which is stored in an external database. The user's type is determined according to the kind of the building which consists of different kinds of groups of parties.
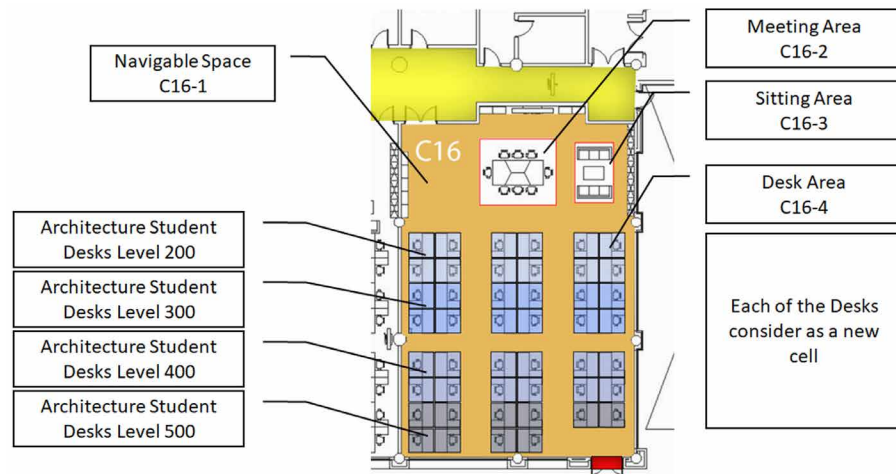
FIG. 6.3 Division of the cell into smaller sub-cells based on functional use rights.

In order to start the combination, the cell space transfer the indoor space data to LADM. As shown in Figure 6.4, the cell space in IndoorGML provides the spatial information about the indoor space type to LA_SpatialSource, which is a class of surveying and representation subpackage. The LA_SpatialSource is responsible for gathering/documenting spatial source information for the LADM, and the LA_SpatialSource has a relation with LA_Point, LA_BoundaryFaceString, and LA_Boundary Face to cover all kinds of spatial data. LA_SpatialSource associates the spatial information to LA_SpatialUnit. Based on the information, the LA_ SpatialSource carries the role of surveyor or architect of the spatial source to LA_ Party and a description of the extent of the property via LA_SpatialUnit to LA_BAUnit.
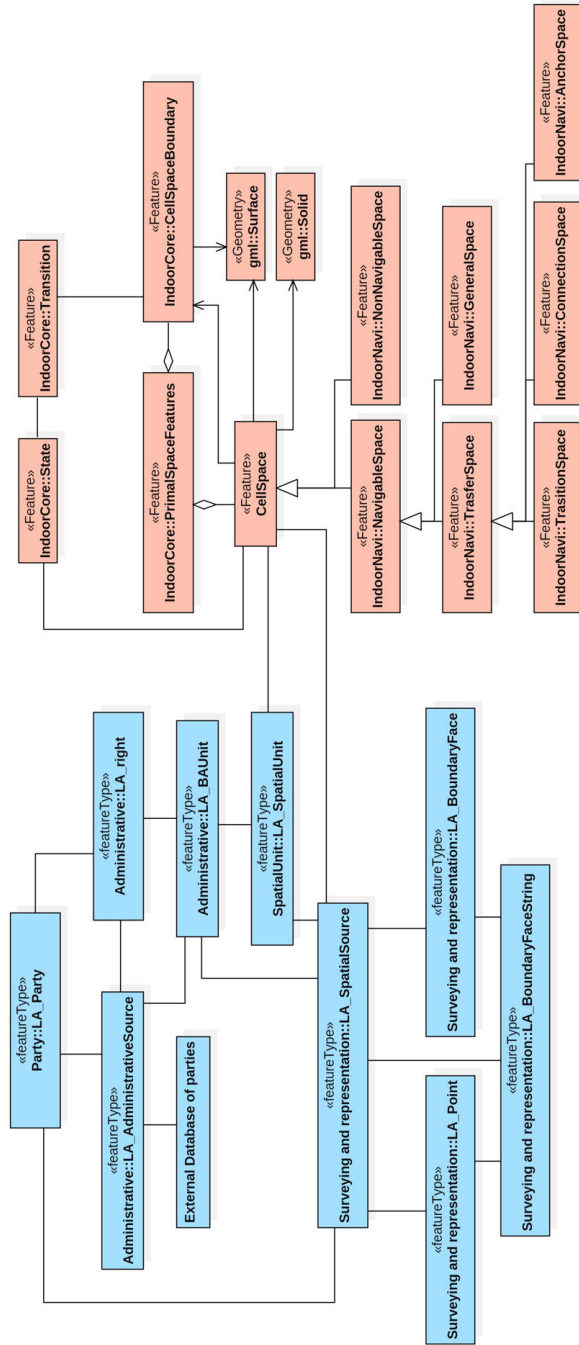
FIG. 6.4 Combined LADM-IndoorGML conceptual model, the LADM classes are in blue and IndoorGML classes are in coral.

On the other hand, LA_AdministativeSource is a subclass of LA_Source that provides the party information to LA_Party and specifies the party that plays the role of the conveyancer. The LA_AdministativeSource documents the origin/source of right, restrictions, and responsibilities for LA_BAUnit, and a description of the rights, restrictions, and responsibilities that are held by a party and affect the LA_BAUnit for LA_RRR.

6.4 Developing the LA_Party package

The Party Package represents the party information and consists of the class LA_Party and the subclass LA_GroupParty, and the LA_PartyMember, which is an optional association class that is located between the LA_Party and LA_GroupParty. The current LA_Party class has several attributes, such as the ID number of the party, the type of party, and the party role type. For situations where the party is not an individual, the LA_GroupParty defines the group ID and the group party type. Additionally, the Party Package contains code lists that are used to represent lists of values for Party Package attributes.

Based on the case studies, the party information was divided into three categories, students, employees, and visitors (either at individual or group level), see Table 6.1. Each category had several necessary attributes, such as for students, the educational programs, and educational levels. For the employee category, there are different attributes that are based on party function/career; for example, there are academic staffs, administrative staffs, and security staffs. The Party Package could not represent the needed information correctly by using the existing attributes and requiring the extension of the code lists of the LA_Party class or the LA_GroupParty subclass. Thus, to properly cover all information of the three categories (student, staff, visitor), we explored different modelling options to extend the expressiveness of the Party Package. Two of the options will be presented and discussed: *Option A* (just adding Attributes to LA_Party) and *Option S* (adding Subclasses to LA_Party and LA_GroupParty).

The *Option A* model includes additional attributes in LA_Party class, which are: *party employee type, party department type*, and *party educational level,* as shown in Figure 6.5a. Each attribute has a code list that represents the allowed values. For the attribute *party employee type*, the code list includes academic staff, administrative

staff, security team, cleaning team, and maintenances team. The code list of the attribute *party department type* contains architecture, landscape, geomatics, urban (and for certain students also the values orientation year and student mix departments), and not related to faculty. The last additional attribute is *party educational level*, which includes the following code list values: bachelor, master, and PhD.

The subclass LA_GroupParty is kept without any modification to represent the group ID and the group role type. By including the additional attributes to the LA_Party class, this option supports the representation of the individual party. However, this simple extension could lead to the misuse/confusion of the model in certain cases. For example, the representation of the employee's types, educational program, and educational level information in the LA_Party class cannot be used for all the categories of parties (staff, student, visitors). This disorder is caused as a result of trying to represent all types with only one class. Moreover, the same information will be repeated to all parties that are sharing the same information (e.g., staff members of same department of students of the same cohort), and that will increase the size of the data when access rights are stated for every individual party. The advantage of option A is that it is relatively simple.

The *Option S* model tries to avoid the problems associated with *Option A*. It first concentrates on developing the LA_GroupParty to represent each user category in the different subclass to avoid mixing the representation of the categories. The LA_Party class holds the same attributes that are similar to the original class with subclass LA_Employee, which has one optional attributes to represent the *party employee type* as shown in Figure 6.5b. The rest of information will be included in the subclasses of LA_GroupParty based on the *group party type*.

For the description of the 'students' category, a new subclass called LA_ GroupStudent is created to represent the *educational program type* and *educational level*. For the attribute *educational program type*, the code list includes values, such as architecture program, landscape program, geomatics program, and urban program. For the attribute *educational level*, the code list contains values, such as bachelor, master, and PhD. The second subclass is created to represent the employee category. The LA_GroupEmployee contains one attribute to represent the *party origination unit* which contains the hierarchy organizational levels of the organization: Level 1 represents the university, level 2 represents the faculty, and level 3 represents the departments. Note that there can be groups of groups; e.g., a number of departments to together form a faculty. Model *Option S* shows the ability to cover several types of parties by using LA_GroupParty.

Students

Staff

Visitors

Security Team

Cleaning Team

Maintenances Team

«feature Type»
Party::LA_Party

+exPId: Oid [0..1]
+name: CharacterString [0..1]
+pID: Oid
+role: LA_PartyRoleType [0..*]
+type: LA_PartyType
+employeeType: LA_PartyEmployeeType
+Department: LA_PartyDepartmentType
+EducationalLevel: LA_PartyEducationalLevelType

«featuresType»
Party::LA_PartyMember

+share: Fraction [0..1]

+parties   2..*

+groups   0..1

«feature Type»
Party::LA_GroupParty

+groupID: Oid
+type: LA_GroupPartyType

«codeList»
Party::LA_PartyType

+baunit
+group
+naturalPerson
+nonNaturalPerson

«codeList»
Party::LA_GroupPartyType

+association
+baunitGroup
+Family
+tribe
+students
+employee
+Visitors

«codeList»
Party::LA_PartyRoleType

+students
+employee
+Visitors

«codeList»
Party::LA_PartyEmployeeType

+AcadimicStaff
+AdministrativeStaff
+SecurityTeam
+CleaningTeam
+MaintenancesTeam

Party::LA_PartyEducationalLevelType

+bachelor
+master
+PhD

«codeList»
Party::LA_PartyDepartmentType

+Architecture
+Landscape
+Geomatics
+Urban
+Non (orientation year)
+StudentsMixDepartments
+notRelatedToFaculty

«featureType»
Administrative::LA_RRR

+party   0..*
+rrr   0..*
+rrrparty   0.1
+rrr   1..*

«featureType»
Administrative::LA_BAUnit

+unit   0..*
+unitRrr   1
+unit
+baunit   0..*
+su   0..*
+suBaunit

«featureType»
Spatial Unit::LA_SpatialUnit

+baunitAsparty

a)

b)

FIG. 6.5 (a) Option A: Content of the Party Package of the first option model and the code lists to represent the party of indoor space; and (b) Option S: Content of the Party Package of the second option model and the code lists to represent the party of the indoor space.

The Party Package is flexible and straightforward based on this second option, which we further used in our research. The only drawback is that the model may look more complex due to the increased number of (sub)classes. Note that we did not add a subclass at individual level for students as there were no new attributes (all of the student attributes could be included at group level), and we want to keep the model as simple as possible. The same reasoning for not introducing subclasses for visitors (at individual or at group level). Table 6.1 represents the types of users with a description of the functional rights of each type, which is also shown in Figure 6.5b. The class LA_Party carries the party information for instances which can be either individual or group of party associated to LA_RRR.

TABLE 6.1 Represents different types of users and their type of rights

Party	Description
Individual student	Has a unique ID number and a private right to use the space
Individual employee	Has a unique ID number and a private right to use the space
Individual visitor	Has a unique ID number and a private right to use the space
Group of students	Has unique ID number and share a common right to use the space
Group of employees	Has unique ID number and share a common right to use the space
Group of visitors	Has unique ID number and share a common right to use the space

The LA_RRR is an abstract class that contains three subclasses, LA_Right, LA_Restriction, and LA_Responsibilities. The right associates between LA_Party and LA_BAUnit. LA_RRR describes the rights, restrictions, and responsibilities that affected the LA_BAUnit. LA_BAUnit collects the spatial unit that has the same rights, restrictions, and responsibilities, and the party that is attached. More than one spatial unit can be registered as part of a LA_BAUnit if all of them share the same rights, restrictions, and responsibilities. It defines the type of basic administration unit type and defines the ID number of the unit. LA_BAUnit could play the role of a party.

LA_SpatialUnit contains information about the spatial cell from the IndoorGML cell space. It defines the type and dimensions of the spatial unit. Additionally, it can provide a textual description of the spatial unit. The spatial unit can be a part of another spatial unit. The spatial unit associates the cell to the LA_BAUnit. Since the LA_BAUnit could cover more than one spatial unit in the same instance object, the LA_SpatialUnit carries the subdivision of the primal space to the CellSpace in IndoorGML.

6.5 Case study of two different university buildings

This section represents two cases study with a real data for the users and different information from the facility management for the Faculty of Environmental Designs at King Abdulaziz University, Saudi Arabia, and the Faculty of Architecture and the Built Environment at TU Delft, Netherlands (both shown in Figure 6.6) to explore the combined use model between the LADM and IndoorGML with real world data.

FIG. 6.6 (a) Faculty of Environmental Designs at King Abdulaziz University and (b) Faculty of Architecture and the Built Environment at TU Delft

6.5.1 Faculty of Environmental Designs at King Abdulaziz University, Saudi Arabia

The building of the faculty consists of five floors and four departments, namely, the Architecture Department, Geomatics Department, Landscape Department, and Urban Department. Each department includes some classrooms and labs that are located on different floors. The study starts by associates the cell information from IndoorGML (the cell space) to the spatial source subclass in the LADM. The information contains the geometry information, and each cell has an ID number with the function of the cell. The parties of the building should be specified in order to identify the functional rights for each cell using LADM. Based on the type of the building, the parties are divided into three categories: students, employees, and visitors, as shown in Figure 6.7.

Based on the relationship between the users and the function of the indoor space of the building, the NavigableSpaces could be divided into several types of cells that have various rights with LADM. Each color represents specific rights of use for a specific party or groups of parties, as shown in Figure 6.8. To build the 3D model of the Faculty of Environmental Designs at King Abdulaziz University, we had to start by collecting information about each indoor space of the building, such as architectural 2D plans, and the function of use for each room. The next step is to use software called Revit (Autodesk software) to build the 3D model and to define the 3D space for each room. The software allows creating a schedule to store all the information about the space, such as the name of the space, the 3D volume, usage function, space number, and the space level. By exporting the 3D model from Revit to the IFC extension, the 3D space of each room is connected to the schedule and is ready to be classified based on the usage function of the space. Solibri Model Checker is a BIM software that can classify the 3D space model based on the property set. By using this feature of the software, we can connect the 3D with the schedule and represent the 3D model, as shown in Figure 6.8.
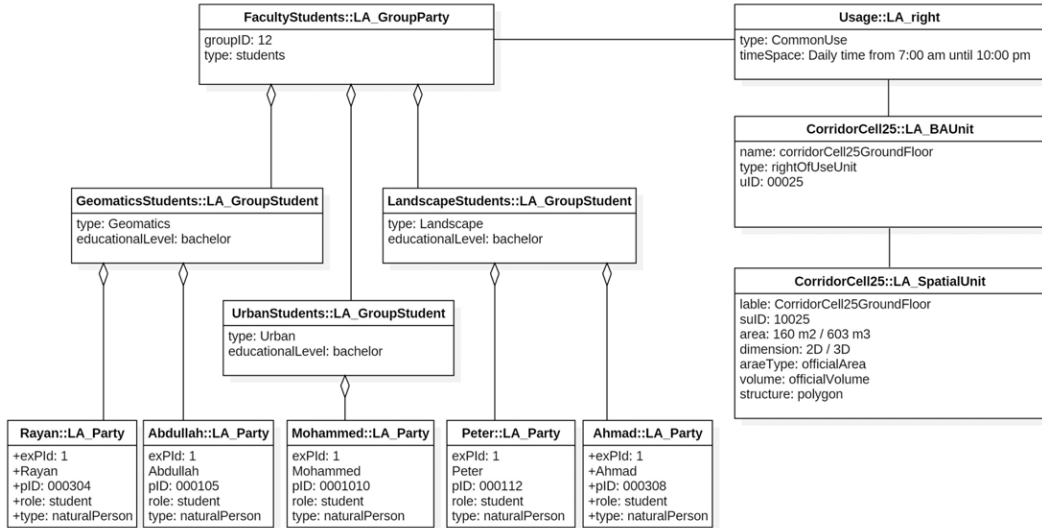
FIG. 6.7 Instance level diagram showing the party common rights based on the building type.
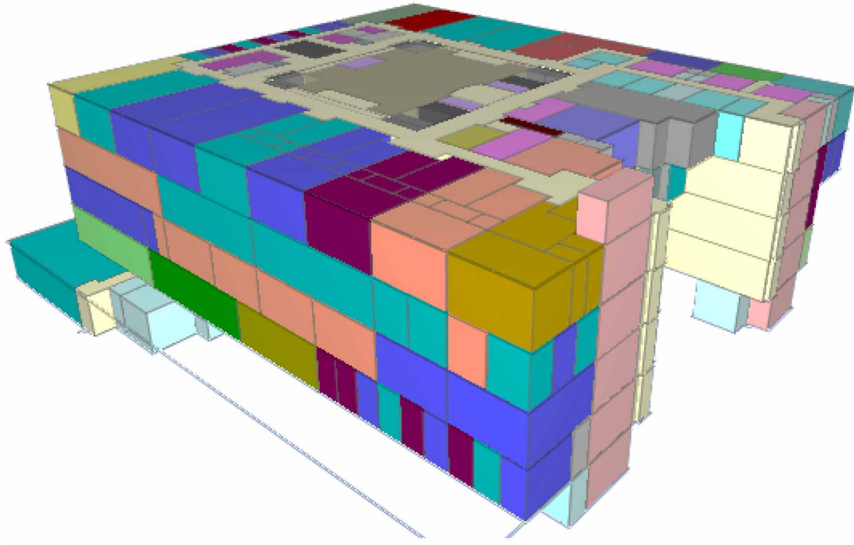
FIG. 6.8 Classification different type of cells based on functional use rights.

The next step is to extract common areas (public areas), where common rights may exist between the parties from all of the departments. Based on the relationship between the parties and the function of the cell, we could determine the common area, as shown in Figure 6.9. The sitting areas, stairs, lifts, corridors, and toilets are the common areas that all of the parties have the same right to use and no users could be excluded. The common rights areas cover around 20% of the floor area. The next step is to include one private rights areas of one specific group (department) to the common areas to represent the relationship between them, as shown in Figure 6.10.
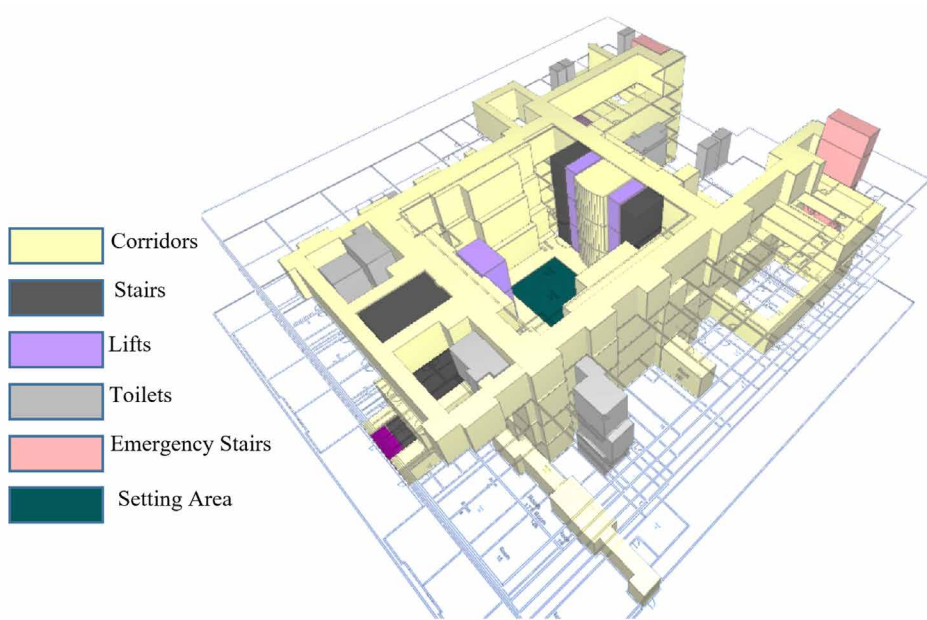
FIG. 6.9 The common rights areas based on functional use rights
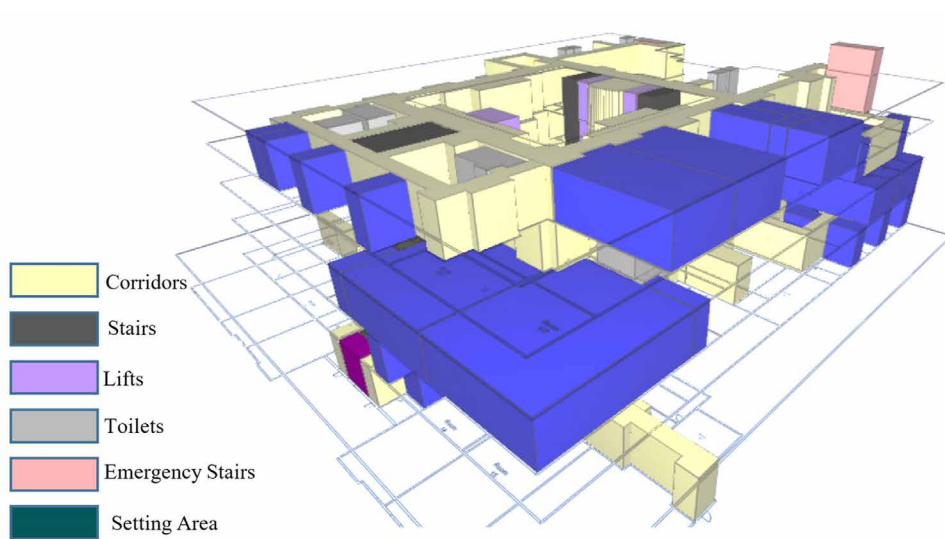
FIG. 6.10 The common rights and private rights areas of the Urban Department based on functional use rights.

The parties of the Urban Department have access to the blue cells as private rights areas with the common areas in their daily life activities. However, the rest of the floor is considered as a non-accessible area for the Urban Department. In some of the other floors parties of the Urban Department have accessibility to use the common classrooms and labs. As we mentioned before in Figure 6.3, the LADM can be used to divide each cell into smaller cells to represent the rights of the space, based on rights, restrictions, and responsibilities. The right of each cell is attached based on the party, and then the right is registered to the LA_BAUnit, as shown in Figure 6.11. In this Figure, cell 16 is split into many smaller cells based on parties rights. Each sub-cell connected with a main cell is to be registered in the LA_BAUnit, and then the private rights with a description will be created to be assigned to the party.
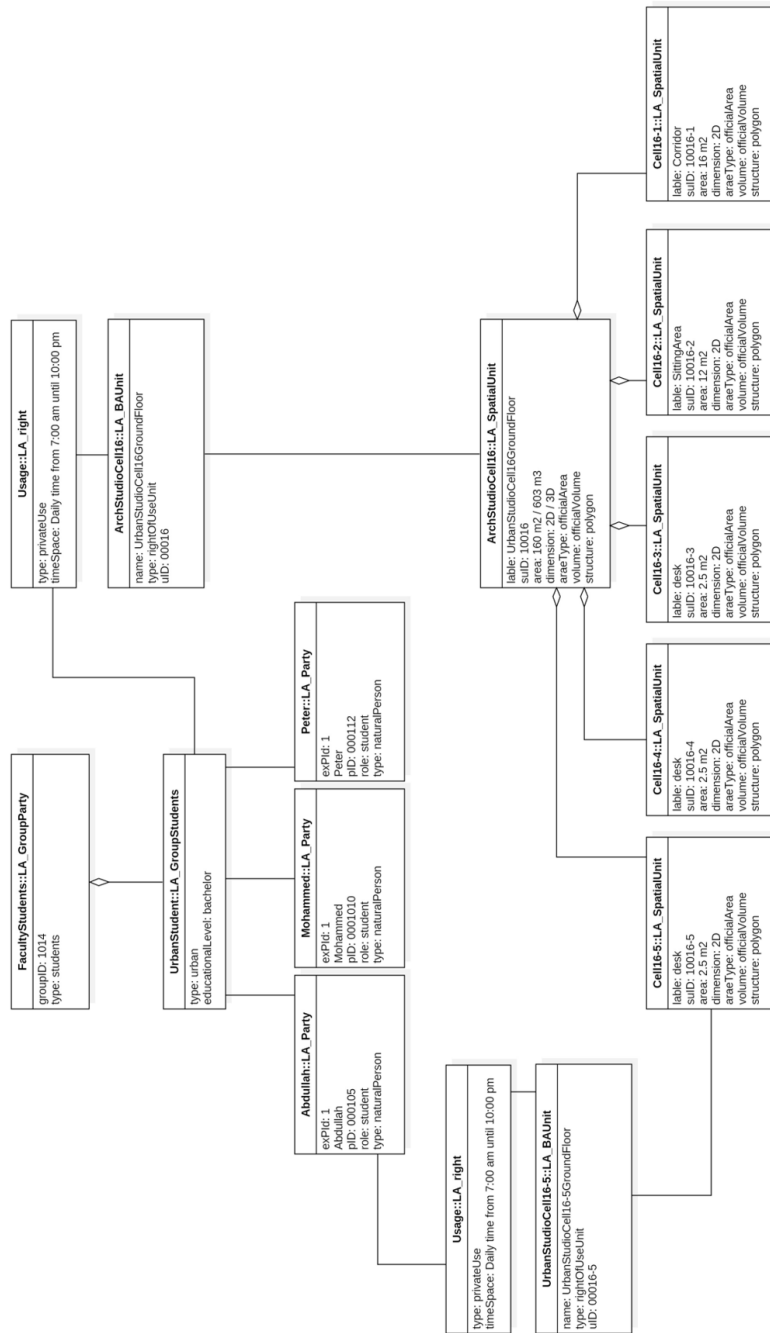
FIG. 6.11 Instance level diagram shows the division of the cell into smaller sub-cells based on functional use rights.

Faculty of Architecture and the Built Environment at TU Delft, Netherlands

The second case study is the Faculty of Architecture and the Built Environment at TU Delft, which consists of four floors and two sub-floors. There are five departments, including Architecture (AR), Architecture Engineering and Technology (AET), Management in the Build Environment (MBE), Research for the Built Environment (OTB), and Urbanism (URB). Each department has supporting spaces, such as staff offices, secretary offices, meeting rooms, and printing space. The first step to create the 3D model, is to obtain two types of information: the 2D floor plans of the building and the function information of each space. Therefore, the facility management department of TU Delft has been contacted to obtain the necessary information. By having the 2D floor plans of the building, the 3D model was created by using Autodesk Revit and Dinamo extension, as shown in Figure 6.12.
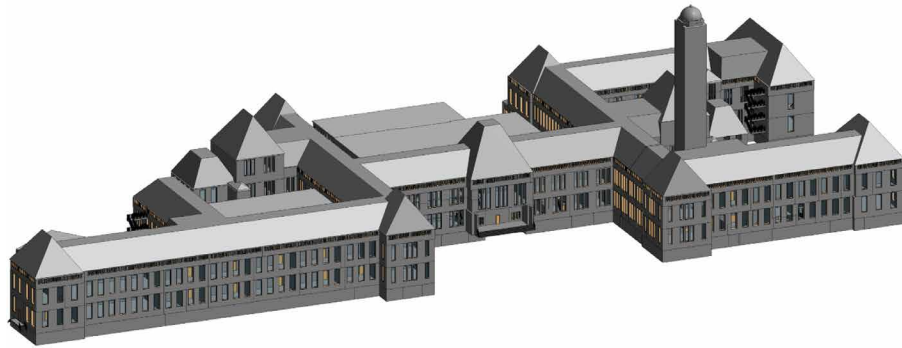
FIG. 6.12 3D model of the Faculty of Architecture and the Built Environment at TU Delft

After creating the 3D BIM/IFC model, the model was enriched by adding the semantic information to each space. The information received from the facility management department of TU Delft needed to be transformed and integrated into the model. This information was attached to the 3D spaces (ifcSpace) that differ from the physical elements of the building, such as walls, doors, or windows. Creating the 3D spaces for the entire building without having a table that contains the semantic information is a difficult, mostly manual process. Therefore, a space table (with semantic information / thematic attributes for each room) was created by using the Dynamo extension (https://dynamobim.org). The table includes all the semantic information of the building, as shown in Figure 6.13. Then, the 3D spaces were created by using the Room function in Revit. During the creation of each 3D space,

the correct information was attached to the space by selecting manually the space name from the table. Figure 6.14 illustrates the difference between the physical model and the enriched model.

|	A	B	C	D	E	F	G
	Number	Room Number	Building	Name	Space Name	Usage function	Type
1		08.01.01.010	08 Architecture and the Built Envir	01.Mid.010	BIBLIOTHEEK	A Education	A4 Study room / area
2		08.01.01.050	08 Architecture and the Built Envir	01.Mid.050		H Horizontal traffic	H1 Times
3		08.01.01.100	08 Architecture and the Built Envir	01.Mid.100	BIBLIOTHEEK	A Education	A4 Study room / area
4		08.01.01.801	08 Architecture and the Built Envir	01.Mid.801		H Horizontal traffic	H1 Times
5		08.01.01.802	08 Architecture and the Built Envir	01.Mid.802		H Horizontal traffic	H1 Times
6		08.01.01.803	08 Architecture and the Built Envir	01.Mid.803	BIBLIOTHEEK	A Education	A4 Study room / area
7		08.01.01.804	08 Architecture and the Built Envir	01.Mid.804		H Horizontal traffic	H1 Times
8		08.01.01.851	08 Architecture and the Built Envir	01.Mid.851		V Vertical traffic	V1 Stairs
9		08.01.01.853	08 Architecture and the Built Envir	01.Mid.853		V Vertical traffic	V2 Lift
10		08.01.01.854	08 Architecture and the Built Envir	01.Mid.854		V Vertical traffic	V1 Stairs

FIG. 6.13 Space schedule for the 3D model
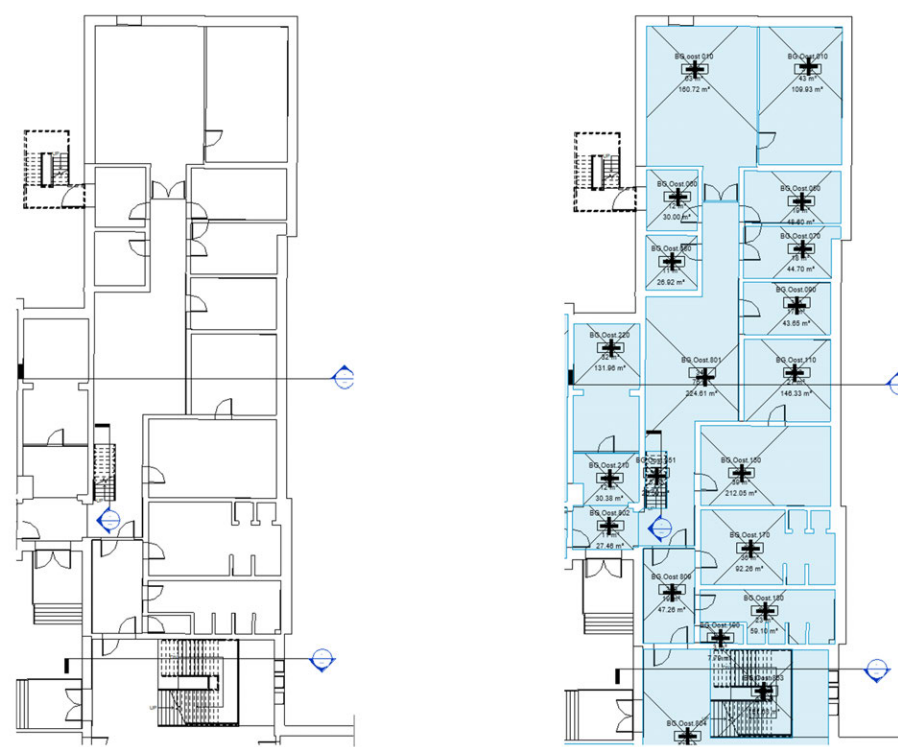
FIG. 6.14 The difference between the physical and the enriched BIM/IFC model

Based on the room schedule, the IndoorGML cell space associates the usage function and the geometry information to LA_SpatialSource in the LADM to classify each space based on the relationship with the parties of the building to assign the rights, restrictions, and responsibilities for each space. Based on the building type, which is an educational building, we define the parties into three different categories, which are students, employees, and visitors.

Based on the relationship between the party and the function of the indoor space of the building, the indoor space is divided into several types of cells with various rights. Each color represents specific rights of use for specific parties or groups of parties, as shown in Figure 6.15.

According to the relationship between the parties and the function of the cells in the LADM, we could extract the common rights areas, as illustrated in Figure 6.16. The common rights areas consist of corridors, stairs, lifts, toilets, restaurants, and copy/printing areas. All types of parties could use the areas without any restrictions. However, the building has other types of cells with different types of rights based on the rights, restrictions, and responsibilities, such as educational and administrative areas and departments.

Each department holds private rights on specific spaces of the building based on the cell's information that is provided by the IndoorGML cell space to the LA_SpatialUnit. The Architecture Department, which is located on the east side of the building has private rights to three offices, two meeting rooms, and a copy/printing space. The rest of the departments are located on the west side of the building and hold private rights for the same types of spaces, as shown in Figure 6.17. Each office space of the Architecture Department is divided into several spaces to determine the rights of the parties that are sharing the space, as shown in Figure 6.18.

The educational areas include several kinds of spaces, such as lecture rooms, drawing room, project room, studios, workshop, and study areas. All of the educational spaces have common rights for departments and students. The educational spaces cover a major area of the building and are located on different floors, as shown in Figure 6.19, with a concentration on the top floor. However, each department has the right to hold private rights to certain educational spaces based on the lecture schedule. The LA_Right class in the LADM provides a TimeSpace that is attribute for defining the period of the type of rights that the party can use, as illustrated in Figure 6.20.

Alongside the departments and the educational spaces, there are support spaces that are used by the parties, and they have common rights, such as meetings rooms and copy/printing areas, and they are distributed among the floors. The faculty includes support administrative departments consisting of the Dean's Office, Finance and Control, Facilities Management, Human Resources Management, Information and Communication Technology, Marketing and Communication, and Education and Student Affairs. They are located on the east side of the building with private rights for the spaces that are used by each department. Each office space is divided into smaller spaces to assign private rights for each employee as shown in Figure 6.3. Figure 6.15 represents the academic departments and their relationship with the spaces that have common rights, such as the meeting rooms, restaurants, and copy/printing areas, and the private areas, such as the support administrative departments.
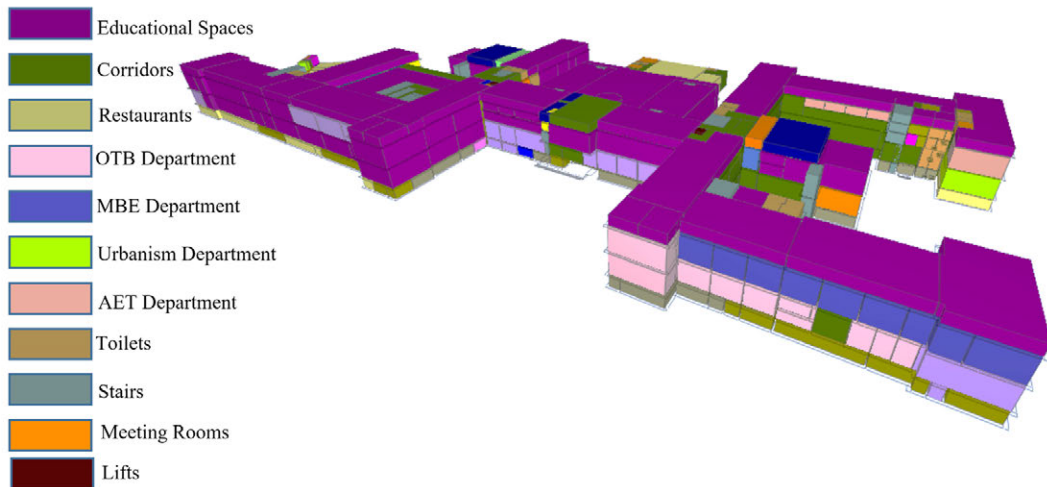
FIG. 6.15 The classification of different types of cells based on functional rights.
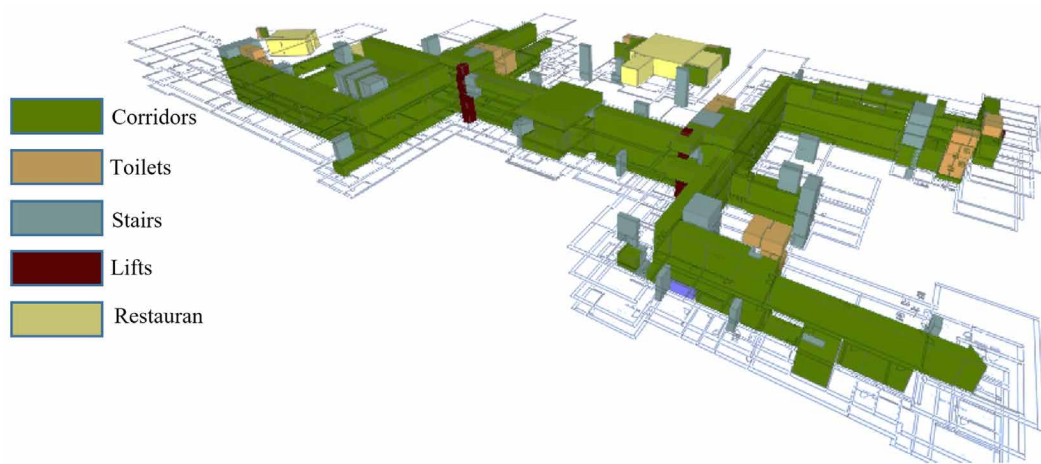
FIG. 6.16 The common areas of the Faculty of Architecture and the Built Environment based on the rights, restrictions, and responsibilities.
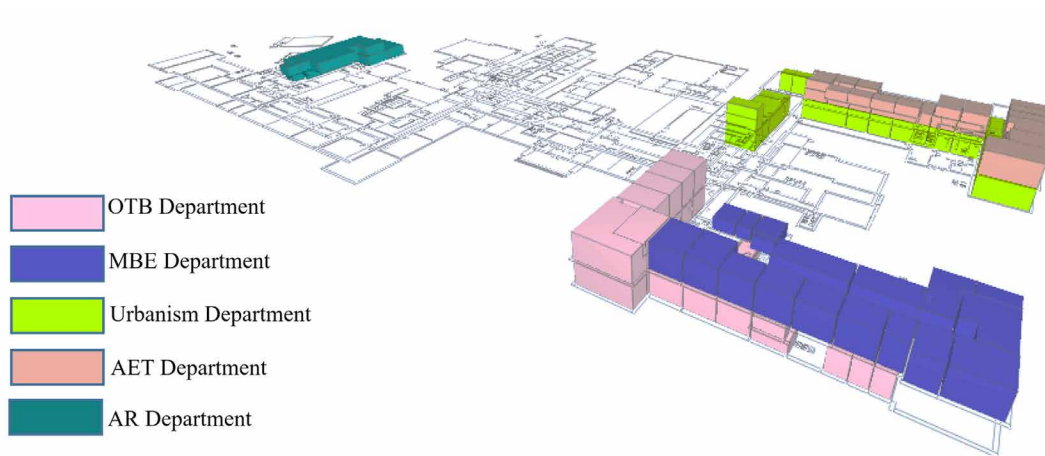
FIG. 6.17 The private spaces of the five departments of the Faculty of Architecture and the Built Environment based on the rights, restrictions, and responsibilities of the LADM.
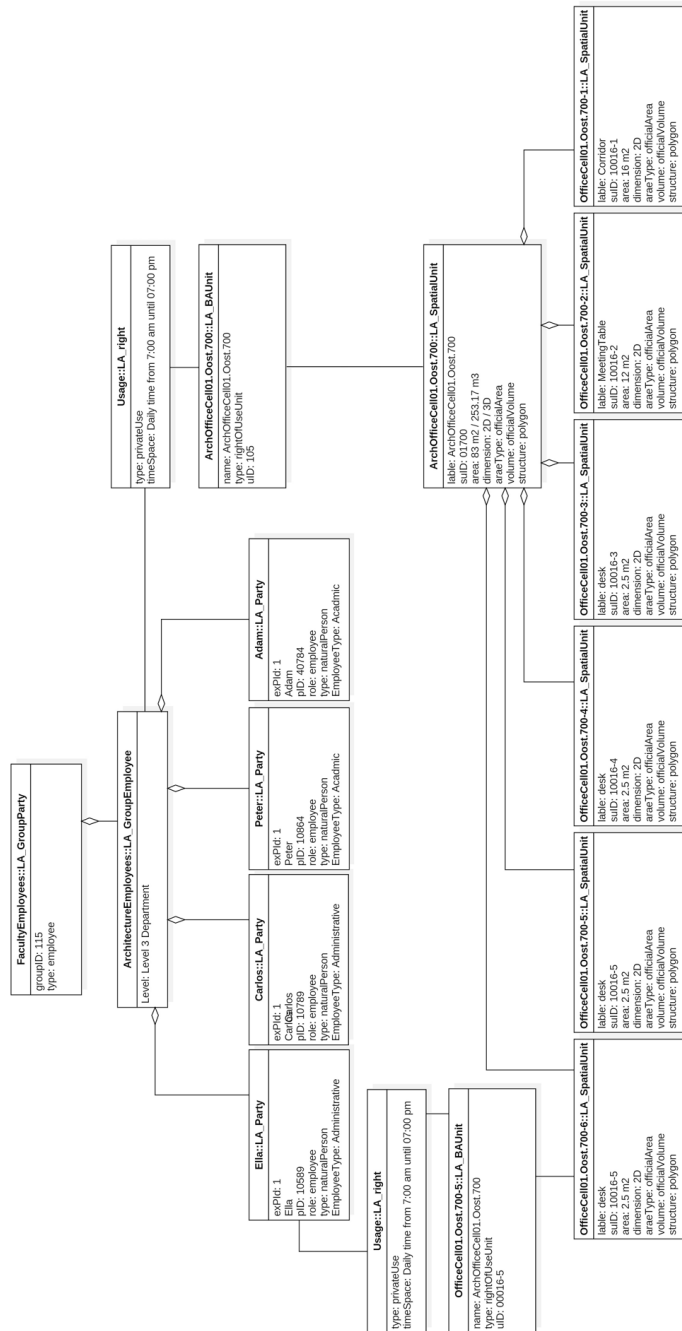
FIG. 6.18 Instance level diagram showing the division of the office cell into smaller sub-cells based on functional rights.
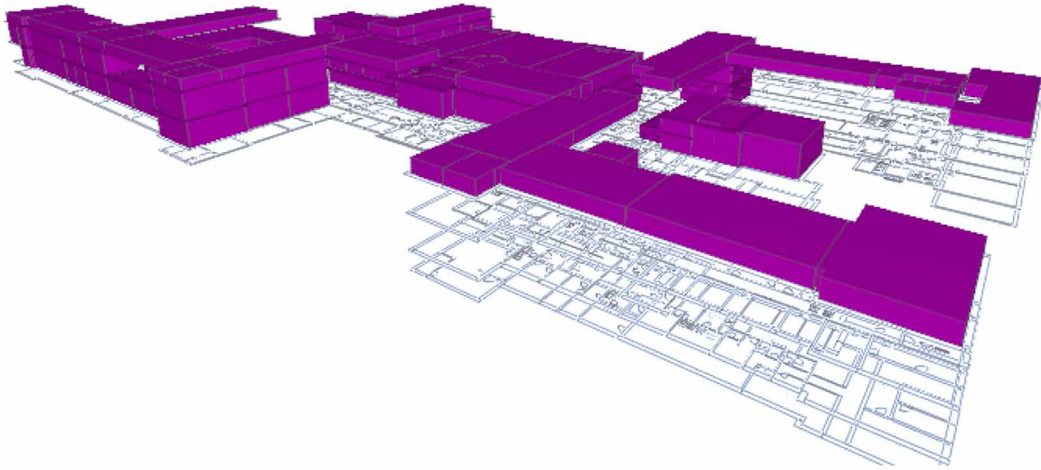
FIG. 6.19 The educational spaces of the Faculty of Architecture and the Built Environment.
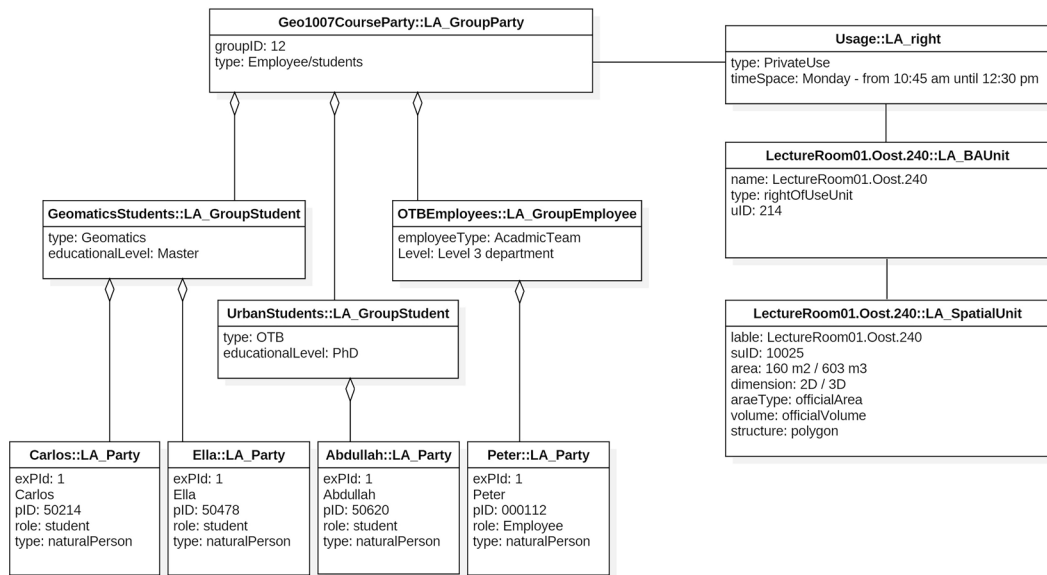
FIG. 6.20 Instance level diagram shows converting a common rights lecture space into private rights for a specific period.

Comparison

The two case studies have shown the impact of the RRR of the LADM on the space accessibility in the buildings by categorizing the spaces based on the relationship between the party and the function of the space. Both buildings have the same type of use and parties. However, they have different indoor components, such as the number of floors, departments, educational spaces, and support spaces, as shown in Table 6.2.

Through determination of the functional right for each space based on the rights, restrictions, and responsibilities, the navigation areas will be influenced according to the party type. For example, when the party is a student, the accessibility areas will be different in both cases. All departments of the Faculty of Environmental Designs at King Abdulaziz University have private rights to educational areas. Thus, the students will have rights to use common rights spaces that belong to the faculty and the private rights areas that belong to their departments.

On the other hand, the student of the Faculty of Architecture and the Built Environment at TU Delft will have the rights to use all of the educational spaces because they have common rights for all of the parties and they do not belong to any department. In both cases, when the party is an employee, the right of access will depend on the employee type and department. The academic employee will have rights to use the spaces that belong to the department and the common right spaces of the building. The spaces that belong to other departments are considered as non-accessible spaces because the party does not hold the rights to use the space. Therefore, by considering the effect of the rights, restrictions, and responsibilities on the indoor spaces, the indoor navigation becomes more efficient and more straightforward for the parties.

TABLE 6.2 The components of each faculty.

Usage Function	Space Type	Faculty of Architecture and the Built Environment at TU Delft	Faculty of Environmental Designs at King Abdulaziz University
Departments	–	– Architecture Engineering and Technology. – Architecture. – Management in the Build Environment. – Research for the built environment. Urbanism.	– Architecture. – Urban. – Landscape. – Geomatics.
Education	Lecture rooms	yes	yes
	Study area	yes	no
	Practicum	yes	no
	Practice room/Labs	yes	yes
	Drawing room	yes	no
	Project room	yes	no
	Studio	yes	yes
	Workshop	yes	yes
	Library	yes	yes
Supporting space	Central Facilities	yes	yes
	First Aid/BHV space	yes	no
	SER	yes	yes
	Meeting room	yes	yes
	Copy/print space	yes	yes
	Pantry	yes	no
Restaurant/Cafe	Restaurant	yes	yes
Storage space	Storage space	yes	yes
Horizontal traffic	Corridors	yes	yes
Vertical traffic	Stairs	yes	yes
	Lifts		
Sanitary	Toilets	yes	yes
	Shower room		no
	Workplace		yes
Installations	Accessible Shafts	yes	yes
	Technical Workshop		
	Installations		
Administrative offices	–	yes	yes

TOC

6.6 Navigation example using rights, restrictions, and responsibilities

This section shows the use of the populated combined IndoorGML–LADM model for three navigation examples, which the use of rights, restrictions, and responsibilities on the 3D geometry of the building based on the party type. We have used ifcSpace of IFC. We can generate a network of the indoor spaces through using Poincare Duality to represent the topological associations, such as adjacency and connectivity between indoor spaces, which are the basis to generate a connectivity graph of all the spaces. Based on our approach, we do not generate a network for the whole building. First, we select the available spaces based on the RRRs of the specific user or group of users, and then we create a network and generate a navigation path using only the subset of spaces available for the party.

The NavigableSpace consists of two subclasses, and they are the TransferSpace and the GeneralSpace. The TransferSpace is used as a passage between the GeneralSpaces. The GeneralSpace is defined as any NavigableSpace not considered as a TransferSpace, for example, a lecture room, office room, toilet, and labs. To link between TransferSpace and the GeneralSpace, the navigation network has to be derived from the primal space by generating the state (node) and the transition (edge). The state is representing the space object in the primal space, and the transition is representing the connectivity relationship between the states.
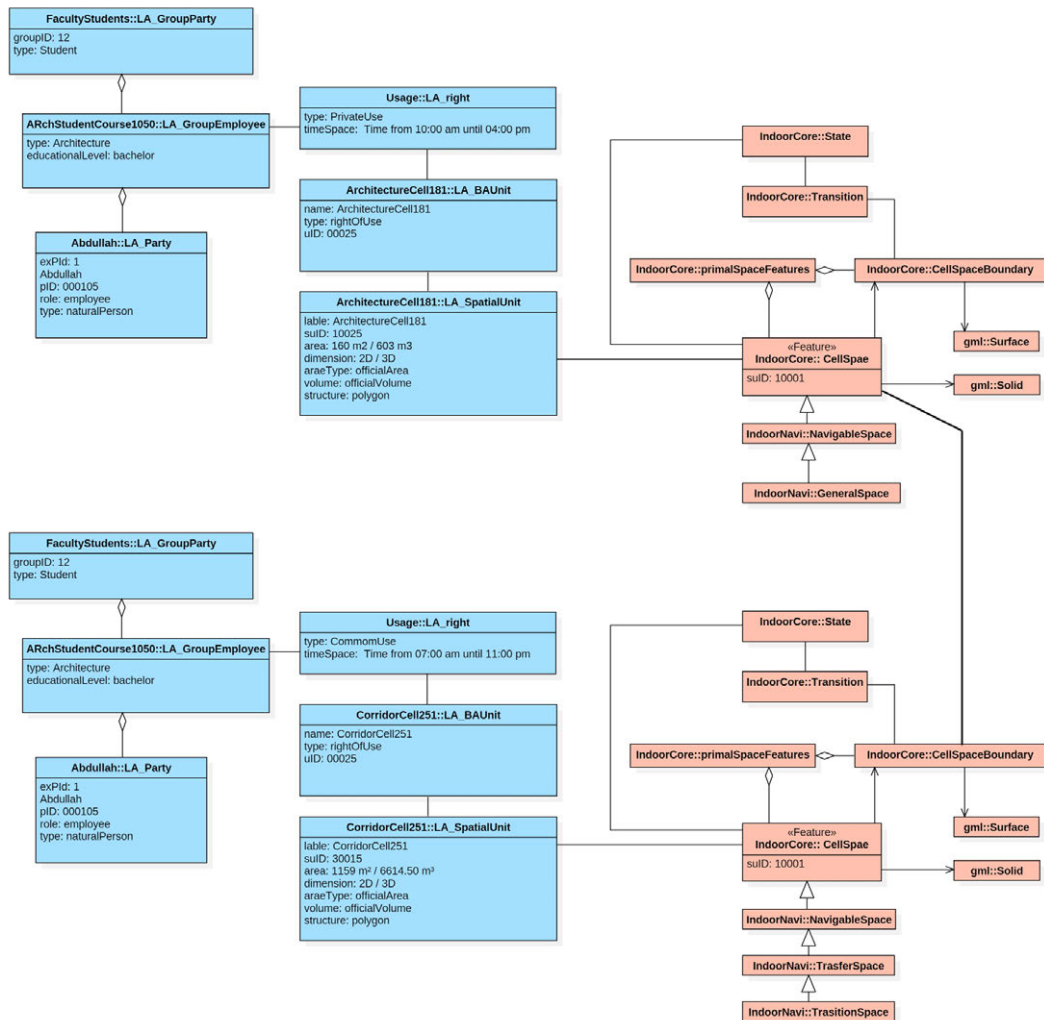
FIG. 6.21 (top) Instance level diagram shows private rights of use a lecture space (GeneralSpace) held by a student from the architecture department; (bottom) and the instance level diagram shows common rights of the use of a lecture space (TransferSpace) held by a student from the architecture department.

The first example shows a case study for a student that has the right to use the lecture room (ArchitectureCell181) on the third floor, as shown in Figure 6.21 (above). The student is located at the entrance space on the first floor. Based on the user rights, the network has been created and is used to generate the navigation path that is a series of states (nodes) that are linked by transitions (edges) to connect the CellSpaces. The user (student) started the journey from

the entrance to the lecture space, passing several TransitionSpaces to reach the GeneralSpaces. The CellSpaceBoundary describes the boundary between the two spaces by surface geometric objects to show the relationship between the spaces, as shown in Figure 6.21. Additionally, the user has different rights between the TransferSpaces and the GeneralSpace, which are described in the LA_Right classes. Figure 6.22 represents the NavigableSpaces that are available based on the user rights and depicts the shortest navigation path between their current location and the lecture space.
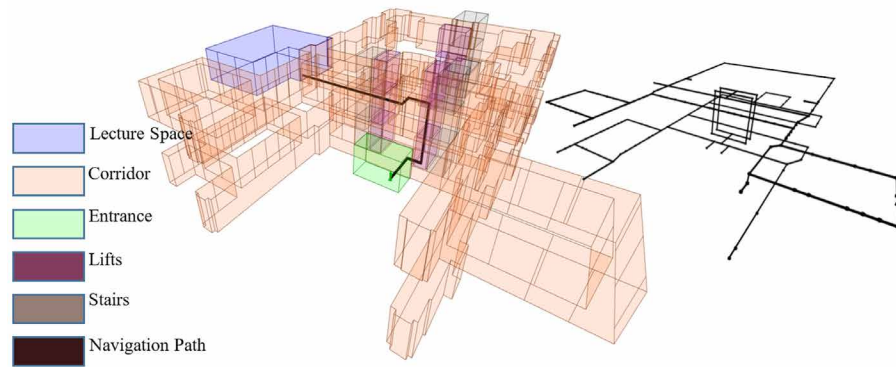
FIG. 6.22 The primal space and a navigation path (left) and the accessibility network (right) derived from the primal spaces, both for student's rights.

The second navigation example, using the populated combined IndoorGML–LADM model, represents an academic team member that has the right to use a lecture space (GeomaticsCell15) on the ground floor, as shown in Figure 6.23. The navigation path starts from the party office (GeneralSpace), which is located on the third floor through the corridor (TransitionSpace) passing all of the non-accessible spaces to reach the lift (TransitionSpace), which is located on the other side of the building and arrive to the ground floor corridor (TransitionSpace) to the final destination (GeneralSpace). As shown in Figure 6.24, the party has hardly any rights to use the first, second, and fourth floors (just the spaces of the stairs and elevators). Again, it is clear that the 3D geometry of the navigation path is heavily impacted by the party rights.
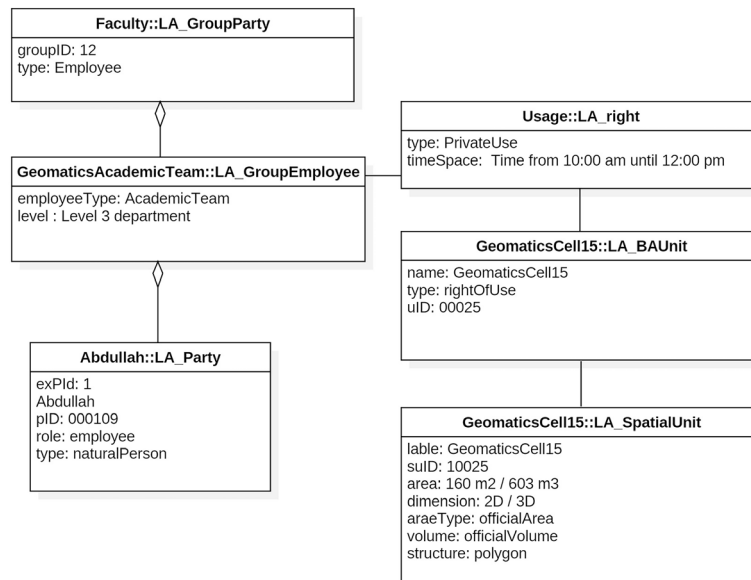
FIG. 6.23 Instance level diagram shows private rights of the use of a lecture space held by an academic team member from geomatics department.
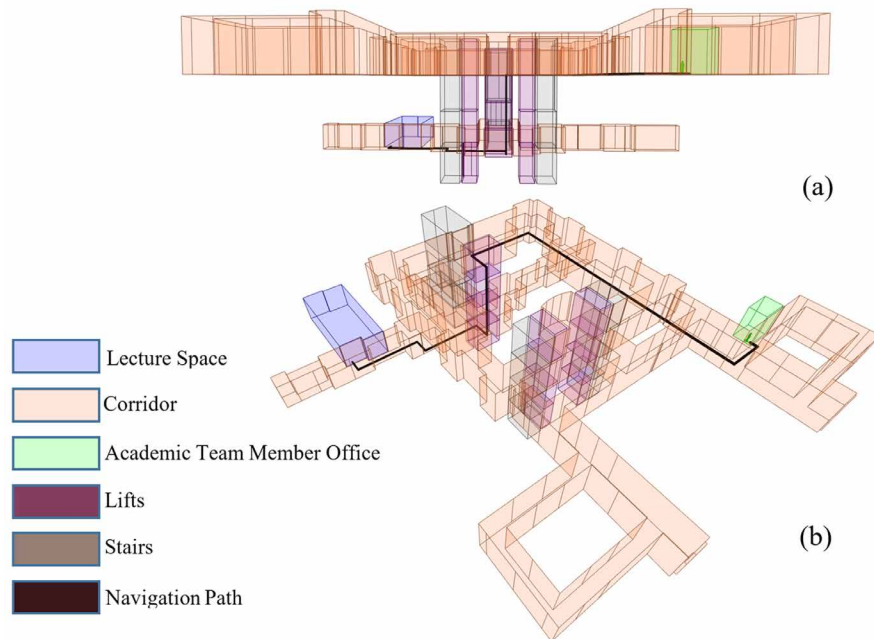
FIG. 6.24 The primal spaces (a) and a navigation path (b) based on the academic team membership rights.

The last example is about a cleaning team member that has a private right to enter and clean the dean's office (DeanOfficeCell308), as shown in Figure 6.25. Both of the spaces are located on the fourth floor. Figure 3.26 illustrates the navigation path between the cleaning room and the dean's office, which are both GeneralSpaces, connected via a series of TransitionSpaces. The cleaning team member has the right to clean the office between 07:00 am and 08:00 am, as indicated in the timeSpace attribute of LA_Right. Each right assigned to users has a time limit that should be specified when the right is issued. As a result, the timeSpec attribute is responsible for providing this kind of information for each right. The timeSpec attribute, in addition, has the capability of supporting various types of temporal descriptions, such as (every weekend, every summer, etc.).
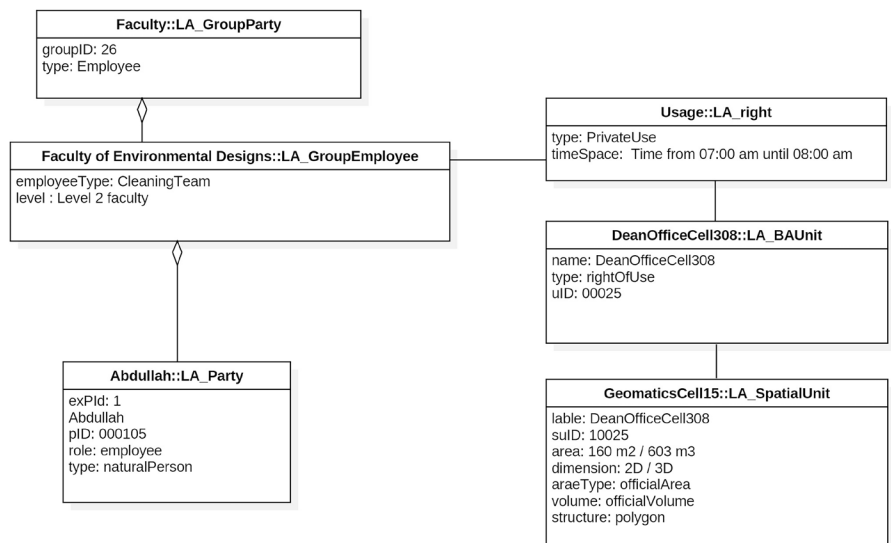
FIG. 6.25 Instance level diagram shows private rights held by a cleaning team member for cleaning the office of the dean.
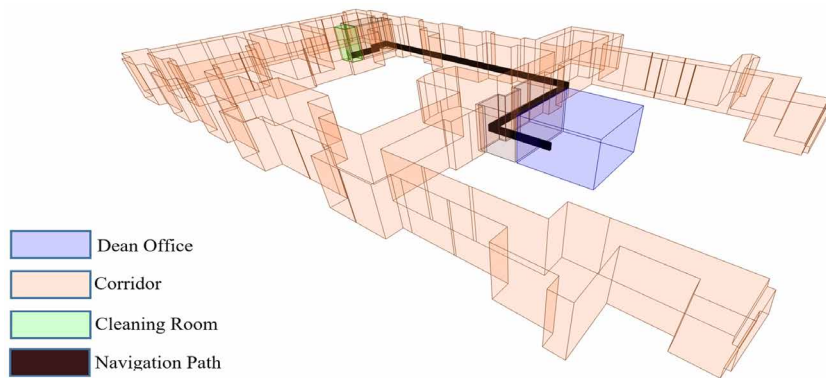
The primal spaces and the navigation path between the cleaning room and the dean's office based on the rights of the cleaning team member.

6.7 Summary

This chapter shows the combined use of IndoorGML and LADM models for supporting the accessibility of the indoor spaces based on the user rights. The combination is realized by linking the abstract level of LADM with the conceptual implementation level of the IndoorGML to reflect the effect of rights, restrictions, and responsibilities on the indoor navigation process based on the party rights. Each type of building has unique indoor spaces that are used by several types of parties. The Party Package represents the different types of parties based on the function of the indoor spaces. However, the standard ISO 19152 version of the Party Package could not represent the variety of parties information, yet.

For the refinement of the Party Package, two options have been presented for the refined model; the first option (Option A) has better support for the individual's representation by adding several attributes to the LA_Party class. However, this option has some drawbacks, such as unused attributes for certain party types and the repetition of the same information for staff of students at the individual level. Therefore, the second option (Option S) focused on the representation of the group parties by developing the LA_GroupParty to include several subclasses that are based on the type of party. Each subclass has unique attributes and code lists to cover the party information. This option provides a flexible and straightforward

representation of several kinds of parties. By classifying the indoor space based on rights, restrictions, and responsibilities, there are two kinds of spaces: common rights spaces and private rights spaces. The IndoorGML CellSpace associates the geometry and function of the spaces to LADM to assign the functional rights of use for each NavigableSpace based on the party right type.

The case studies which are based on real data about the users and function of building spaces, demonstrate the impact of rights, restrictions, and responsibilities on the NavigableSpaces (GeneralSpaces and TransferSpaces) per user. The case studies are the Faculty of Environmental Designs at King Abdulaziz University and the Faculty of Architecture and the Built Environment at TU Delft. The two cases have the same building type function and parties. The rights, restrictions, and responsibilities have further refined the information about the building based on the relation between the spaces and the parties. Each party has certain rights to use the spaces of the building, and according to these rights, the navigation paths can be more precisely computed. This chapter has answered the following Sub-questions: C1. What is the proper way of linking LADM and IndoorGML conceptual models to define the access rights of use based on the party/user type? C2. What are the main types of indoor spaces according to the accessibility rights? and C4. What is the capability of LADM Party package to represent different types of users in several indoor environments? The Integrated model of LADM and IndoorGML provides a conceptual model that can be implemented for any types of buildings to support indoor navigation based on the users' access rights.

7 Technical model of the combined LADM and IndoorGML model

In chapter 6, the integrated model of LADM and IndoorGML was developed. This chapter investigates the transformation of LADM-IndoorGML conceptual model into the technical model. The aim is to investigate the issues that could occur during the transformation from class diagram to table diagram and then to Structured Query Language Data Definition Language (SQL DDL). During the transformation from step to step several issues did appear and they are addressed in detail to enable more automated transformation possibilities from the conceptual model to technical model. In addition, this chapter presents the development of a database in PostgreSQL and analyses the challenges related to generating, querying and visualizing the information of the database.

This chapter is organized as follows; section 7.1 presents the model transformation. Generating the table diagram form class diagram is presented in section 7.2. Generating of the SQL code from table diagram in section 7.3. Section 7.4 includes the generating, loading data, and accessing the database. The chapter ends with summary in section 7.5.

7.1 Model transformation

The conceptual LADM-IndoorGML model presented in Chapter 6 allows determining the accessibility of the indoor spaces based on the ownership or the functional right of use for educational buildings. The LADM-IndoorGML conceptual model defines the user-space access rights over time in order to provide efficient navigation for individuals or groups of users of the indoor environments. The LADM-IndoorGML conceptual model applies LADM to establish a relationship between the indoor spaces and the users by assigning rights, restrictions, and responsibilities to each indoor space to indicate the accessible spaces for each type of user. After determining the user-space access right for each type of user of the indoor space, IndoorGML provides a navigation path based on the current access rights for the user.

The conceptual model deals with several types of data that need to be converted into information to be used. However, good actions need accurate information generated from raw data, and when data is stored in a database, it will be handled effectively (Coronel and Morris, 2016). Databases are specialized structures that enable computer-based systems to store, manage, and retrieve information easily. Developing a database for the conceptual model will allow having all information accessible for analysis in one standardized environment. In addition, having a database will provide access to users from different applications and front-end software on different devices such as desktop, mobile, tablet. Also, modifying the data will be done independently from the application.

Therefore, this chapter presents the development of the technical model of the conceptual model of LADM and IndoorGML to conclude with respect to the conceptual model's possibilities and drawbacks. The aim is to investigate the issues that could occur during the transformation from class diagram to table diagram and then to SQL DDL. During the prototype development, several decisions about the design of the conceptual model have been taken to convert the conceptual model into the technical model. Enterprise Architect (EA) was used to convert the UML diagrams into a database with the intention to achieve a fully automated conversion from conceptual to technical model.

7.2 Generating tables diagram from the UML diagram

One of the essential advantages of having a conceptual model is to implement it correctly. Therefore, this section presents the conversion of the conceptual model into a technical model for the integrated model of LADM and IndoorGML. By having the conceptual model of LADM and IndoorGML, it is essential to convert it into a technical model to generate the indoor navigation route based on user-space RRRs. Furthermore, the technical model allows loading data about the users and the indoor spaces to define the indoor navigation routes. Therefore, by using the transformation tool model in Enterprise Architect, the UML diagram of LADM-IndoorGML is converted into a table diagram. This step starts by defining PostgreSQL as our default database in the software under the settings menu (there are many options for other databases).

The transformation model conducts the transformation for the current package, and by including all the classes in the same package, the transformation will create a table for each class and association between the classes, as shown in Figure 7.1. The class diagram contains several types of relationship associations, such as generalization, composition, and aggregation. Each type of these relationship has a different function. To illustrate inheritance, a generalization is employed. The generalization implies that the source inherits the target's properties when it is drawn from a particular classifier to a generic classifier. An aggregation connector is a link that indicates that one element contains or is made up of other components. A Composition is a connection of an element composed of smaller components. However, during the transformation from the class diagram into a table diagram, the transformation tool will change all the generalization, composition, and aggregation into associations to show the existence of a link between two tables.
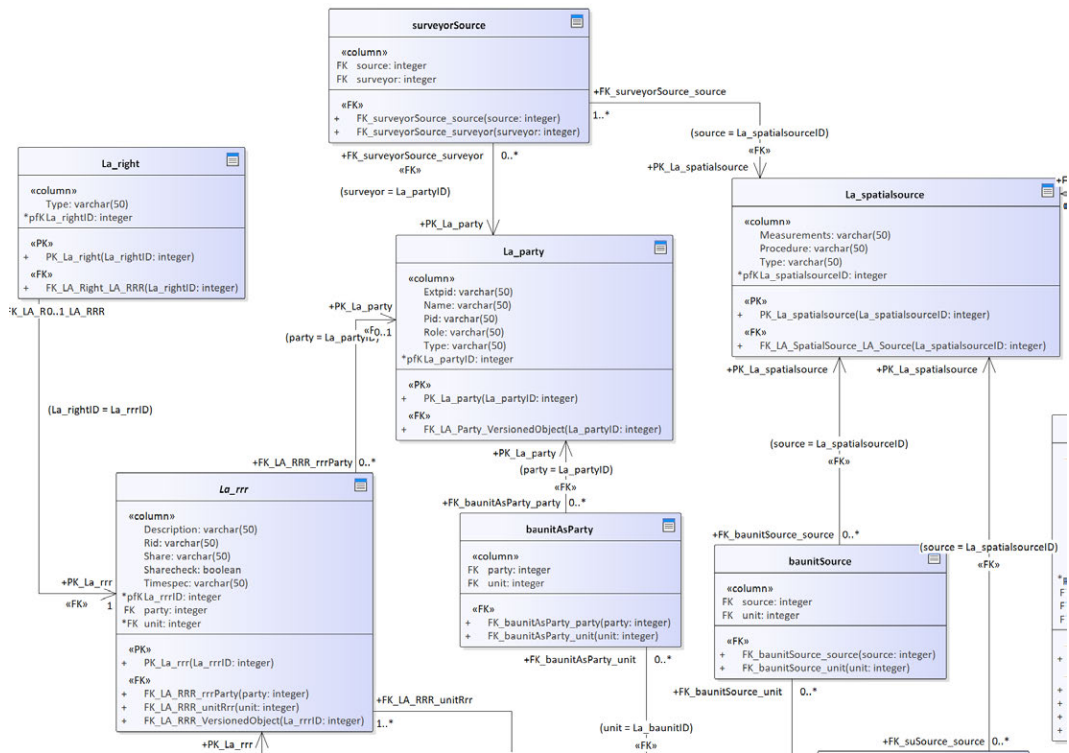
FIG. 7.1 UML table diagram for LADM–IndoorGML UML model

7.2.1 Inheritance

When the association between two tables is a generalization as in Figure 7.2, there are three options to inherit the attributes:

— By using a flat model which means all the attributes of the parents are copied to the children's classes. This option makes the model to contain the same attributes over and over again in all the children's classes.

— The second option is to create a super class that is used as a reference class and the children classes refer to the super class by using PK and FK. This option has been used in this case to avoid the duplication of the attributes all over the model.

— The third option is to define the children's class as a subclass of the parent's class by defining the parent class as object which will allow the children's classes to store the attributes of the parent class.
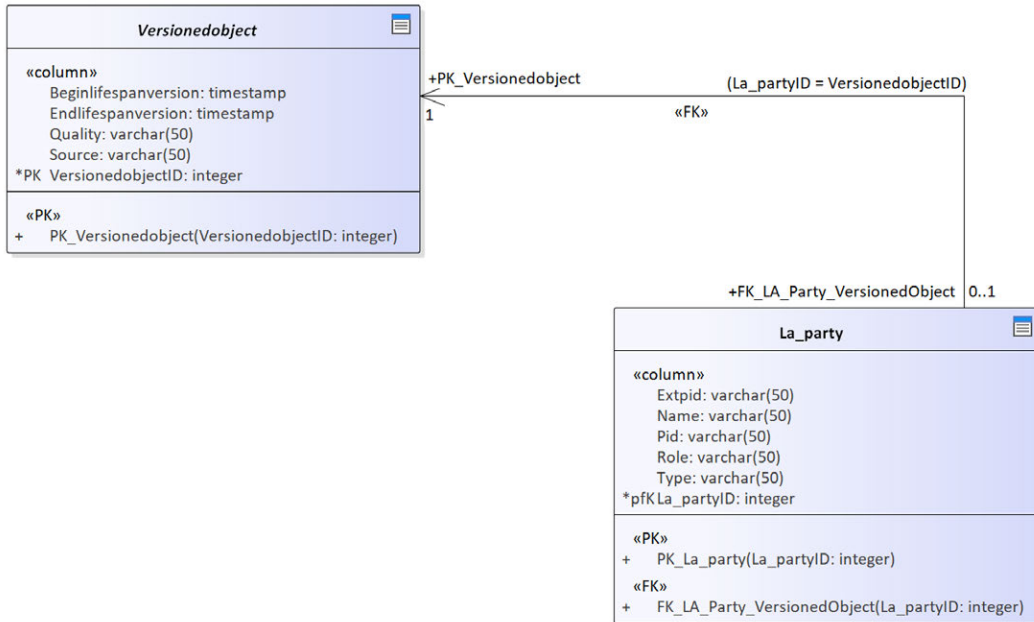
FIG. 7.2 Shows a generalization association

7.2.2 Primary key and a foreign key

The transformation tool creates a PK and a FK based on the relation between the tables. However, the software has generated a new unique attribute for each table even if the UML class has an ID attribute. The name of the new Primary key is "TableName + ID". As shown in Figure 7.3, the LA_Party table already has Pid attribute which is considered as the ID of the table, however, there is a new attribute called LA_partyID that has been created automatically by the software and has been used as PK for this table. To correct the PK for the tables that have an ID attribute, the correction has been done manually by eliminating the association between the tables and then select the correct attribute.

FIG. 7.3 Additional Primary key has been created for each table

7.2.3 Association class

The LA_PartyMember is an optional association class between LA_Party class and LA_GroupParty. The transformation model created a table for LA_PartyMember that has a separate connector to the LA_Party table and LA_GroupParty as shown in figure 7.3. The connector has used the PK to define the relationship between the tables.

7.2.4 Multiplicity of association and attributes

The transformation model does not transform the multiplicity of the attributes to tables, and there is no solution to fix this issue. Moreover, the multiplicity of the association (connectors) between the tables is different from the class diagram and that needs to be corrected manually after the transformation. For example, the multiplicity for LA_GroupParty in the UML model is 2..*; however, the transformation replaced it with 1, and this has to be modified manually as shown in Figure 7.4.
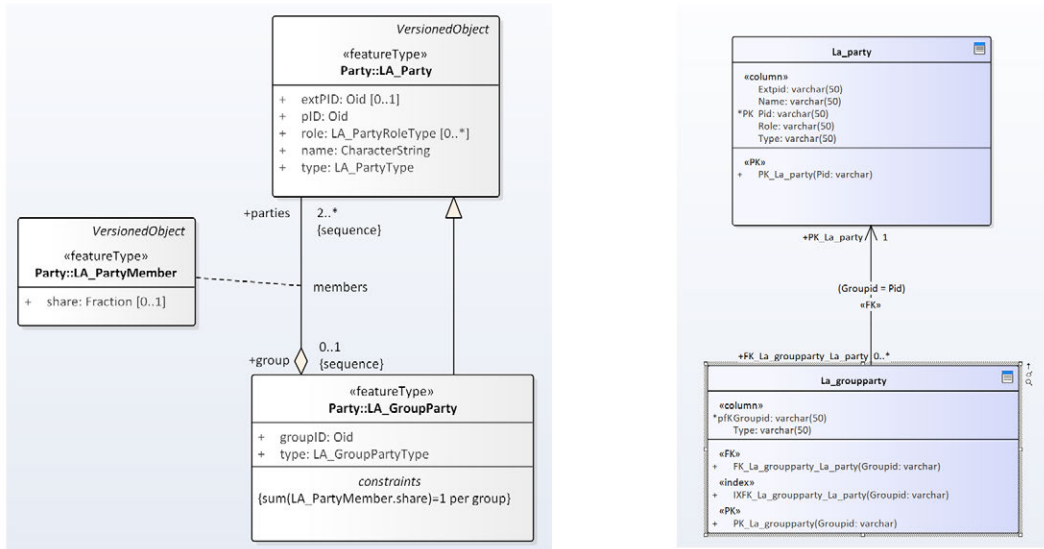
FIG. 7.4 The multiplicity for the association between the tables, left figure shows class diagram, right figure shows the tables diagram

7.2.5 Constraints

The constraint of the Class diagram is not modelled during the transformation to table diagram. For example, the LA group party has a constraint that the sum of the shares of LA_PartyMember association class is equal to one per group. However, the table diagram of the LA_GroupParty does not contain the constraint even when changing the appearing feature of the table.

7.2.6   Data type

The data types that the LADM-IndoorGML offers such as Oid and Fraction have a very important meaning. The Oid is a generic data type that is used as an identifier for the objects. It consists of a local identifier and nameSpace that used as an identifier for the data source. The transformation model does not consider the Oid and Fraction as data type and it replaces them with "varchar" in the table diagram. There is no solution to modify the data type in the table diagram. These issues could be solved by editing the SQL code. The rest of the attributes of the conceptual model has the same issue. They have a specific data type, however, the software during the transformation assign "varchar" as a data type for all of them.

7.2.7   Spatial data type

The spatial classes of the conceptual model such as LA_SpatialUnit, LA_Point, LA_BoundaryFace, and LA_BoundaryFaceString have a spatial data type for some of their attributes. For example GM_Point, GM_MultiSurface, and GM_MultiCurve are spatial data types that are already predefined in the ISO standard; however, the software does not realize their type and select a "varchar" as a data type in table diagram. After the transformation, the software offers a list of spatial data types that could be used, such as geometry, geometry collection, linestring, multilinestring, point, multipoint, polygon, and multipolygon. If the spatial data type does not included in the list, the only way is to define the type manually in the SQL code.

7.2.8   Code list classes

The code List classes in the UML model contain the possible code list values for the attributes. The current class structure of the code list provides a better understanding of the conceptual model as shown in Figure 7.5a. However, for better semantic meaning during the transformation of the code list classes into table diagram, the structure of the code list class has to be modified. Each code list should have a cID, parent_cID, begin_Date_Time, end_Date_Time and description to allow for updating the value of the code list class (Kaloginni et al., 2017 and Kaloginni, 2016). (Zulkifile et al., 2015) have proposed that the implementation of each code list class will result in a single table. Also, the name of the class of the code list should have a "Type" after the name of the class. So, there are three steps to convert the class digram of the code list into SQL:

- Convert the class diagram of the code list to the intermediate conceptual model that contains the new structure as shown in Figure 7.5b.

- Transform the intermediate conceptual model of the code list class diagram into table diagram as shown in Figure 7.5c,

- And then, generate the SQL code from the table diagram.

Additional to the attributes proposed by (Kaloginni et al., 2017), the code list classes of LADM–IndoorGML have short_Description and long_description attributes as shown in Figure 7.5c.

«codeList»
Party::
LA_PartyRoleType

+   bank
+   certifiedSurveyor
+   citizen
+   conveyancer
+   employee
+   farmer
+   moneyProvider
+   notary
+   stateAdministrator
+   surveyor
+   writer

a

«CodeList»
LA_PartyRoleType

+   cID: int
+   parent_CID: int
+   begin_Date_Time: DateTime
+   end_Date_Time: DateTime
+   Short_Description: char
+   Long_Description: char

bank
certifiedSurveyor
citizen
conveyor
employee
farmer
moneyProvider
notary
stateAdministrator
surveyor
writer

b

La_partyroletype

«column»
   Cid: integer
   Parent_cid: integer
   Begin_date_time: timestamp
   End_date_time: timestamp
   Short_description: char(1)
   Long_description: char(1)
*PK   La_partyroletypeID: integer

«PK»
+   PK_La_partyroletype(La_partyroletypeID: integer)

c

FIG. 7.5 Shows the code list class in conceptual model, left shows the normal class structure, right shows the implementation structure for the code list.

TOC

Indexing

The transformation from the UML diagram into DDL provides in an automated way the index for the PK and the FK. Each table will list all the PKs and FKs that are related related to the table or related to the association between the table and other tables. The transformation creates a B-tree index for the FK as shown in Figure 7.6. Each table contains an index to store the FK that is related to the table. Enterprise Architect software supports only a spatial index (R-tree) that is related to ArcGIS toolbox which in this way it does not fit to this work. The solution is to define the spatial index in the SQL code manually.
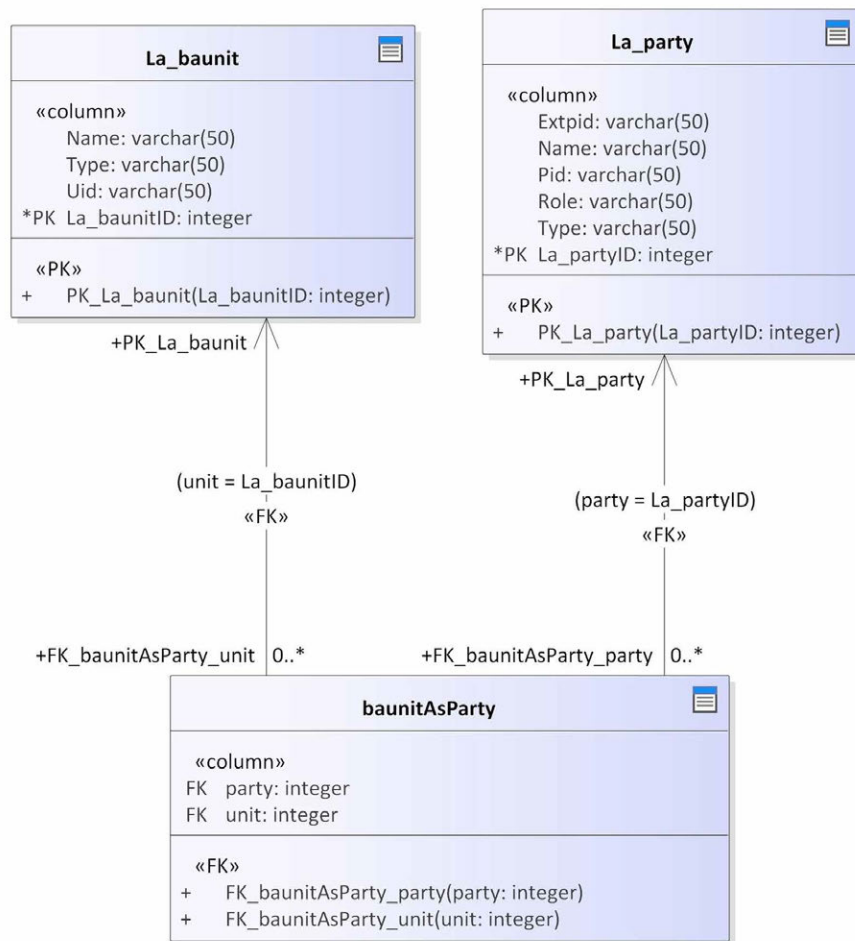
FIG. 7.6 Shows the index that the transformation provides in automated way.

7.3 Generating SQL DDL from UML table diagram

The code engineering in Enterprise Architect software is a tool that generates a SQL DDL from the UML table diagram in automated way. The code engineering converts all the tables for LADM-IndoorGML as shown in Figure 7.7. The SQL code contains the comment that the UML class includes next to each attribute.

```
DROP TABLE IF EXISTS La_party CASCADE
;
CREATE TABLE La_party
(
Extpid varchar(50) NULL,     -- the identifier of the party in
an external registration
Name varchar (50) NULL,      -- the name of the party
Pid integer NOT NULL,      -- the identifier of the party
Role varchar(50) NULL,      -- the role of a party in the data
update and maintenance process
Type varchar(50) NULL     -- the type of the party
)
;
```

FIG. 7.7 Shows the SQL code for creating LA_Party table

Furthermore, the code engineering generates tables for Primary Keys and Indexes as shown in Figure 7.8. Figure 7.9 shows the SQL code for the code list tables.

```
CREATE INDEX IXFK_AddressLA_SpatialUnit_La_spatialunit ON
AddressLA_SpatialUnit (landParcel ASC);
CREATE INDEX IXFK_baunitAsParty_La_baunit ON baunitAsParty
(unit ASC);
CREATE INDEX IXFK_baunitAsParty_La_party ON baunitAsParty
(party ASC);
ALTER TABLE La_availabilitystatustype ADD CONSTRAINT
PK_La_availabilitystatustype
      PRIMARY KEY (La_availabilitystatustypeID);
ALTER TABLE La_baunit ADD CONSTRAINT PK_La_baunit
      PRIMARY KEY (Uid);
```

FIG. 7.8 SQL code for Primary Keys, and Indexes

TOC

```
CREATE TABLE La_partyroletype
(Cid integer NULL,
        Parent_cid integer NULL,
        Begin_date_time timestamp without time zone NULL,
        End_date_time timestamp without time zone NULL,
        Short_description char(1) NULL,
        Long_description char(1) NULL,
        La_partyroletypeID integer NOT NULL);
```

FIG. 7.9 SQL code for codelist table

7.4 Generating and accessing database for the conceptual model

In this section we generate and assess a database for the conceptual model of LADM-IndoorGML. The aim of this work is to investigate all issues that are related to generating the database and visualizing the content of the database.

7.4.1 Transformation to technical model

We have selected some classes of the conceptual model of LADM-IndoorGML to create a database in PostgreSQL/GIS as shown in Figure 7.10. Figure 7.11 shows the table diagram of LADM-IndoorGML technical model. The data type and the spatial data type has been modified manually in this stage. EA does not support geometry type "multipolygon z,". Therefore, this needs to be corrected manually in the SQL code.
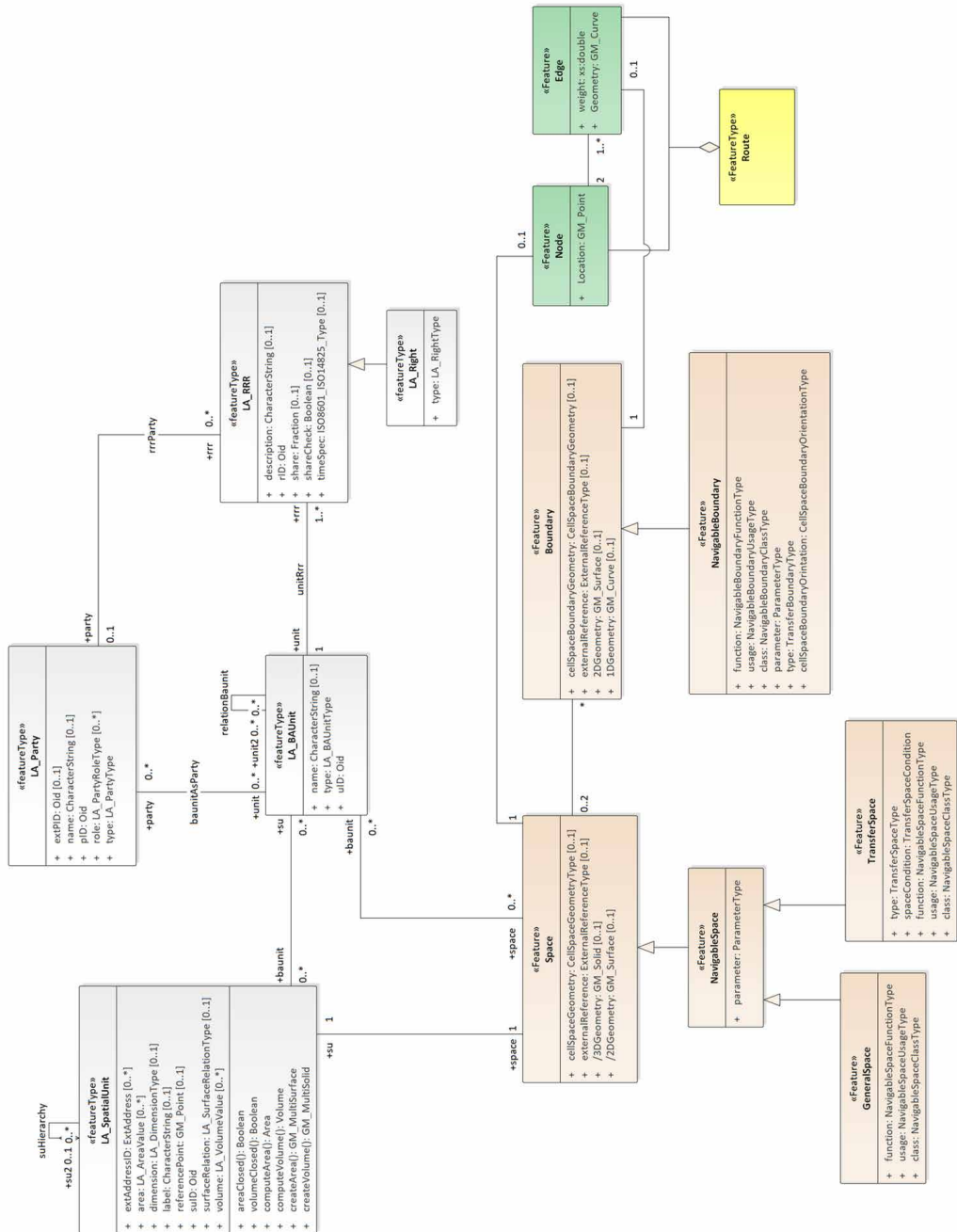
FIG. 7.10 The selected classes from the conceptual model of LADM-IndoorGML

TOC
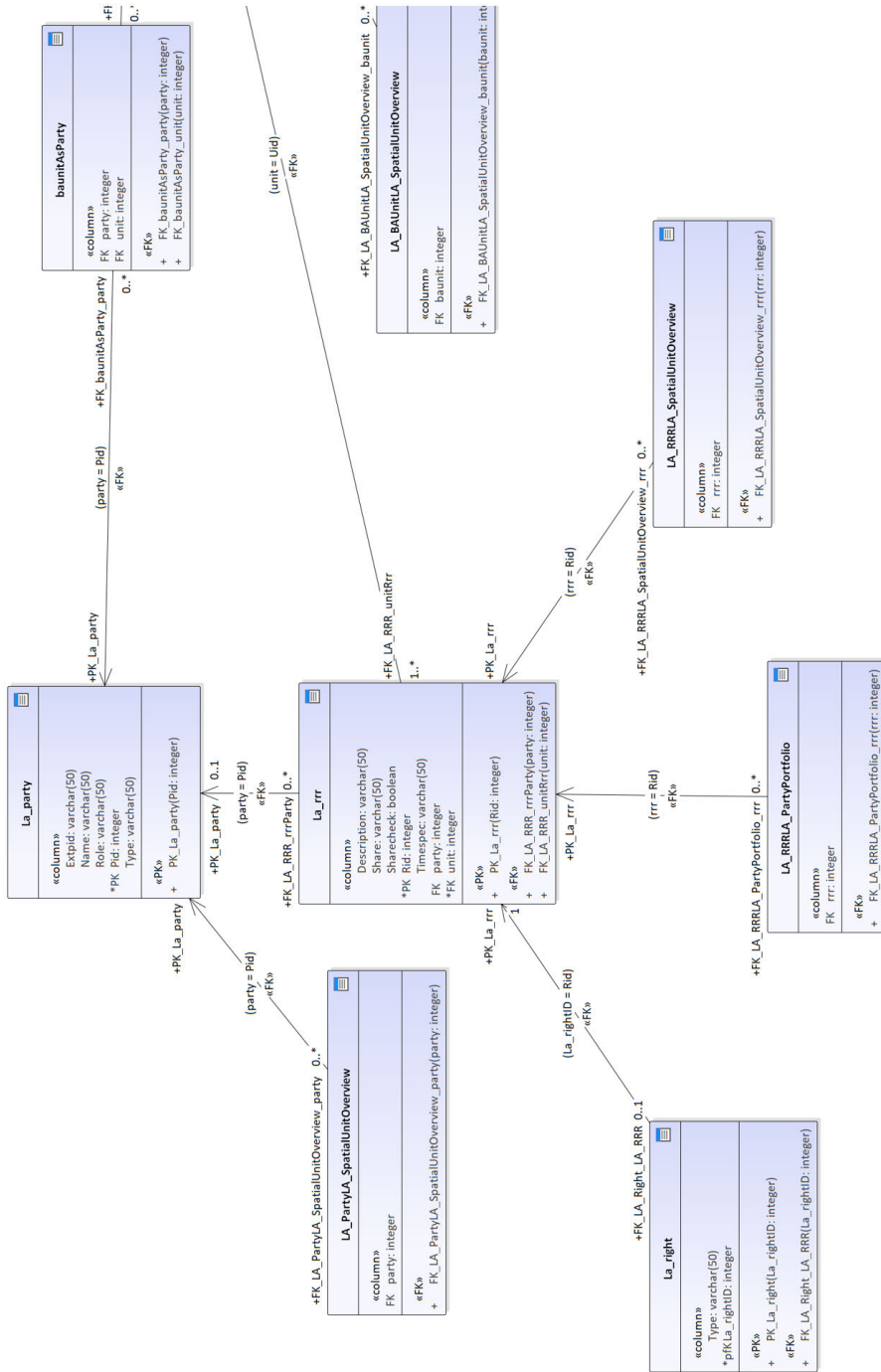
FIG. 7.11 Part of the table diagram

A SQL DDL has been generated by using the code engineering tool in EA. The code engineering has converted the entire table diagram into SQL DDL. Figure 7.12 shows the SQL code for LA_RRR and LA_SpatialUnit classes (for the complete SQL Code see appendix A).

```
CREATE TABLE La_rrr
(
Description varchar(50) NULL,
Share varchar(50) NULL,
Sharecheck boolean NULL,
Rid integer NOT NULL,
Timespec varchar(50) NULL,
party integer NULL,
unit integer NOT NULL
)
;
CREATE TABLE La_spatialunit
(
Extaddressid varchar(50) NULL,
Area varchar(50) NULL,
Dimension varchar(50) NULL,
Label varchar(50) NULL,
Referencepoint geometry(point) NULL,
Surfacerelation varchar(50) NULL,
Suid integer NOT NULL,
Volume varchar(50) NULL,
su2 integer NULL,
space integer NOT NULL
)
;
```

FIG. 7.12 SQL code for creating LA_RRR and LA_SpatialUnit tables

7.4.2 Generating database and visualizing the data

By having the SQL code, a database could be generated in PostgreSQL as shown in Figure 7.13. The 3D geometry of the building has been created in Revit software and has been imported into the database by in-house software using Open Database Connectivity (ODBC). The semantic information of the building has been exported directly from Revit. The 3D geometry has been linked to the semantic information and all other properties in the database by the unique geometry ID. Afterwards, the data have been re-organised according to the spatial schema of LADM-IndoorGML using SQL queries. The tables related to LADM have been populated manually.
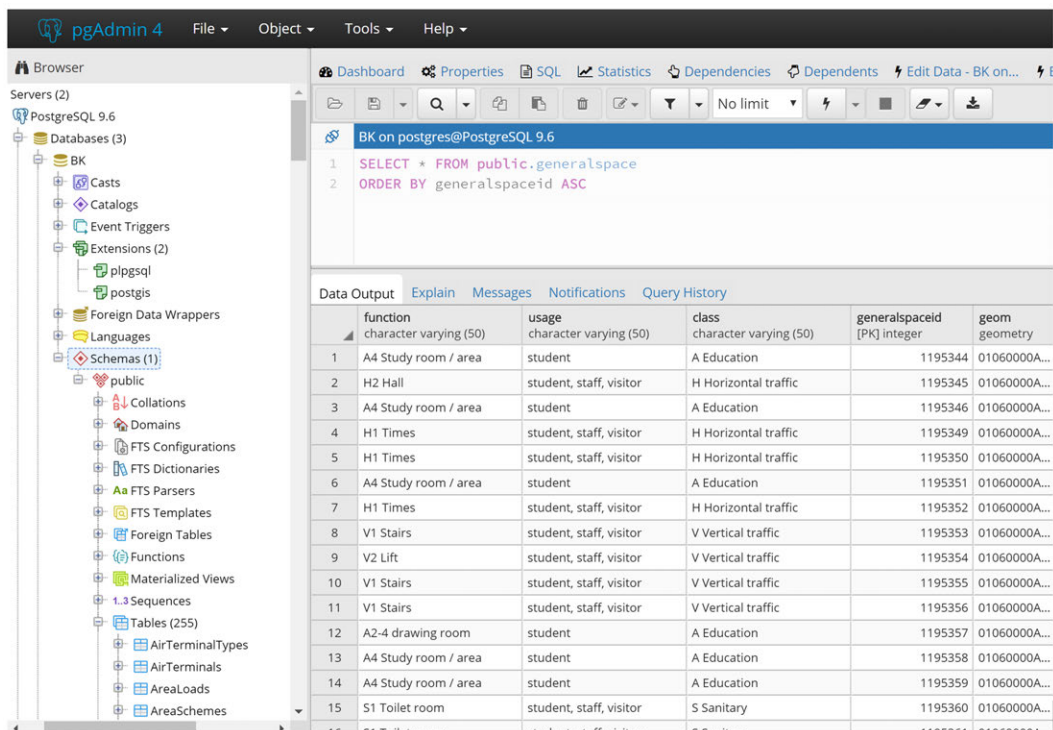
A number of queries was performed to illustrate how the DBMS can be used. For example, figure 7.14 shows the spaces that are accessible for student (a) and staff (b).

a)
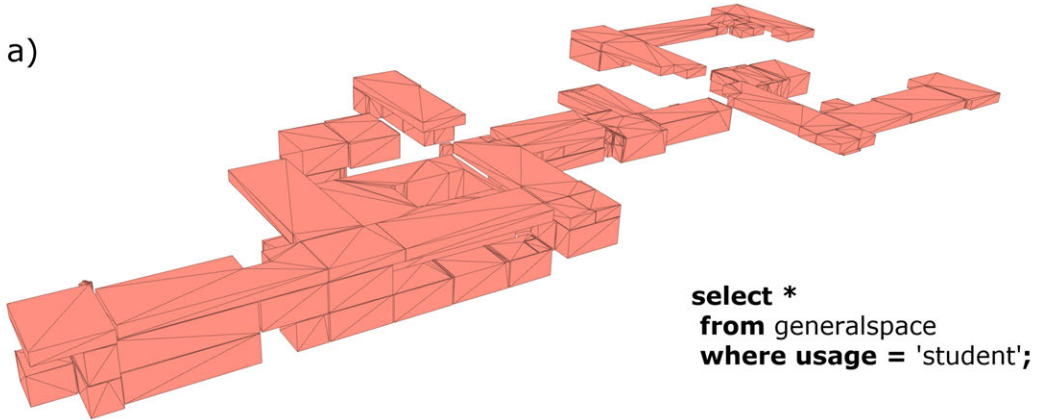
```
select *
 from generalspace
 where usage = 'student';
```

b)
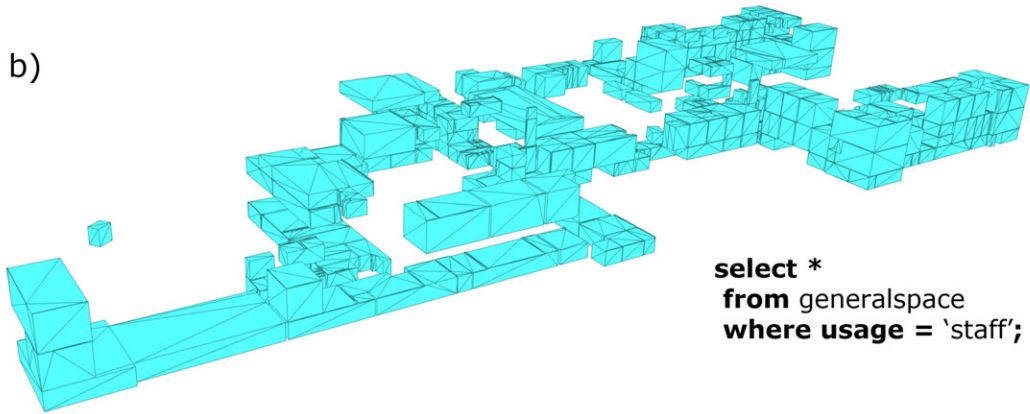
```
select *
 from generalspace
 where usage = 'staff';
```

FIG. 7.14 Accessible spaces for a) student and b) staff

Summary

This chapter presented the mapping of the conceptual model of LADM-IndoorGML to the technical model. This chapter shows that by using Enterprise Architect software, there are still many issues that need attention and manual adjustment, and can be summarized as follows:

— The transformation tool creates a new unique attribute assigned as PK to all tables, even if the class diagram has a unique ID attribute modelled in the UML class diagram. The solution to this issue is correcting the PK for all tables manually.

— The additional PK also affects the associations between the tables, which must be modified manually.

— The multiplicity of the classes diagram has been changed in the table diagram, and in some cases, there is no solution to modify that yet.

— Additionally, the transformation does not cover the multiplicity related to the attributes.

— The spatial index has to be defined manually in the SQL code.

Furthermore, this chapter has presented the development of a database for the conceptual model of LADM-IndoorGML after converting the class diagram into a table diagram and then to SQL DDL for a selected set of classes. The chapter illustrates that the process of conceptual modelling to technical implementation can be largely automated. Very few aspects require manual intervention. This experiment has also illustrated a workflow for the import of data into LADM-IndoorGML relational tables. The software package Revit can export all textual data to Postgre/PostGIS, but not the 3D geometry. Therefore, an ODBC importer was developed to import the 3D geometry of ifcSpace. As such, most of the tables of the schema have been populated in an automated way. Only a few tables of LADM have been populated manually in this experiment. With all the information stored in the database, many queries can be performed, and the result can be visualized in different front-end visualization softwares (FME, 3DQGIS, RHINO, ArcGIS) that can read ST Geometry data types. This chapter has answered the sub-question "T1. What specifications are needed to map a conceptual model to a technical model and then to an implementation model?". In addition, this chapter provides a complete description of all the issues that could occur during the transformation from conceptual model to technical model for any standard by using Enterprise Architect software.

8 The use of LADM-IndoorGML during a building evacuation

The previous chapter has introduced the issues that occur during transformation of the conceptual model into a technical model. This chapter addresses the impact of the access rights of the indoor spaces during an emergency evacuation. The aim of this chapter is to utilize the integrated conceptual and technical models of LADM-IndoorGML that define the accessibility of the indoor spaces based on rights, restrictions, and responsibilities of the users of the indoor space during a crisis.

This chapter is structured as follows; section 8.1 presents the introduction of using the integrated model during crisis. The development of the party package for crisis situations is described in section 8.2. Then in section 8.3, the evacuation exercise scenarios are presented. The collected WiFi data during the exercise are presented in section 8.4. Section 8.5 presents the database import, analysis, and visualisation. The results of the evacuation exercise based on the collected WiFi data are shown in section 8.6. The comparison between the results of the WiFi data and the observer data of the evacuation is presented in section 8.7. Finally, the chapter end with a summary in section 8.8.

8.1 Incident management in buildings

During an incident in the indoor environment, an efficient evacuation is required to help and protect a large number of people by evacuating them from the incident zone and the surrounding areas to a safe area, which is usually outside the building. The indoor environment is a sophisticated space during the normal situation, and that complexity increases during an incident. The users of the indoor environment must find the safest route from their location to the emergency exit. For this reason, several researchers have concentrated on the modelling of the network and the indoor wayfinding (Xiong et al., 2017). Many emergency evacuations models have been developed on different computational rules and to represent effective approaches for the designers to estimate the evacuation safety during the integration with GIS-based spatial models such as Firescap, Exoudus, Simulex, Esm, and Mascm (Tang and Ren, 2012). Additionally, their study proposed a spatial simulation model that merges behaviours, fire simulation, and building geometry to examine the spatial features and support the evacuation decision makers to a certain level.

A 3D indoor-outdoor spatial model has been proposed by (Tashakkori et al. 2015). They have introduced the required information for finding the route during the emergency incident response, and they included information about the building and the network between the floors. Furthermore, they discussed the awareness of the situation that is needed for managing the emergency and for the decision that will be performed for a successful emergency respond according to the 3D network navigation and blockage analysis. (Lujak et al. 2017) have introduced a distributed recommendation route for a situation-aware evacuation guidance in a building.

The lack of information about the internal connectivity of the indoor spaces usually slows down the evacuation, and in this case, some of the users will not know the alternative route to the emergency exit. Users of the indoor spaces usually take the same route that they use in the normal situation and ignore the emergency route or exit that should be taken during the incident (Sime, 1984).

However, those researchers have not addressed the necessary information to identify the access rights for the users during the evacuation and how that will affect the evacuation routes for the users of the indoor environment during the incident. There are two types of spaces for the users based on their rights: (1) accessible spaces (2) non-accessible spaces during the regular daily activity inside the building. Therefore, it is essential to examine the impact of the access right for the users during the

incident and store this information which can help to improve generating better routes that could be shorter and safer.

This chapter addresses the impact of the access rights of the indoor spaces during an emergency evacuation by employing the conceptual model of LADM-IndoorGML that was defined in chapter 6. Currently, navigation during the incident has been studied without any consideration of the impact of the access rights for the users; therefore, this chapter assesses the conceptual model of LADM-IndoorGML to define the accessibility rights during an incident. A real evacuation exercise for an educational building at the Technical University of Delft is considered. Two scenarios have been prepared for the evacuation and WiFi trajectory data have been collected to study and compare the movement of the users during the evacuation. A 3D model has been created for the building and several types of information for each space such as space type, area, space function, level etc. have been defined.

8.2 Developing the party package for crisis situation

The conceptual model of LADM-IndoorGML defines the access rights for the users of the indoor environment as shown in Figure 8.1. Each space of the indoor environments has a different relationship with the users, and by determining these relationships, LADM could define access right for each type of users.

The Party package includes the user information, and it contains LA_Party class, LA_GroupParty, and LA_PartyMember as an optional association class. The Party package has been developed to cover more information about the users of the indoor Environment for better representation and that by including three more classes. Within the scope of this thesis, the Party package was extended to add two subclasses to the LA_GroupParty class to represent particular groups of users based on the type of the indoor environment: (1) LA_GroupStudent and LA_GroupEmployee. In this case of incident management, the LA_GroupParty has been extended to have a new subclass to represent the Emergency Response Team (ERT). The new subclass has a LA_GroupEmergencyResponseTeamType attribute to represent several types of Emergency Response Teams such as Emergency Medical Technician, Firefighters, Police, and ERT as shown in Figure 8.2. The aim of the new subclass is to define the access rights during an incident for the Emergency Response Team users.
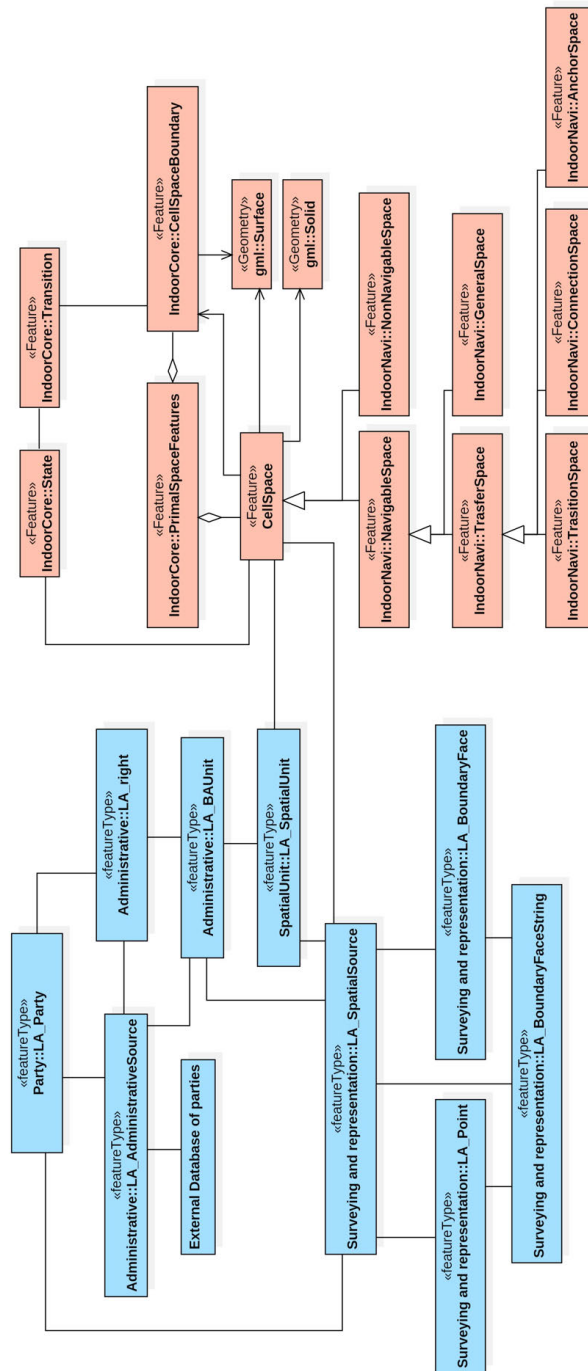
FIG. 8.1 The conceptual model of LADM (blue) and IndoorGML (red)
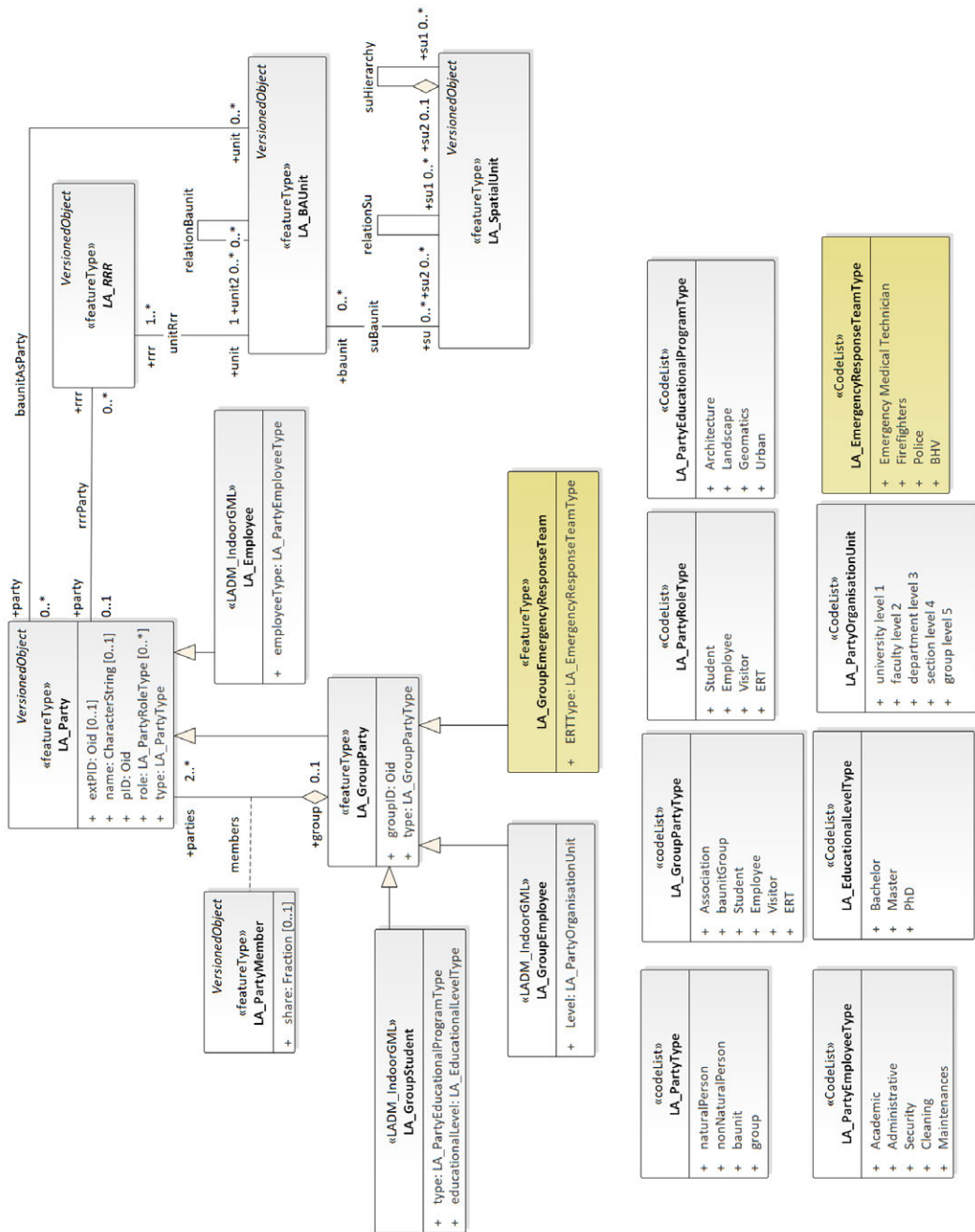
FIG. 8.2 New subclass for the LA_GroupParty class and code list (yellow)

As mentioned previously, the administrative package consists of two subclasses: the LA RRR and LA_BAUnit. The LA RRR is an abstract class which includes of three subclasses: LA_Right, LA_Restriction, and LA_Responsibilities. The LA_RRR class has a timeSpace attribute that is responsible for the temporal description of every rights, restrictions, and responsibilities such as every week or every winter as shown in Figure 8.3.
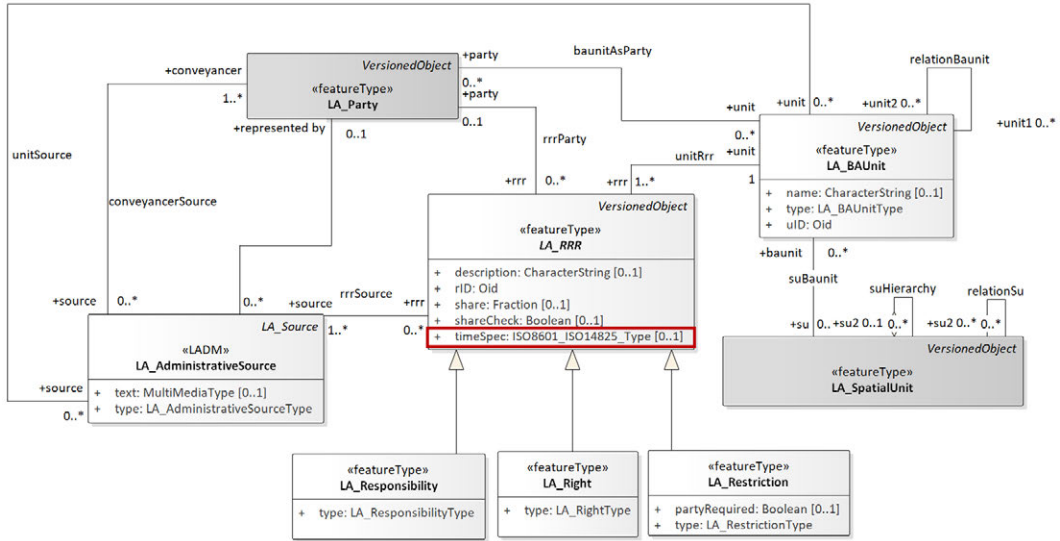
FIG. 8.3 The administrative package of LADM

The timeSpec attribute is different for each user of indoor space based on their RRR. Also, the RRR is changeable based on the condition of the indoor space. For example, the ERT has the access right to enter all indoor spaces during an incident. However, they do not have this kind of access right during the normal condition of the space. Figure 8.4 shows the same access right for different users of the same indoor space but with different timeSpace conditions. Figure 8.4a represents students that have private rights to access a lab during the normal office hours, and they do not have access right to the lab out of the normal office hours. In figure 8.4b, the cleaning team has private access rights but after the normal office hours. Also, the ERT has the right to access the same space during an incident as shown in Figure 8.4c.
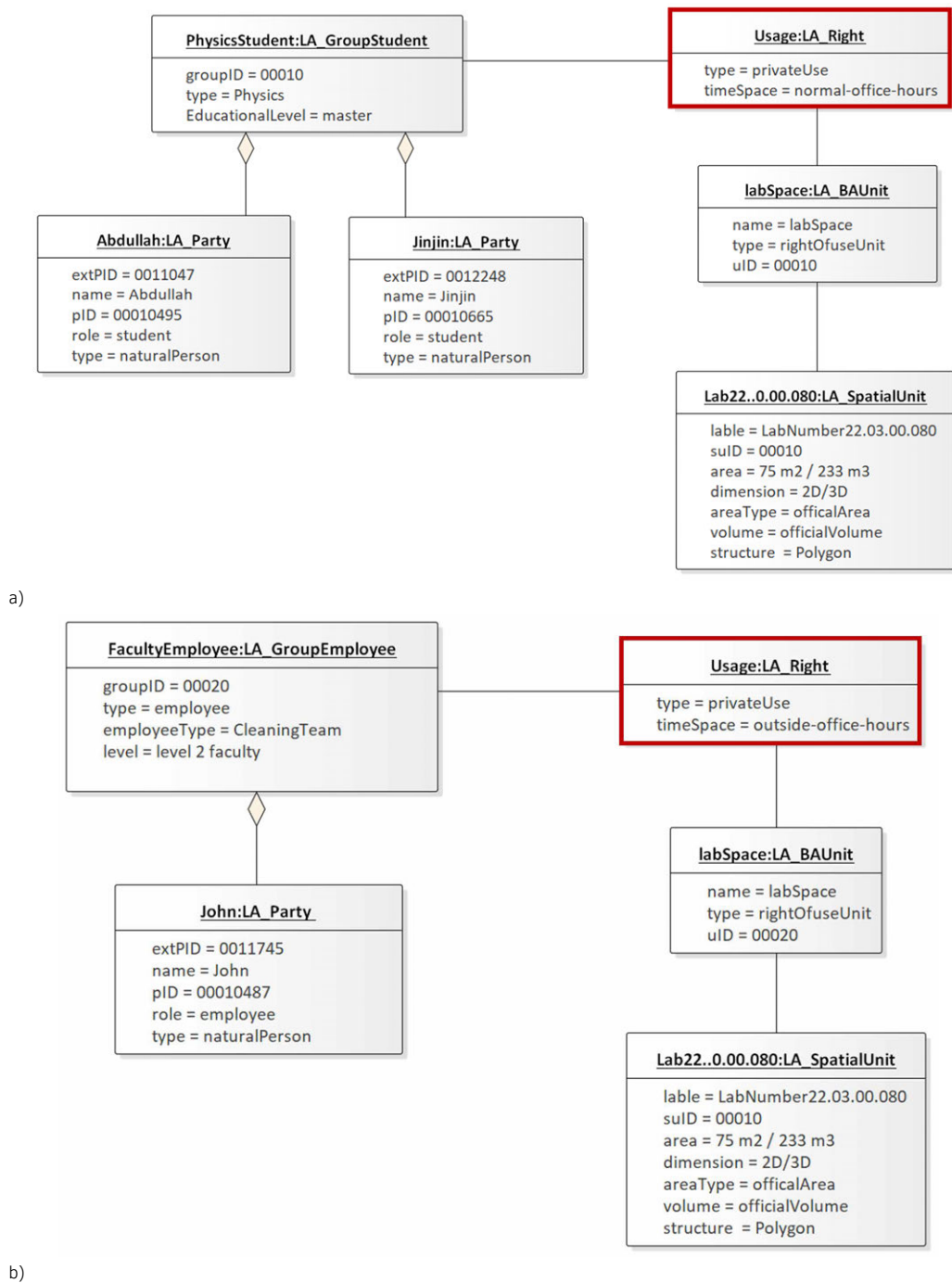
a)

b)

FIG. 8.4 Shows different timeSpace conditions for the same access rights
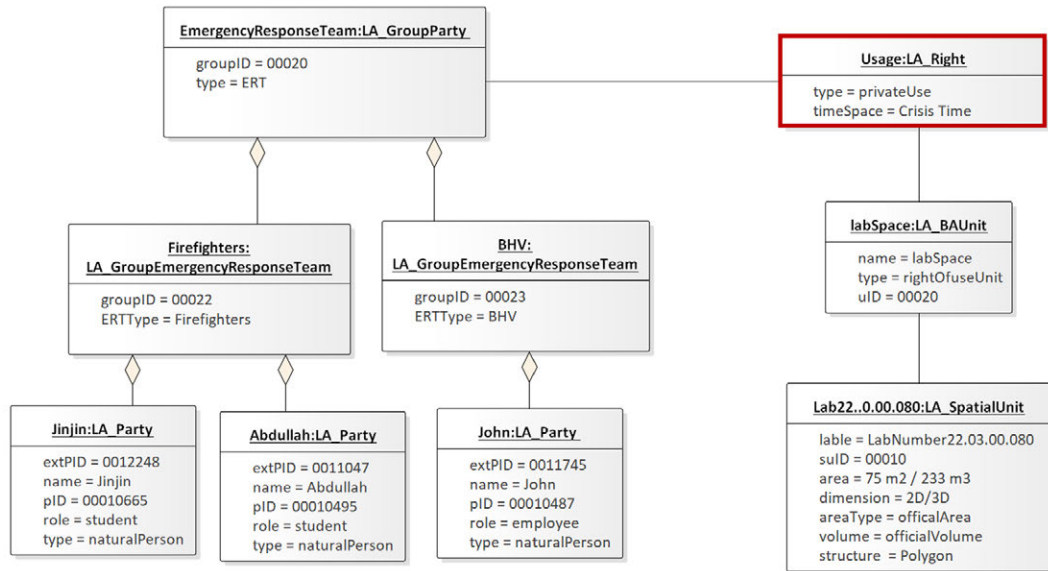
FIG. 8.4 Shows different timeSpace conditions for the same access rights

The three types of users have the same rights but the timeSpace attribute has changed the temporal condition for their accessibility rights. Users of the indoor space need to find the safest route from their location to the exit area and that is affected by their knowledge of the space. In many cases, the users will try to use the same route that they use every day. However, sometimes this will not be possible based on the incident condition. The users have to discover another route, and this may require them to pass through some spaces that are restricted for the users. However, by using the timeSpace attributes of the LA_RRR class, the user can have a conditional access rights based on the condition of the incident. This is allowing more choices for the user to escape from the dangerous zone to safe area.

TOC

8.3 Evacuation exercise scenarios

In this section, we investigate the access rights for the users during an incident by preparing two scenarios that are tested in a real exercise in an educational building during normal office time. The evacuation exercise takes place at the Faculty of Applied Sciences at Delft University of Technology, Netherlands. The building of the Faculty consists of six wings that have around 1200 spaces. Seven departments are sharing the building facilities. Therefore, based on the procedure during an incident, the Emergency Response Personnel (ERT) team has to assist users of the building to find their way to the emergency exit. Therefore, we have prepared two scenarios and a 3D model that contains several types of information about each space such as space number, usage, type, specification, organization unit, cleaning frequency (Cleaning), floor finishing (carpet or marble), chair information, department information, and section information as shown in Figure 8.5. The building consists of the main building front (F wing) and five wings behind (A, B, C, D, and E).
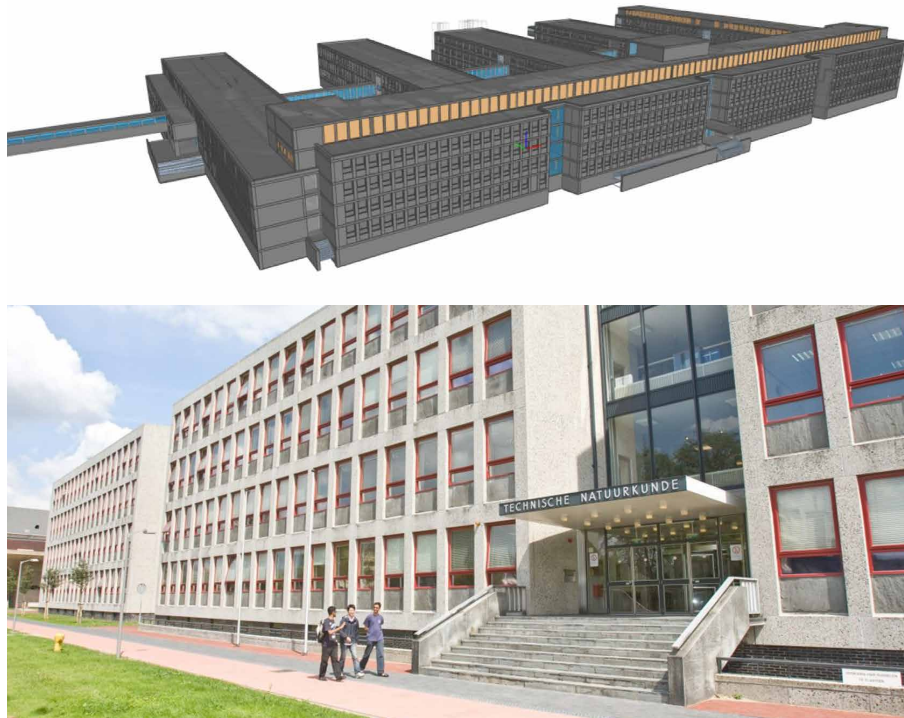
FIG. 8.5 3D model for Faculty of Applied Sciences (upper) and real picture of the entrance (bottom) (2016)

The Physics Engineering building consists of a front block with five wings at the back; this gives the building the shape of a hand, looking from above. Each wing has emergency exits at the connection with the front block, in the middle and at the end. The Physics building hosts chemical and physics laboratories, as well as offices, meeting rooms, lecture rooms and technical rooms. The central wing (C-wing) is the main logistic route from the goods delivery to the front block and its elevators and from there to the rest of the building. A number of laboratories and workshops are located in the C-wing.

8.3.1 Scenario A: Bomb reported

At a certain working day, the Physics Engineering reception is phoned about a bomb being placed in a staircase near the main entrance of the building. The exact location of the bomb is not given. The management decides to evacuate the building, keeping distance from the most eminent danger zones being the staircases of the C-wing and two adjacent wings (B and D), at its connection with the front block. The first responder teams are instructed accordingly and posted on strategic places to direct evacuees away from those staircases and out of the building. The slow-whoop is activated, supported by spoken words.

Just when the slow-whoop starts, one of the technicians is in the ground floor corridor of the C-wing transporting a large Dewar vessel with liquid nitrogen. In an attempt to get the Dewar out of the escape route, he misjudges his maneuver, hits an object on the floor and the Dewar topples over. Liquid nitrogen pours out of the Dewar and its vapour starts suppressing breathable air in this segment of the corridor, which is now separated from the rest of the corridor by the closed fire doors. Immediate action is needed to get al. people out of this airless section and to block entrance by others. However, a group of 15 workers are now trapped between the bomb area and the airless corridor. To evacuate them, an alternative bypass through a locked workshop had to be opened, leading the group to the safe exit in the middle of the C-wing. Based on the available information about the incident, the dangerous spaces could be highlighted and controlled by the ERT, to assist the users to find an alternative route to the emergency exit, even if the users usually do not have access rights to pass through some spaces. For the first Scenario, we created 2D and 3D evacuation plans to reflect the incident situation and to guide the user to exits of the building as shown in Figure 8.6. The 2D and 3D plans represent the ground, first and second floors.

Legend

Escape Route → Entrance & Transfer Area ▨
Emergency Exit ▨ Corridor ▨
Incident Zone
Blocked Corridor ▨
Detained Area ▨
Blocked Stairs ▨
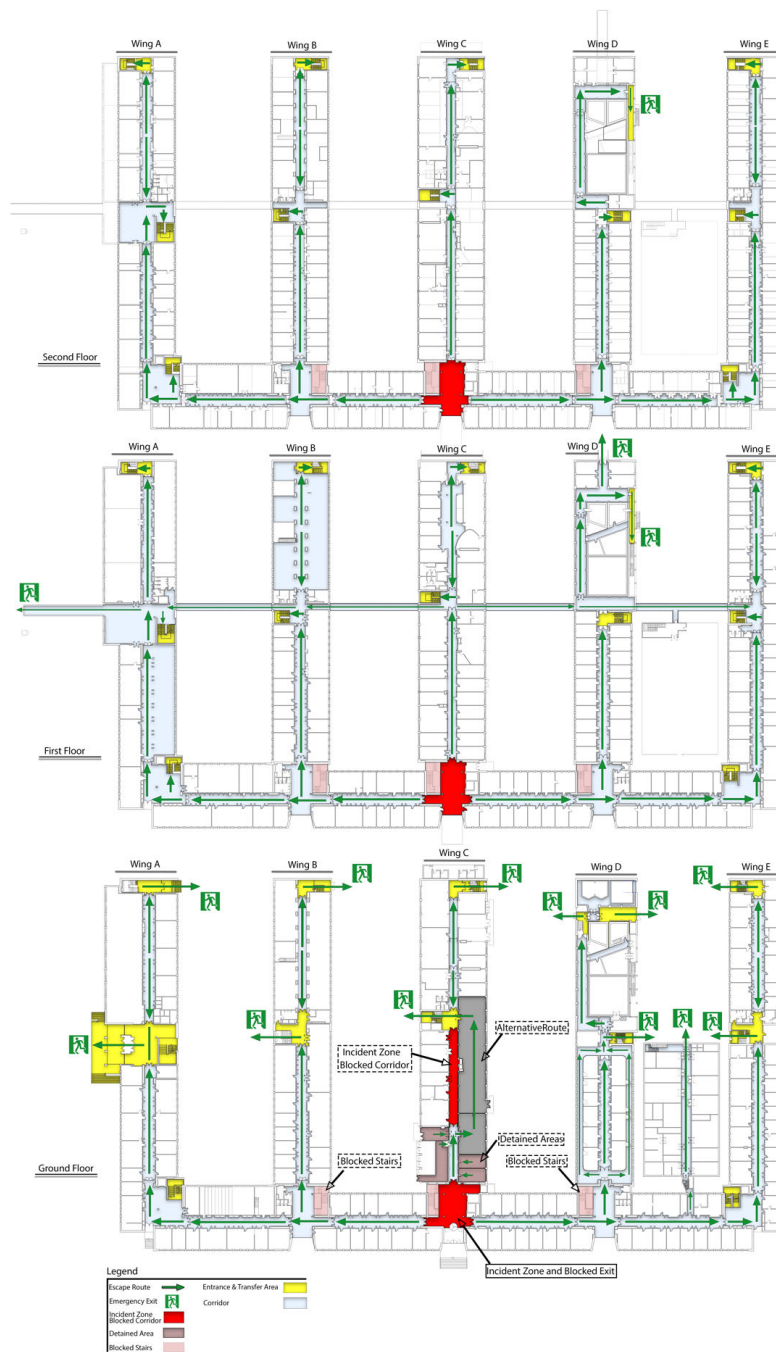
1

FIG. 8.6 2D and 3D plans for Scenario A: Bomb reported

2

FIG. 8.6 2D and 3D plans for Scenario A: Bomb reported

Zoom-in to the main incident area
on the ground floor
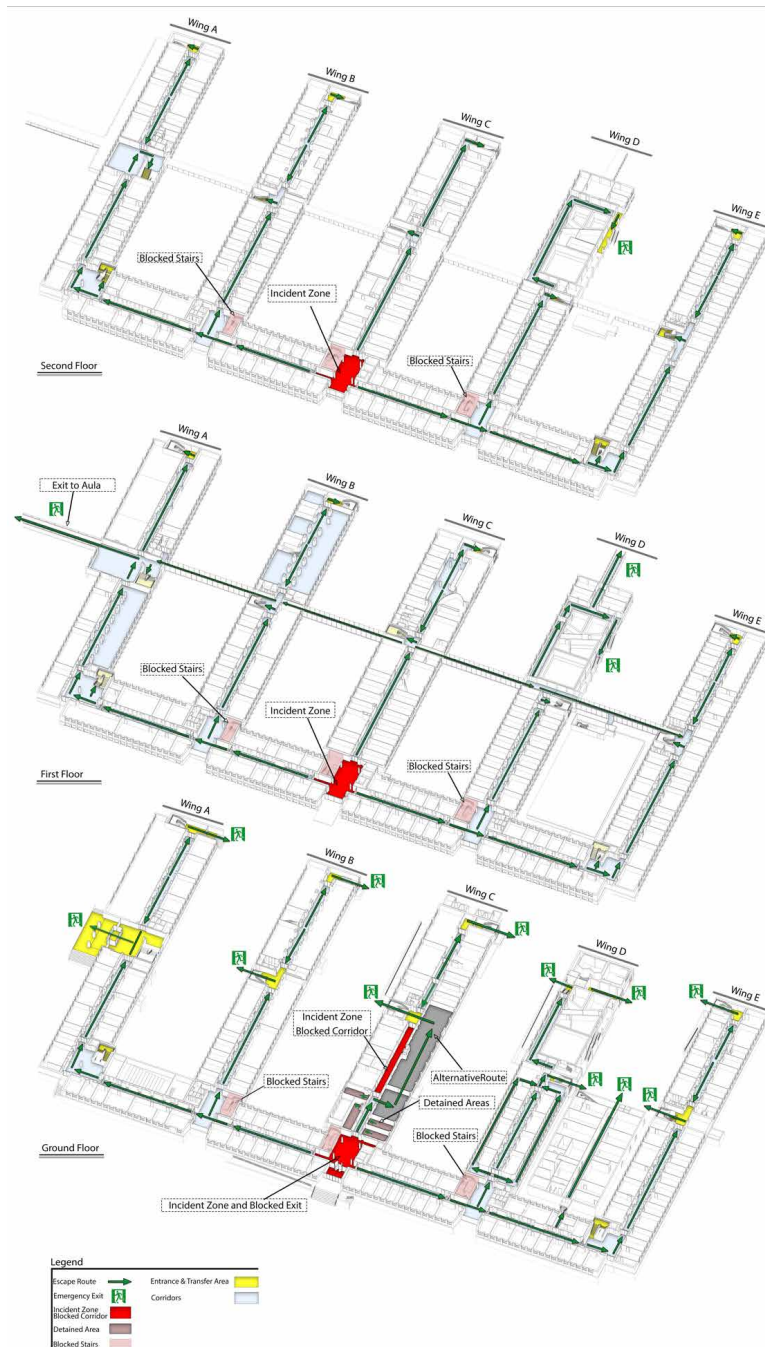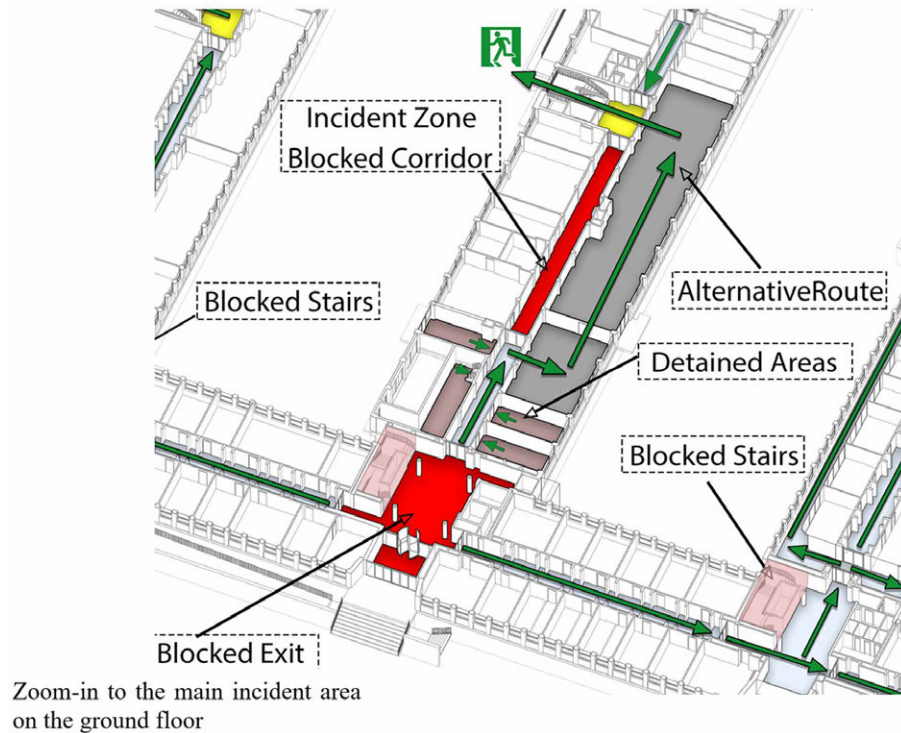
3

FIG. 8.6 2D and 3D plans for Scenario A: Bomb reported

Scenario B: Flammable gas leakage

At a certain working day, a leakage of flammable gas from a pipe feeding a laboratory, is noticed in the cellar of front wing near the C-wing. It is unclear how much gas has escaped and how far the gas has spread within the building. Because an explosion risk might be present, the management decides to evacuate the building, keeping distance from the most eminent danger zones. These danger zones are all floors in the center part of the F-wing and the all floors in the first section of the B, C and D-wings.

According to the available information about the incident, the ERT team could control the dangerous areas by closing the doors of that space to assisting the users to find an alternative route to the emergency exit. The first responder teams are instructed accordingly and are posted halfway the wings to block people from entering the danger zone. The slow-whoop is activated, supported by spoken words. People in the danger zone evacuate quickly through the main entrance (F-wing). People outside of the danger zone are directed to one of the many emergency exits of the A - E wings. Once all people are safely outside, the fire brigade ventilates the building by opening windows while technical staff seals the gas leak. After half an hour, the building is considered safe again. For the Scenario B, a 2D evacuation plan has been created to reflect the incident situation and to guide the user to exits of the building as shown in Figure 8.7. The 2D plan represents the ground, first and second floors.

1

FIG. 8.7 2D plan for Scenario B: Flammable gas leakage

Legend

Escape Route	➤	Entrance & Transfer Area	
Emergency Exit	🏃	Corridor	
Incident Zone Blocked Corridor			
Detained Area			
Blocked Stairs			
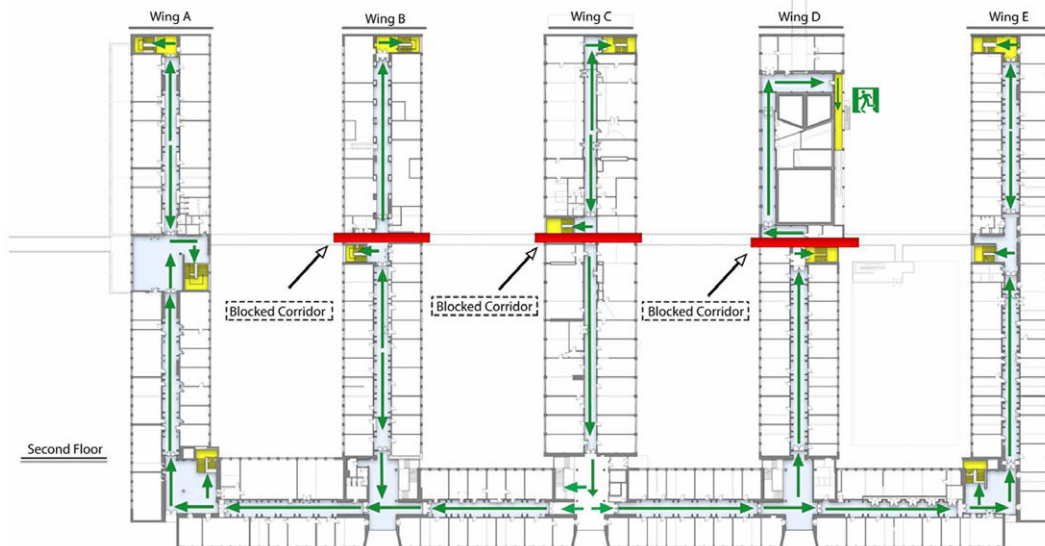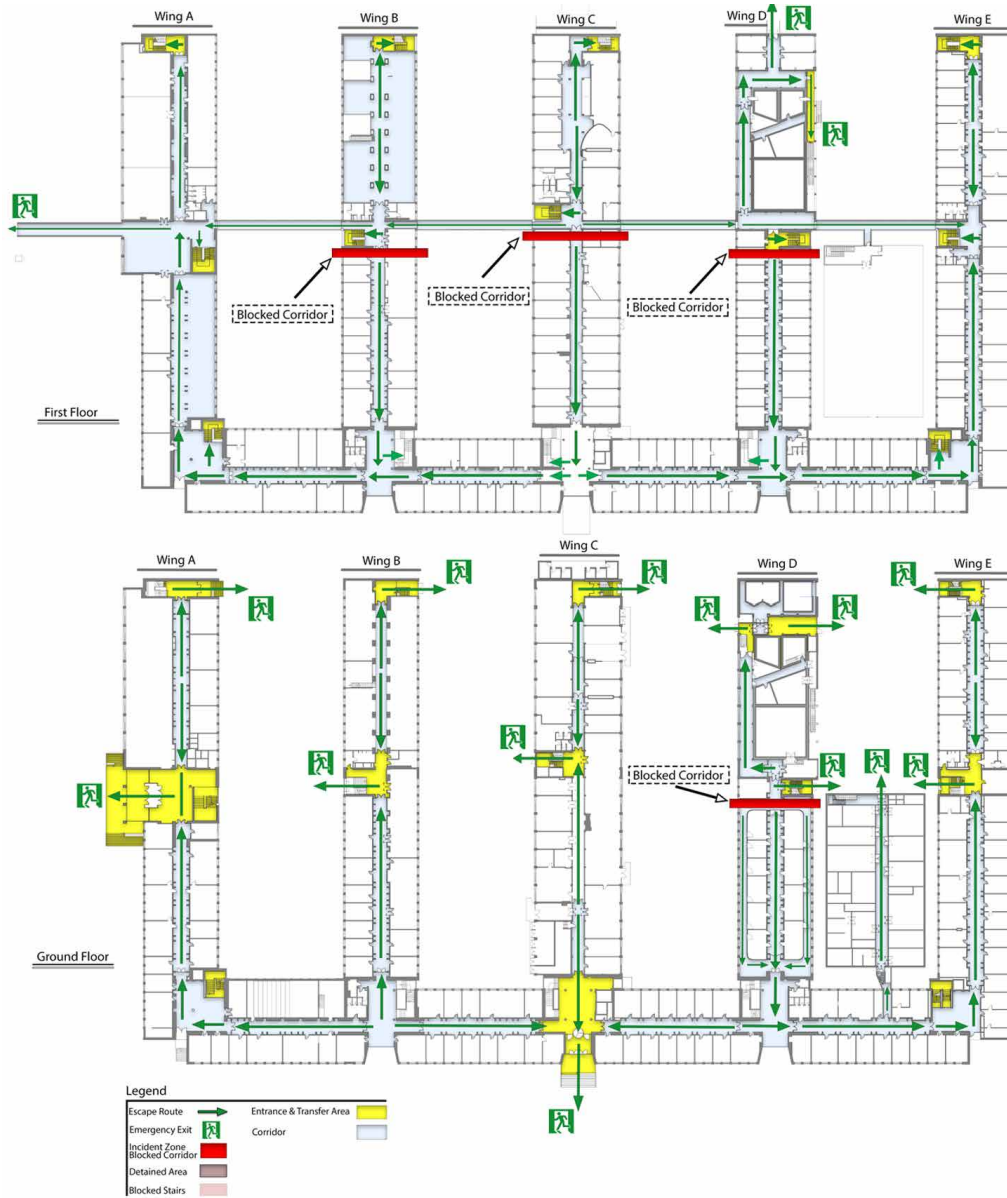
2

FIG. 8.7 2D plan for Scenario B: Flammable gas leakage

Initial result of the evacuation exercise

This section presents the result of the evacuation exercise in the Faculty of Applied Sciences. In the morning of the exercise day, there was a meeting with the Emergency Response Team (ERT) team to discuss the ideas behind the Scenarios and to have their approval. They had chosen scenario B for the exercise, and they started the preparation for the exercise. There were eight observers to cover the exits and to report the user's behaviour during the exercise. When the emergency alarm launched, the users of the building started to move from their offices and labs to the exits of the building. Based on the scenario, the users had to run the opposite direction of the blocked areas. However, most of the users anyhow choose to use the main entrances of the building.

Based on the observer's reports, the main entrance of the main building had been used by more than 120 users to escape from the building. The emergency exit that is located in middle wing C had been used by just 4 users as shown in Figure 8.8. The middle exit of wing B had been used by 75 users to escape and the other emergency exit of the same wing was closed, and that force the users to change their route to find another emergency exit as shown in Figure 8.9. The bridge between the Aula building (a neighbouring building does not show on Figure 8.5) and the Faculty of Applied Sciences was not used by any user to escape. The second main entrances of the building in wing A had been used by 64 users. The major conclusion of the reports was that users keep following the same route of their daily activity even during an incident.
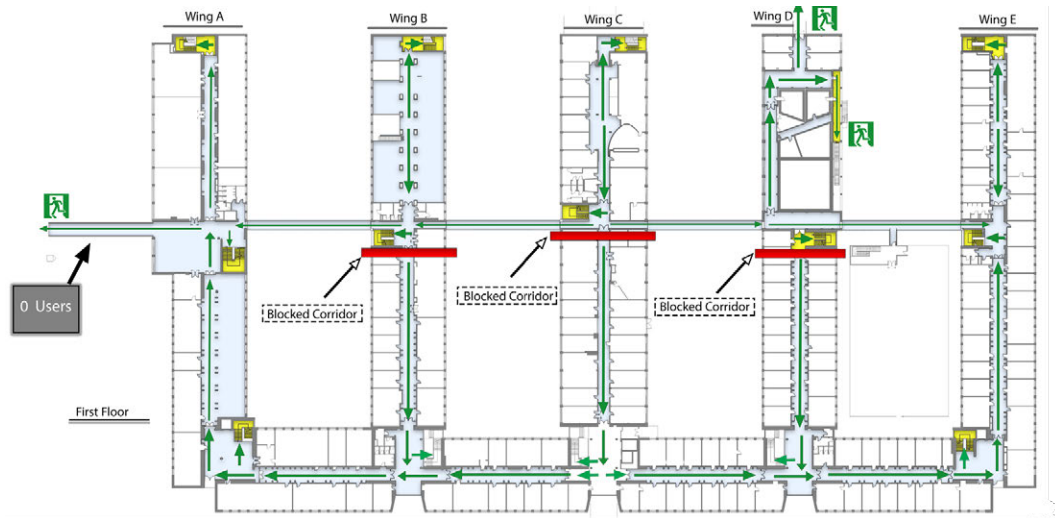
1
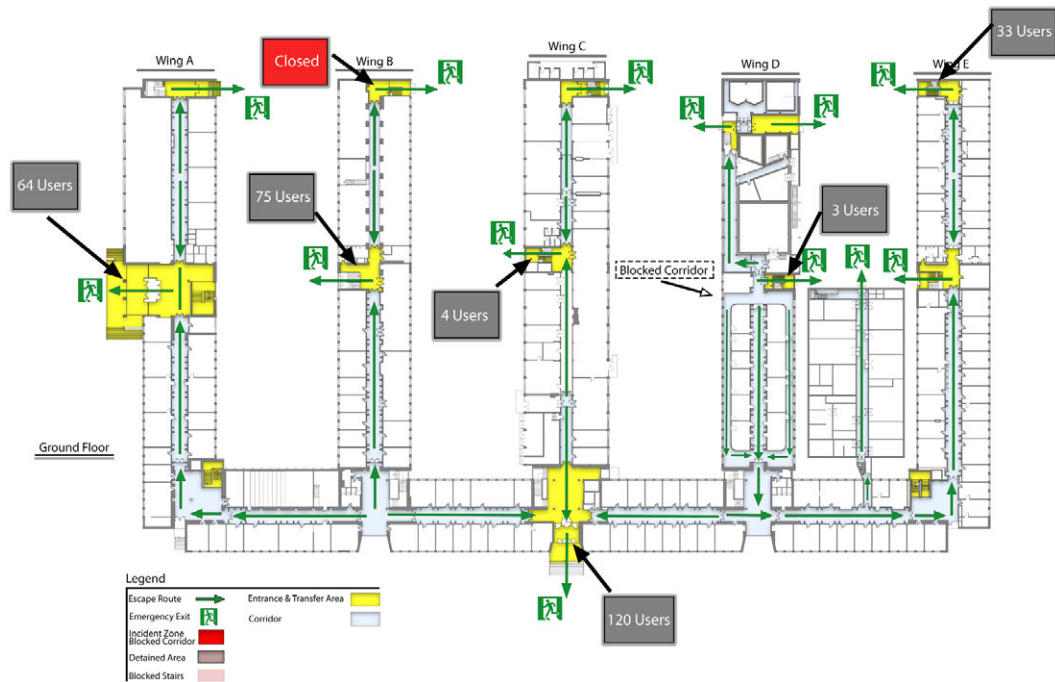
2

FIG. 8.8 2D floor plans represent the number of users that escape from the building
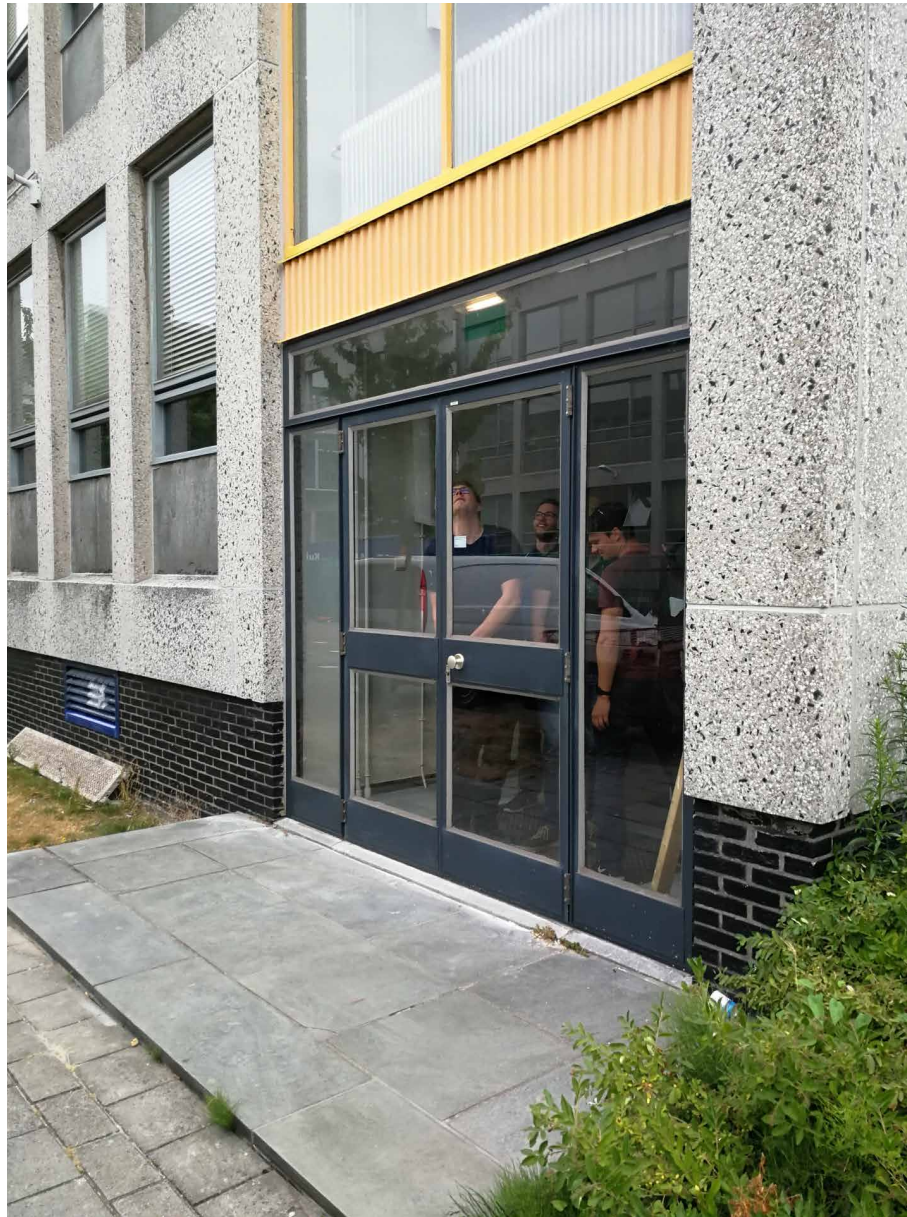
FIG. 8.9 An emergency exits was closed during the evacuation exercise

8.4 The collected WiFi data during the exercise

The evacuation exercise allowed to explore the user's movements during the exercise (reports from observers) and by collecting WiFi log data from the main WiFi network of TU Delft. The WiFi log data were important source of information to understand the movements and to complement the conclusions of the observers.

8.4.1 Description of the WiFi data

The WiFi log data has been collected from the WiFi network of TU Delft (Eduroam network). The accessibility of this WiFi network is limited to the employees, students and ERT. The WiFi log data table consists of eight columns and 13858 rows that represent the users logging data for the entire day as shown in Figure 8.10. Each column has different value as describe in Table 8.1.

	A	B	C	D
1	Client Username	Client MAC Address	Association Time	AP Name
2	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Wed Jul 11 10:42:49 CEST 2018	A-22-0-002
3	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Wed Jul 11 14:32:14 CEST 2018	A-22-0-002
4	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Wed Jul 11 14:37:19 CEST 2018	A-22-0-002
5	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Wed Jul 11 16:24:20 CEST 2018	A-22-0-002
6	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Wed Jul 11 17:40:12 CEST 2018	A-22-0-002
7	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:11:55 CEST 2018	A-22-0-002
8	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:16:59 CEST 2018	A-22-0-002
9	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:32:15 CEST 2018	A-22-0-002
10	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 14:57:40 CEST 2018	A-22-0-002
11	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 15:23:01 CEST 2018	A-22-0-002
12	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 15:43:20 CEST 2018	A-22-0-002
13	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 16:19:16 CEST 2018	A-22-0-002
14	4iTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Wed Jul 11 16:34:28 CEST 2018	A-22-0-002

FIG. 8.10 The users logging data for During evacuation exercise

TOC

TABLE 8.1 Description of the log data

Column title	Description
Client Username	A unique ID for each user and could be repeated more than once in the same data
Client MAC Address	A unique ID for each device and could not be repeated in the same data
Association Time	The time and date for each data log
AP Name	The name of WiFi access point
Map Location	The location of WiFi access point for example Building 22
Session Duration	The Session Duration describe the connection time for each device to specific access point
SNR	The signal to noise ratio
RSSI	The received signal strength indicator

The Client Username is the Username of the user of the WiFi network, and it is a unique ID that could be repeated more than once in the same data. The second type of information is the Client MAC Address, and it is the media access control address. The Client MAC Address is a is a unique identifier for a particular part of hardware such as mobile phone, laptop etc. Besides, each user could have more than one Client MAC Address in the same data. The Association Time column provides the date and time for each device record. The AP Name is the name of the WiFi access point, and it is a unique name. The location information (Building Number, Level etc.) for each WiFi access point is described in the Map Location column. The Session Duration column describes the connection time for each device to a specific access point. The signal to noise ratio (SNR) is a record for each device by comparing the signal strength to the level of background noise. The received signal strength indicator (RSSI) represents the collected signal strength (Bon et al., 2016).

The column format of the WiFi log data was modified to be used later in PostgreSQL. For example, all the spaces between the words were replaced with an underscore and the Association Time column was replaced with two separate columns as Date and Time as shown in Figure 8.11.

	A	B	C	D	E
1	Client_Username	Client_MAC_Address	Date	Time	AP_Name
2	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Jul 11 2018	10:42:49	A-22-0-002
3	2OwujnM8CCuhOYC/C+V9lkzlYXUWTtjN7XQXqBkDDag=	/KAwXVQDBTfm62e7ownm1/X1PTHxySqMcXfEq/469L0=	Jul 11 2018	14:32:14	A-22-0-002
4	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Jul 11 2018	14:37:19	A-22-0-002
5	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Jul 11 2018	16:24:20	A-22-0-002
6	QwQBHLfkHTNeHMItzCp9MMn6vaBtTCbVWcHTBgwFxoA=	sUhVoxVsz5MUCGO9FuNSF5gcPRtkamiiOgzAVhO5iaA=	Jul 11 2018	17:40:12	A-22-0-002
7	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:11:55	A-22-0-002
8	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:16:59	A-22-0-002
9	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:32:15	A-22-0-002
10	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	14:57:40	A-22-0-002
11	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	15:23:01	A-22-0-002
12	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	15:43:20	A-22-0-002
13	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:19:16	A-22-0-002
14	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:34:28	A-22-0-002
15	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:39:32	A-22-0-002
16	4jTkOldiJUtbFG61b9nZBkd87laG09RPUFI2o1tiZT4=	x8y50/NQDdPkx3H5e9/gKJG+rd15usQDETpnEosdBTE=	Jul 11 2018	16:59:47	A-22-0-002

FIG. 8.11 The replacement of the Association Time column with two separate columns as Date and Time

8.4.2 Positioning of the WiFi access points

Based on the WiFi log data, the WiFi access points were identified. However, the log data does not provide the XYZ coordinate for each WiFi access point. Therefore, we used the only available data, which was a paper map for each floor that represents the location of WiFi Access point, as shown in Figure 8.12.

The position of each WiFi access point was digitized manually in Revit and included in the 3D model of the Faculty of Applied Science. In total 387 WiFi access points around the entire building were digitized. The XYZ coordinates were extracted to a schedule in Revit and then exported to an Excel sheet, as shown in Figure 8.13.

FIG. 8.12 Part of the paper map of WiFi access point locations

<pointcoor>					
A	**B**	**C**	**D**	**E**	
Mark	Level	SetoutPoint-X_Coo	SetoutPoint-Y_Coo	SetoutPoint-Z_Coo	
1	Basement	207.278	96.025	1.500	
2	Basement	210.228	85.125	1.500	
3	Basement	202.563	73.155	1.500	
4	Basement	207.028	63.060	1.500	
5	Basement	211.488	48.660	1.500	
6	Basement	202.863	42.956	1.500	
7	Basement	211.488	29.403	1.500	

	A	B	C	D	E
1	AP-Name	Level	X	Y	Z
2	A-22-0-001	Basement	207.278	96.025	1.5
3	A-22-0-002	Basement	210.228	85.125	1.5
4	A-22-0-003	Basement	202.563	73.155	1.5
5	A-22-0-004	Basement	207.028	63.06	1.5
6	A-22-0-005	Basement	211.488	48.66	1.5
7	A-22-0-006	Basement	202.863	42.956	1.5
8	A-22-0-007	Basement	211.488	29.403	1.5
9	A-22-0-008	Basement	207.363	18.158	1.5
10	A-22-0-009	Basement	171.684	18.658	1.5
11	A-22-0-010	Basement	167.087	29.608	1.5
12	A-22-0-011	Basement	163.777	36.048	1.5
13	A-22-0-012	Basement	169.831	43.718	1.5
14	A-22-0-013	Basement	163.777	53.348	1.5
15	A-22-0-014	Basement	170.899	59.543	1.5

FIG. 8.13 Shows the coordinates of the WiFi access points from Revit to excel sheet

8.5 Database import, analysis and visualization

A database was created in PostgreSQL, and there were three steps to populate the database from the technical model of the LADM-IndoorGML and the 3D model. The first step was to import the technical model (SQL DDL) directly to Postgres. All the tables that are related to the conceptual model have been created and populated manually. The second step was to import the textual information of the 3D model to the database, and that has been done by using Open Database Connectivity (ODBC) to link between Postgres and Revit software. The schedule that has all the information about the spaces was imported to the database in an automated way.

TOC

The 3D geometry of the 3D model was imported into the database in the third step by converting the 3D spaces into IFC model. Consequently, the IFC model was imported to the database by using in-house software. The 3D geometry was linked to the semantic information, schedules, and all other properties in the database by the unique geometry ID. Afterwards, the data have been reorganized according to the spatial schema of the LADM-IndoorGML model using SQL queries. Figure 8.14 shows the table in Postgres that contains information about the function of the spaces and the 3D geometries. A number of queries was performed to illustrate how the DBMS can be used. For example, Figure 8.15 shows the spaces that are accessible for students and staff.

FIG. 8.14 Part of the LADM-IndoorGML schema

a)

Select name, usagefunction, geom
From uspaces

b)

Select name, usagefunction, geom
From uspaces
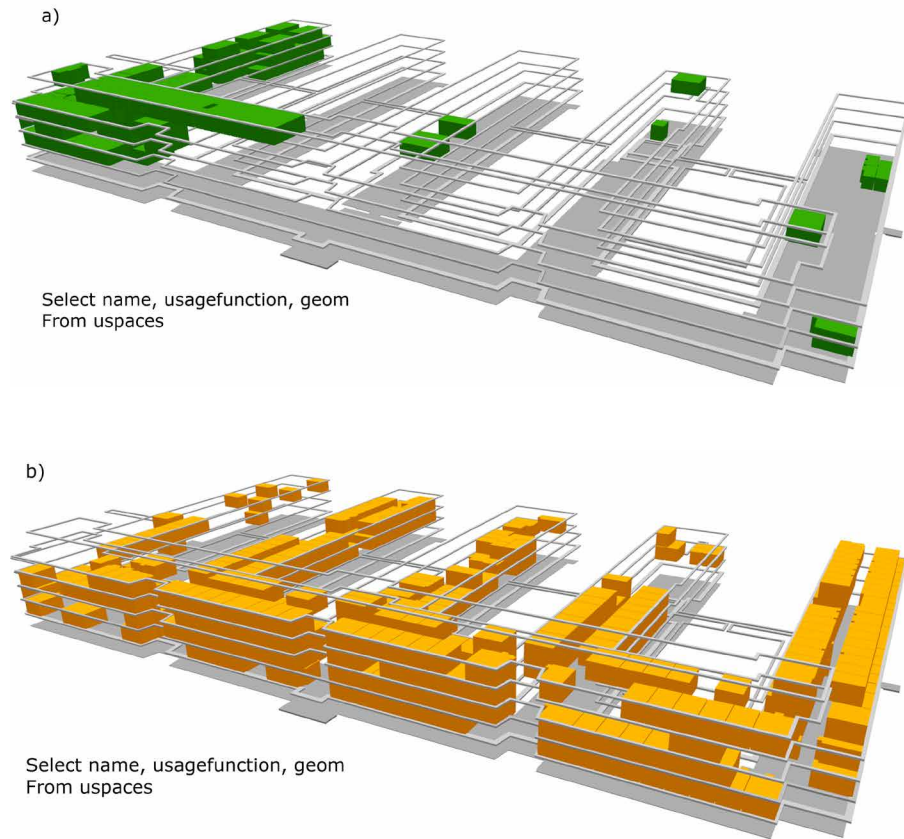
FIG. 8.15 Accessible spaces for a) students and b) staff

Using the Excel sheets for the WiFi Log data and the XYZ coordinates for all
WiFi access points, the tables were created in the LADM-IndoorGML database
in PostgreSQL. The XYZ coordinates table were used to convert the position
of each WiFi access point into geometry as shown in Figure 8.16 by using the
following query:

```
create table pointgeom
as select ST_MakePoint(x, y, z), ap_name, level
from WiFiaccesspoint;
```

TOC

FIG. 8.16 Geometry table of WiFi access points

The WiFi Log data table included records for two days (10-07-
2018 and 11-07-2018) while the evacuation exercise was on 11-07-
2018 from 15:55:00 to 16:35:00 hours. Thus, a new table was created that includes
only the records for evacuation exercise period as shown in Figure 8.17 by using the
following query:

```
create table userandpointgeomfinal
as select WiFi.client_username , WiFi.ap_name, WiFi.time, WiFipointgeom.level,
WiFipointgeom.st_makepoint
from WiFi
inner join WiFipointgeom on WiFi.ap_name=WiFipointgeom.ap_name
where date ='2018-07-11' and Time between '15:55:00' and '16:35:00'
order by WiFi.time;
```


FIG. 8.17 Log data table for evacuation exercise in PostgreSQL

Furthermore, the FME software was used to check if the WiFi access points
(geometry) overlap with ifcSpaces of the 3D model of Faculty of Applied Science as
shown in Figure 8.18.

TOC

8.6 Results of the evacuation exercise based on the collected WiFi data

8.6.1 Identification of individual trajectories

The WiFi log data shows that each user has several records during the evacuation exercise. The way we used this data to analyses the movement is illustrated with two examples.

Example 1: The records have shown that the user X was connected to six different WiFi access points and the time difference between each connection was around five minutes as shown in Figure 8.19. The position of the first WiFi Access point was in the Basement level and the time of the record was 16:03:59. The user was on the

basement until 16:14:07 and then a new connection record shows that the user moved from the basement to the ground floor, and then the user connection returned to the basement for the next 15 minutes. The last WiFi access point that appeared in the log data for this user was in the basement and very close to the emergency exit. The records show that the user has moved from wing E to Wing B during the evacuation exercise.

	client_username character varying	ap_name character varying	time time without time zone	ap_name character varying	level character varying
1	LFFQvTIBbkxxwiw1v…	A-22-0-004	16:03:59	A-22-0-004	Basement
2	LFFQvTIBbkxxwiw1v…	A-22-0-008	16:09:03	A-22-0-008	Basement
3	LFFQvTIBbkxxwiw1v…	A-22-0-046	16:14:08	A-22-0-046	GroundFloor
4	LFFQvTIBbkxxwiw1v…	A-22-0-017	16:19:16	A-22-0-017	Basement
5	LFFQvTIBbkxxwiw1v…	A-22-0-021	16:24:20	A-22-0-021	Basement
6	LFFQvTIBbkxxwiw1v…	A-22-0-023	16:29:24	A-22-0-023	Basement

FIG. 8.19 The log records for single user

The Log data for the user was used to create trajectory line as shown in Figure 8.20 by using the following query. The trajectory has been visualized as a 3D line in QGIS as shown in Figure 8.21.

```
SELECT ST_MakeLine (ARRAY(SELECT st_makepoint FROM pointgeomuser1 ORDER BY
time));
```

	st_makeline geometry
1	010200008006000000037894160E5E0694048E17A14AE874F40000000000000F83F560E2DB29DEB69409CC420B072283240000000000000F83FF2D24D6210

FIG. 8.20 Generating line geometry for movement of single user
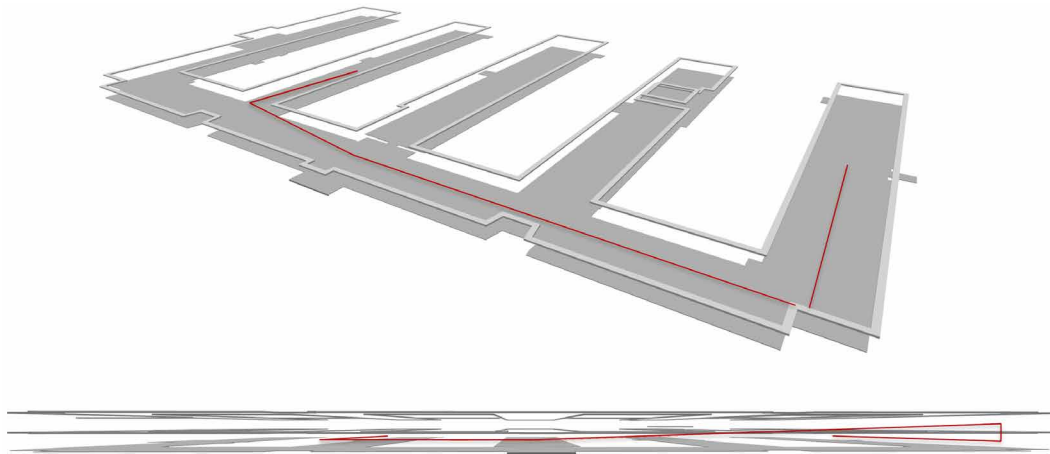
FIG. 8.21 The trajectory line for single user

Another single user Y was connected to three different WiFi access points. The first record was at 16:03:58 on the ground floor (in front of the main entrance) and then the user had another record at 16:09:02 on ground floor around the corner of the building between wing A and the main wing of the building as shown in Figure 8.22. The last record of the user was in the basement next to the emergency exit. The log data have been used to create a trajectory line for the movement of the user as shown in Figure 8.23.

	client_username character varying	ap_name character varying	time time without time zone	level character varying	st_makepoint geometry
1	Tvt7wYNA4KLQjUFO...	A-22-0-066	16:03:58	GroundFloor	010100008021B0726...
2	Tvt7wYNA4KLQjUFO...	A-22-0-087	16:09:02	GroundFloor	01010000804C37894...
3	Tvt7wYNA4KLQjUFO...	A-22-0-017	16:19:15	Basement	0101000080A69BC4...

FIG. 8.22 The log records for single user
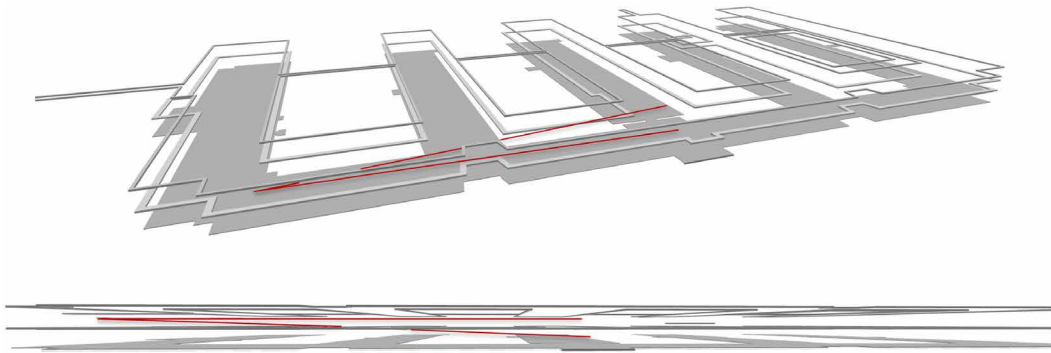
FIG. 8.23 The trajectory line for single user

Visualization of movements

The visualization of trajectories is important, but it is confusing when too many people are being monitored. Therefore, we have explored another approach, in which the WiFi log data are analyzed per access point and not per induvial user. We count the number of devices that are connected to each WiFi access point during an interval of five minutes. The time of the evacuation exercise has been divided into eight periods, and there will be a separate snapshot for each period that describes the movements as a group of users during the time of the evacuation exercise as shown in Figure 8.24. All the records are subdivided into eight time-frames as explained below.

The first time-frame is between 15:55:00 and 16:00:00 hours and the total number of devices is 105. The second floor and ground floor have the highest number of connected devices, while the basement and fourth floor have the lowest as shown in Table 8.4. The WiFi access points have been classified into four groups based on the number of devices that were connected to each WiFi access point as shown in Table 8.2. The distribution of the four groups shows that most of the activity was on the ground floor, second floor, and third floor. Several WiFi access points had between two and four connected devices as shown in Figure 8.24a.

The Second time-frame is between 16:00:00 and 16:05:00 hours and the total number of devices is 102. Table 8.4 shows the number of devices that were connected to the WiFi network based on the floor level, and the largest number of connected devices were in second, ground and first floors. The WiFi access points have been classified into three groups as shown in Table 8.2. The WiFi access points that had three connected devices were on the third floor. While the rest of the WiFi access points of the second time frame had between one and two connected devices and these WiFi access points were all over the building as shown in Figure 8.24b.

The third time-frame is between 16:05:00 and 16:10:00 hours and the total number of devices is 224. The highest number of devices that were connected to the WiFi network is on the second floor. The ground, first, and second floors contained almost all the connected devices as shown in Table 8.4. The WiFi access points have been classified into ten groups as shown in Table 8.2. The second floor of the main building had two WiFi access points that had 11 and 25 connected devices in the third time frame. While the first and second floor of wing A had two WiFi access point that had 12 and 13 connected devices. Furthermore, the ground floor of wing A had one WiFi access point that had six connected devices. The rest of the WiFi access points in this time frame had between one and five connected devices and they were distributed all over the building as shown in Figure 8.24c.

The fourth time-frame is between 16:10:00 and 16:15:00 hours and the total number of devices is 133. The number of devices that were connected to the WiFi network on the ground floor was the second highest number after the second floor as shown in Table 8.4. The WiFi access points have been classified into seven groups based on the number of devices that were connected to each access point as shown in Table 8.2. The WiFi access points that were on the second floor had the most significant number of connected devices between 2 and 11 devices. At the same time, the WiFi access points of the ground floor had up to eight connected devices. The WiFi access points on the first floor had no more than four connected devices. The rest of the WiFi access points had between one and three connected devices as shown in Figure 8.24d.

TABLE 8.2 The number of WiFi access points and their connected devices in the first, second, third, and fourth time frames.

Time-frame number	Group number	Number of WiFi Access points	Number of connected Devices
First	1	68	1
	2	12	2
	3	3	3
	4	1	4
Second	1	59	1
	2	17	2
	3	3	3
Third	1	56	1
	2	15	2
	3	14	3
	4	2	4
	5	3	5
	6	2	6
	7	1	11
	8	1	12
	9	1	13
	10	1	25
Fourth	1	32	1
	2	14	2
	3	8	3
	4	5	4
	5	1	8
	6	1	10
	7	1	11

The Fifth time-frame is between 16:15:00 and 16:20:00 hours and the total number of devices is 238. The Ground floor had the largest number of connected devices as shown in Table 8.4. The WiFi access points have been classified into six groups based on the number of devices that were connected to each access point as shown in Table 8.3. The WiFi access points of the ground floor had between one and seven connected devices while the WiFi access point of the first floor had up to five connected devices. The rest of WiFi access points of this time frame had between one and three connected devices as shown in Figure 8.24e.

The Sixth time-frame is between 16:20:00 and 16:25:00 hours and the total number of devices was 154. Table 8.4 shows the number of devices that were connected to the WiFi network in the first floor was the highest in this time frame. Then, the second and the ground floors contained two large groups of devices. The WiFi access points have been classified into five groups based on the number of devices that were connected to each access point as shown in Table 8.3. The first floor of wing B had WiFi access points that had between two and five connected devices. On the other hand, the ground floor of the main building and wing E had WiFi access points that had between two and four connected devices. The rest of the levels had WiFi access points that had between one and three connected devices as shown in Figure 8.24f.

The seventh time-frame is between 16:25:00 and 16:30:00 hours and the total number of devices was 98. Table 8.4 shows the number of devices that were connected to the WiFi network in the ground floor. The WiFi access points have been classified into four groups based on the number of devices that were connected to each access point as shown in Table 8.3. The Second and third floors had one WiFi access point that had for connected devices while the rest of the levels of the building had WiFi access points that had between one and three connected devices as shown in Figure 8.24g.

The eighth time-frame is between 16:30:00 and 16:35:00 hours and the total number of devices was 83. Table 8.4 shows the number of devices that were connected to the WiFi network based on the floor level. The WiFi access points have been classified into three groups based on the number of devices that were connected to each access point as shown in Table 8.3. The second and third floor had one WiFi access points that had between one and three connected devices. On the other hand, the rest of the floors had WiFi access points that had between one and two connected devices as shown in Figure 8.24h.

TABLE 8.3 The number of WiFi access points and their connected devices in the fifth, sixth, seventh, and eighth time frames.

Time-frame number	Group number	Number of WiFi Access points	Number of connected Devices
Fifth	1	110	1
	2	38	2
	3	8	3
	4	4	4
	5	1	5
	6	1	7
Sixth	1	84	1
	2	20	2
	3	3	3
	4	4	4
	5	1	5
Seventh	1	63	1
	2	9	2
	3	3	3
	4	2	4
Eighth	1	59	1
	2	9	2
	3	2	3

TABLE 8.4 Number of connected devices during the entire time of the evacuation

Level	T-F 1	T-F 2	T-F 3	T-F 4	T-F 5	T-F 6	T-F 7	T-F 8
Basement	5	5	5	1	14	7	3	4
Ground	27	25	53	40	72	37	32	19
First	23	20	67	26	66	41	22	20
Second	28	33	90	59	49	38	24	22
Third	17	116	9	7	36	25	14	17
Fourth	5	3	0	0	1	6	3	1

a) Time Frame from 15:55:00 to 16:00:00

Legend
- Fourth Floor
- Third Floor
- Second Floor
- First Floor
- Ground Floor
- Basement Floor
- Emergency Exit

Number of Devices
1   3   5   7   10   12   25
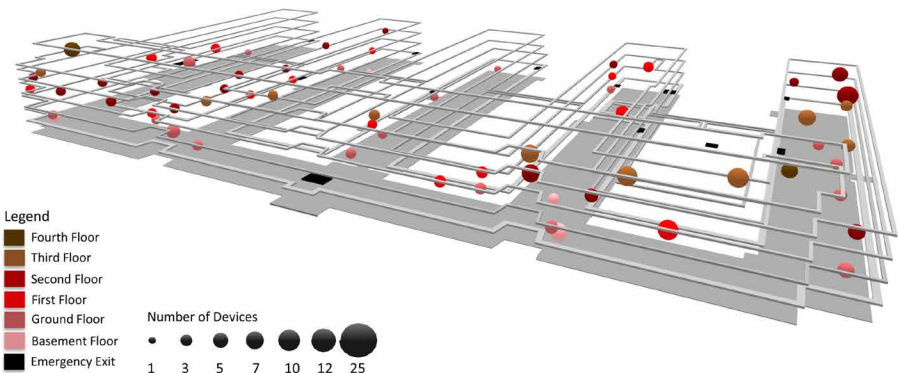
b) Time Frame from 16:00:00 to 16:05:00

Legend
- Fourth Floor
- Third Floor
- Second Floor
- First Floor
- Ground Floor
- Basement Floor
- Emergency Exit

Number of Devices
1   3   5   7   10   12   25
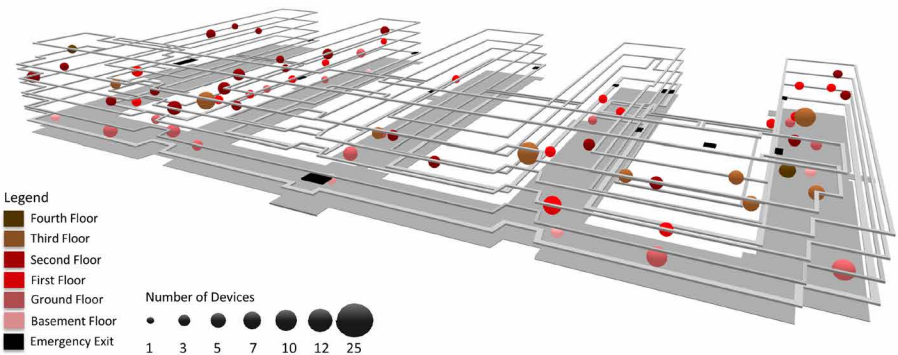
c) Time Frame from 16:05:00 to 16:10:00
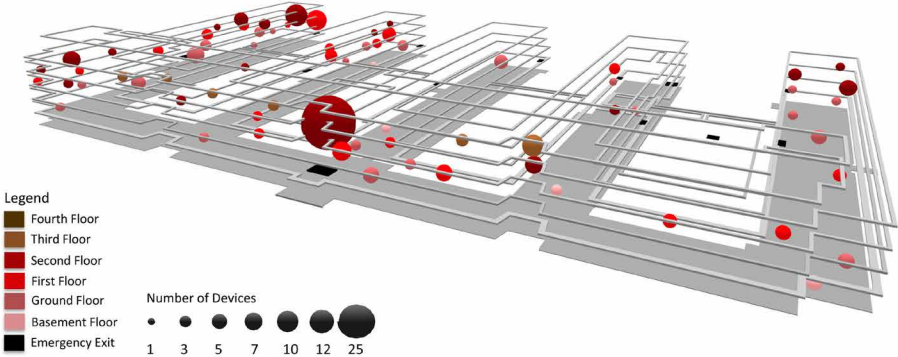
Legend
- Fourth Floor
- Third Floor
- Second Floor
- First Floor
- Ground Floor
- Basement Floor
- Emergency Exit

Number of Devices
1   3   5   7   10   12   25

FIG. 8.24 The eight time-frames that represent the movements of the users as groups

TOC

d) Time Frame from 16:10:00 to 16:15:00

Legend
- Fourth Floor
- Third Floor
- Second Floor
- First Floor
- Ground Floor
- Basement Floor
- Emergency Exit

Number of Devices
1 3 5 7 10 12 25
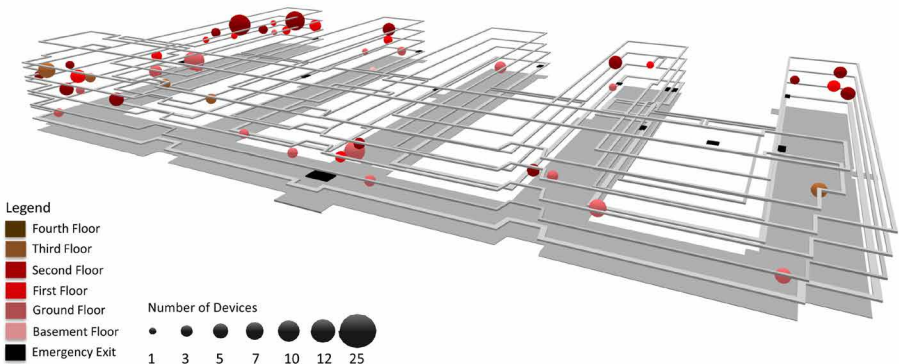
e) Time Frame from 16:15:00 to 16:20:00

Legend
- Fourth Floor
- Third Floor
- Second Floor
- First Floor
- Ground Floor
- Basement Floor
- Emergency Exit

Number of Devices
1 3 5 7 10 12 25
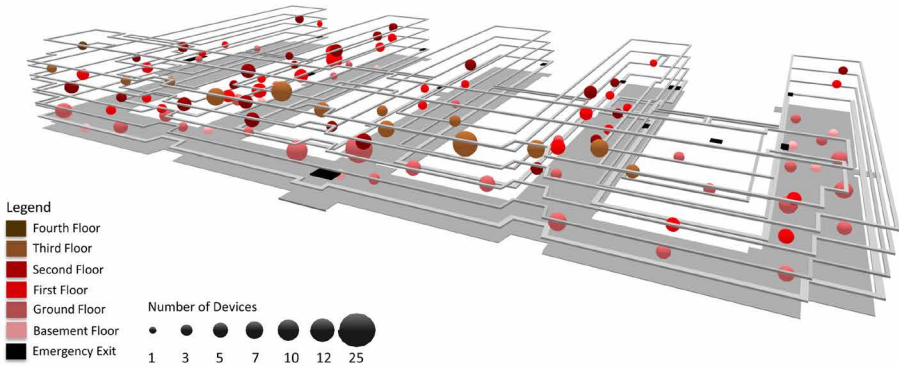
f) Time Frame from 16:20:00 to 16:25:00
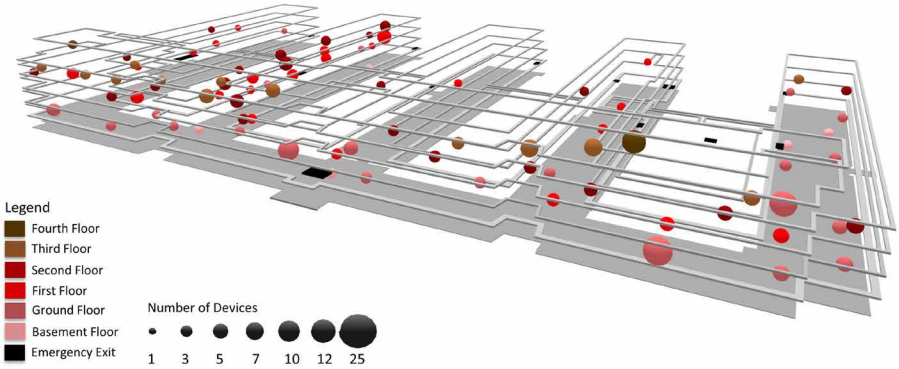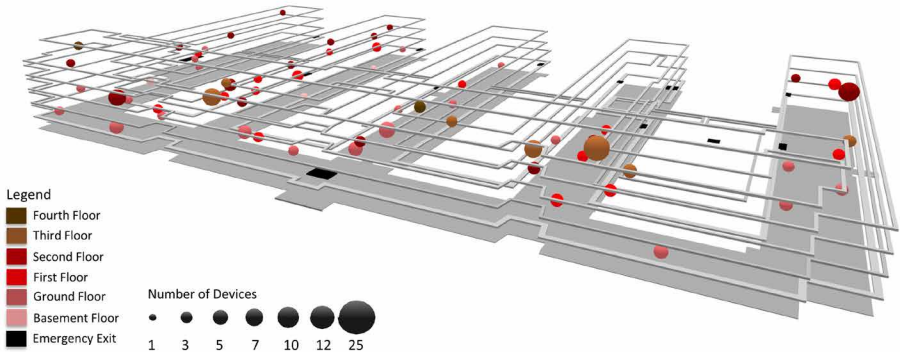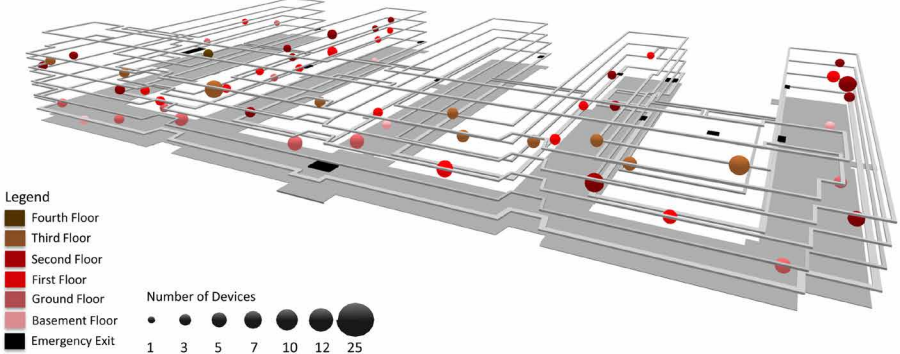
Legend
- Fourth Floor
- Third Floor
- Second Floor
- First Floor
- Ground Floor
- Basement Floor
- Emergency Exit

Number of Devices
1 3 5 7 10 12 25

FIG. 8.24 The eight time-frames that represent the movements of the users as groups

FIG. 8.24 The eight time-frames that represent the movements of the users as groups

Comparison

During the evacuation exercise, the observers counted the number of users that evacuated from the building. Table 8.5 shows a comparison between the number of users that had been evacuated based on the observers and based on the WiFi log data. The WiFi access point has been chosen according to the nearest distance to the emergency exit located on the ground floor.

TABLE 8.5 A comparison between the number of users that had been evacuated based on the reporting of the observers and based on the WiFi log data.

Wing	Based on observers	Based on WiFi log data	WiFi access point
Main	120	29	A-22-0-066
A	64	24	A-22-0-092
B	75	3	A-22-0-080
C	4	1	A-22-0-070
D	3	1	A-22-0-058
E	33	2	A-22-0-035

Another way to compare between the observers' records and the log data, and that by taking into consideration the WiFi access points which is located above or below (in the vertical direction) of the emergency exit. This includes the user movements from all levels to the ground floor as shown in Table 8.6.

TABLE 8.6 A comparison between the number of users that had been evacuated based on the observers and based on the WiFi log data by considering the WiFi access point in the vertical direction.

Wing	Based on observers	Based on WiFi log data
Main	120	83
A	64	30
B	75	24
C	4	4
D	3	5
E	33	22

The third way of comparing between the number of users that had been evacuated based on the observers and based on the WiFi log data was by including the WiFi access points that are on the vertical and horizontal direction for all exits as shown in Table 8.7.

TABLE 8.7 A comparison between the number of users that had been evacuated based on the observers and based on the WiFi log data by considering the WiFi access points in the vertical and horizontal direction.

Wing	Based on observers	Based on WiFi log data
Main	120	130
A	64	70
B	75	82
C	4	9
D	3	11
E	33	34

8.8 Summary

This chapter presented the analysis and visualization of the WiFi log data using the extended LADM-IndoorGML model to support the ERT and the users during an incident. This chapter has answered the sub-questions "C3. How the RRRs of the users will affect the indoor navigation during crisis situations? and C4. What is the capability of LADM Party package to represent different types of users in several indoor environments?". The Integrated LADM-IndoorGML model, defining Rights, Restrictions, and Responsibilities, is extended to cover different times: normal operational time / office hours, outside office hours and crisis situation, and include data of importance for ERT. This type of information is essential to ERT to be able to evacuate the users of the building and to follow the movement of the users during the incident. Furthermore, by indicating and visualizing which areas are considered as restricted or accessible, the ERT can deal with the incident in more efficient way. Out study has clearly shown that the 2D representation of the indoor environments does not provide the entire picture of the indoor spaces and important details such as construction elements. The hypothesis that 3D representations (and route computations) result is better/ faster for evacuation is confirmed.

Each type of buildings has a complex indoor environment and several types of users. The user behaviour is changing based on the type of building and the condition of the indoor space, such as during an incident. By understanding the movement of the users of these indoor environments during an emergency, we are able to provide better navigation routes for different types of users and during different kind of indoor conditions.

The study consisted of several stages to define rights, restrictions, and responsibilities during an incident. A database in PostgreSQL was created according to the technical LADM-IndoorGML model and populated by using real data that has been collected during an evacuation exercise. 2D and 3D floor plans were prepared to support the ERT and the users during the exercise. The WiFi data that was collected during the exercise, was used to analyze and visualize the movements of the users. For this purpose, the locations of the WiFi access points were digitized manually in Revit and imported automatically to the database. The representation of access points in the 3D model allowed to record the relationship between the building elements and the movements of the users.

There were two different types of analysis and visualization that have been covered, 1) following individual users and 2) monitoring the number of users attached to one WiFi access point. The representation of individual user movements has shown that a new record was available every five minutes and that is a long time for a walking person even in a normal day. This period of time is enough for users to move to the other side of the building and return to the same position.

The flow of the users' movement as a group was represented by monitoring the number of users attached to each WiFi access point. Therefore, the time of the emergency exercise was divided into eight time-frames, where each time frame represents the WiFi access points based on the number of connected devices. The presented approach can give a very good picture on the movement towards the (main) exit of the building.

The study has shown that by determining the location of the WiFi access point, the representation of the user's movements is possible as an individual or group of users based on the location of the WiFi access point. The visualization of each WiFi access point as a sphere reflects well the number of connected devices by changing the size of the sphere. Although the study could not provide a very accurate trajectory of movement, it indicated quite well which spaces contained more connected devices (and therefore people) than other spaces. Eventually, this was used to study the users' movements flow. The comparison between the number of users that were evacuated based on the reporting of the observers and based on the WiFi log data

showed that the best match is achieved by considering WiFi access points near to the exit point in both vertical and horizontal direction.

The study revealed a few shortages within the provided WiFi data. The time resolution of the WiFi log data, i.e. that a new record was available every five minutes, is a critical issue. Furthermore, the WiFi data did not include any information about the type of user such as student, employee, etc. because of the privacy issues, and that did not allow to visualize the movements based on their RRR.

9 Web-based application using the LADM-Indoor-GML model

The previous chapter addresses the impact of the access rights of the indoor spaces during an emergency evacuation. This chapter presents the development of a web-based application for the integrated model of LADM and IndoorGML to provide indoor navigation based on the user's access rights in an educational building. Every user with a web browser on a laptop, tablet, or smartphone may use the indoor routing application because it is a web-based application. This chapter provides a complete description of all the steps to design, develop and test the integrated model of LADM and IndoorGML.

This chapter is organized as follows: The introduction of this chapter is presented in section 9.1. Section 9.2 describes the creation of the 3D model. The development of the database is presented in Section 9.3. The client GUI and visualization of the routes in Cesium JS is represented in Section 9.4 and the chapter ends with the summary in section 9.5.

Web-based navigation and visualisation

Many indoor applications have been developed to provide guidance in navigating while inside a building. Each indoor navigation application is based on a different approach and technology to provide the best routing experience, and this resulted in many different applications on different devices. In this respect, a web-based visualisation platform allows every user with a web browser on the laptop, tablet, or mobile to use an indoor routing application. The application provides a better understanding of the indoor environment during the navigation.

Web-based applications are a form of software that lets users communicate with a remote server via a web browser. They have been more common in recent years, displacing desktop programs and establishing themselves as a critical tool for small and large enterprises all around the world. Web-based applications offer several advantages over traditional desktop programs, the most notable of which is their mobility. When utilizing web-based apps, users do not need to install additional software, and developers do not need to build different versions of the same program for various operating systems. Any device that can run a compatible browser and has an active internet connection may use web applications.

Many indoor navigation systems have been developed which besides navigation path also provide localization and user tracking. An indoor navigation system that supports rescuers during emergencies by finding the shortest route has been developed by (Rueppel and Stuebbe, 2008). The system provides the rescuers with information related to their spatial context by utilizing wireless LAN, Ultra-wide Band (UWB), and Radio Frequency Identification (RFID). Additionally, the developed indoor navigation system presents floor plans on mobile devices from the existing 3D BIM models. A self-deployable solution for indoor navigation systems during an emergency has been proposed in (Renaudin et al., 2007). The indoor navigation system is based on radio-frequency identification tags and inertial Micro Electromechanical Sensors to be estimated and matched with the building's pure inertial positioning system.

An indoor navigation system called Near Field Communication (NFC) has been proposed in (Ozdenizci et al., 2011); the system aims to provide more reliable localization using NSF tags, placed inside the building. Such systems providing localization support have been focused on providing navigation to disabled users or users with special needs. A low-cost indoor navigation system for visually impaired, proposed by (Ivanov 2010), is based on mobile terminals, NFC and RFID tags.

The application allows the users to imagine the space's map, such as the space dimensions and the relative location of interest points. Another low-cost system based on 3D models and UWB tags for localization and guidance of visually impaired people has been recently developed and tested by Benitez Sandoval et al.2020.

However, these applications do not consider the users' rights, restrictions, and responsibilities, and as a result they are providing the same routing options for all users. In reality, each user has a different relationship with the indoor environment. Therefore, the integrated model of LADM-IndoorGML should be used to provide an optimal route.

This chapter presents a web-based application for 3D indoor navigation for an educational building based on the integrated model of ISO 19152 LADM and OGC IndoorGML. The international standards aims to ensure that the presented solution works for any building in the world. The integrated model of LADM and IndoorGML allows to compute different routes with respect to the user's (such as student, visitor, maintenance, and teacher) access rights.

The technical implementation of LADM-IndoorGML has been used as a case in the Architecture Faculty of the Delft University of Technology (TU Delft). The 3D geospatial web-platform 'Cesium JS' has been used to create the GUI and to visualize the 3D indoor navigation graph and the optimal path from start to destination.

9.2 The preparation of the 3D BIM/IFC model

In Chapter 6, a 3D (BIM/IFC) model was created for the Faculty of Architecture and the Built Environment at TU Delft, Netherlands, to examine the integrated model of LADM and IndoorGML with real-world data. As mentioned before in chapter 6, the initial stage in creating the 3D model was to gather two sorts of data: the building's 2D floor plans and the function information for each space. As a result, the TU Delft's facilities management department has been contacted to acquire this essential information.

The 3D model was created using Autodesk Revit and the Dinamo extension, based on the 2D floor plans of the building, as illustrated in Figure 9.1. Then, the semantic information was added to each space. The data from TU Delft's facilities management department had to be transformed and included into the model. The semantic information was attached to the 3D spaces (ifcSpace) that are distinct from the building's physical components, such as walls, doors, and windows. As illustrated in Figure 9.2, a table for the doors is built for the web-based application to offer information about the connection of the spaces (from space to space).
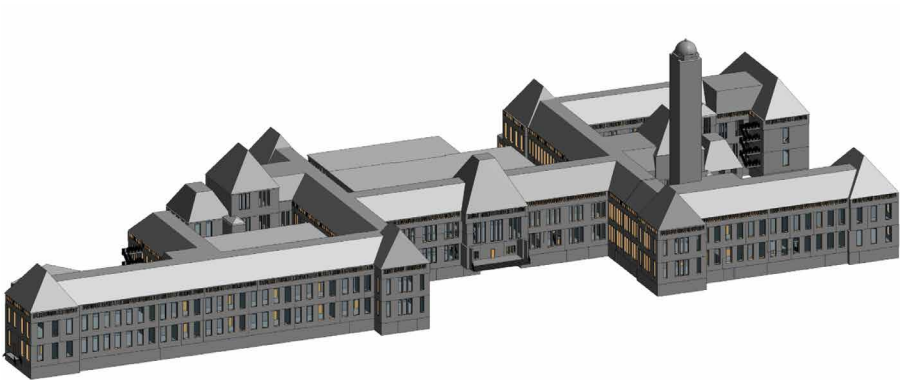
FIG. 9.1 3D model of the Faculty of Architecture and the Built Environment at TU Delft

A	B	C	D	E	F
Mark	Level	From Room: Name	From Room: Room	To Room: Name	To Room: Room Number
3	1st floor	01.Oost.812	08.02.01.812	01.Oost.808	08.02.01.808
6	BG	BG.Mid.803	08.01.00.803		
8	BG	BG.Oost.600	08.02.00.600	BG.Oost.620	08.02.00.620
10	BG	BG.Oost.560	08.02.00.560	BG.Oost.600	08.02.00.600
11	BG	BG.Oost.808	08.02.00.808	BG.Oost.500	08.02.00.500
12	BG	BG.Oost.859	08.02.00.859	BG.Oost.859	08.02.00.859
13	BG	BG.Oost.808	08.02.00.808	BG.Oost.530	08.02.00.530
15	BG	BG.Oost.807	08.02.00.807	BG.Oost.808	08.02.00.808

FIG. 9.2 Door table for the 3D model

After enriching the 3D model with semantic information, the location (xyz) of each 3D space and door had to be extracted to create the nodes and edges of the dual space of IndoorGML. The location (xyz) of the 3D space was defined according to the position of the space during the creation, while the location of the door was selected to be in the center/middle of the door, as shown in Figure 9.3.
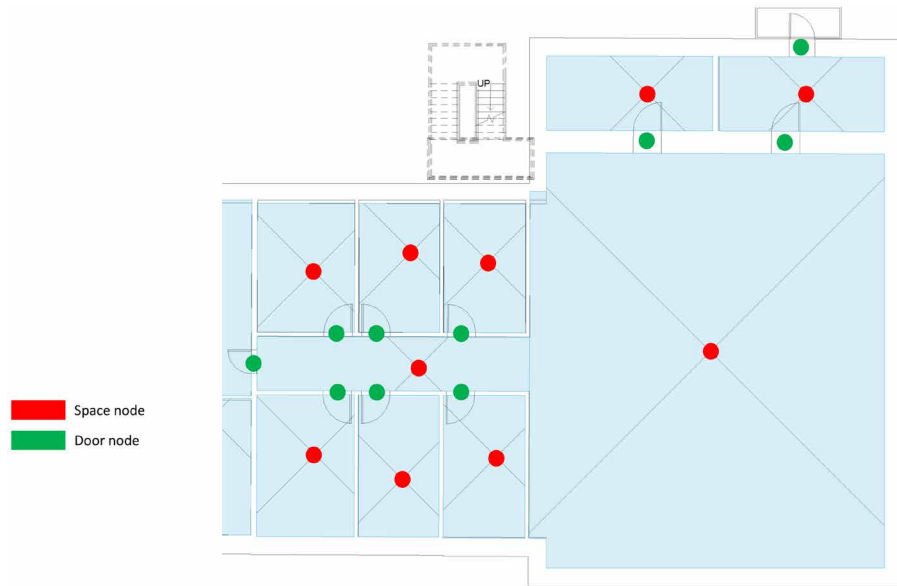
FIG. 9.3 The location (xyz) of the spaces and doors

Extracting the location of any elements from the 3D model is not directly possible in Revit. Therefore, a process flow has been developed in Dynamo to extract the location (xyz). The process flow consists of several steps, where each step is responsible for a specific task. The first step of the process flow defines the target element, such as space or door. The second step is dedicated to the coordinate system's extraction. In this step, the project coordinate system is used to define the location of the element. By identifying the coordinate system and getting the element location, Dynamo transforms the geometry into x, y, z information according to the element location from the project coordinate point.

The third step provides information about the 3D space or the door, such as name and ID. The last step takes care of extracting the information to an Excel sheet. Figure 9.4 shows an example of the Dynamo process flow that has been used to extract the location (xyz) of the spaces. Finally, after extracting the location (xyz) of each space and door, the excel sheet contains all the required information to create the indoor navigation graph as shown in Figure 9.5.
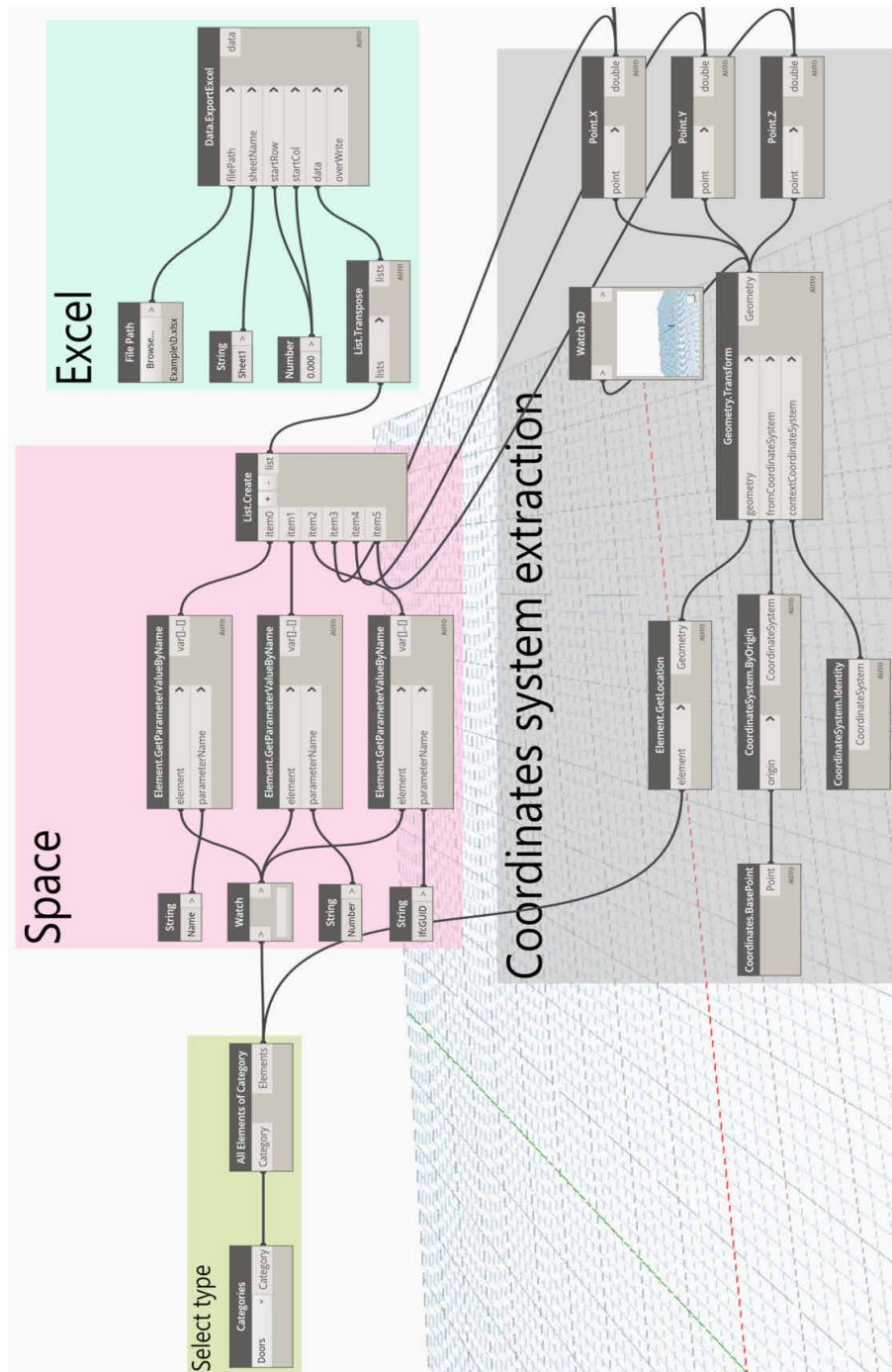
FIG. 9.4 The Dynamo process flow that has been used to extract the location (xyz) of the spaces

	A	B	C	D	E	F	G	H	I	J
1	Id	RoomName	Usagefunction	Type	Area	Level	Volume	X	Y	Z
2	1	01.Mid.010	A Education	A4 Study room / area	190 m²	1st floor	578.12 m³	116.1477	32.92158	9.4
3	3	01.Mid.100	A Education	A4 Study room / area	196 m²	1st floor	1124.14 m³	156.0664	33.49046	9.4
4	4	01.Mid.801	H Horizontal traffic	H1 Times	74 m²	1st floor	424.13 m³	120.2766	39.22927	9.4
5	5	01.Mid.802	H Horizontal traffic	H1 Times	61 m²	1st floor	187.21 m³	133.5149	39.85491	9.4
6	6	01.Mid.803	A Education	A4 Study room / area	161 m²	1st floor	694.34 m³	139.1046	34.1417	9.4
7	7	01.Mid.804	H Horizontal traffic	H1 Times	74 m²	1st floor	424.15 m³	155.7065	39.10685	9.4
8	8	01.Mid.851	V Vertical traffic	V1 Stairs	7 m²	1st floor	37.03 m³	106.5713	35.98489	9.4
9	9	01.Mid.853	V Vertical traffic	V2 Lift	2 m²	1st floor	6.70 m³	129.5513	30.87287	9.4
10	10	01.Mid.854	V Vertical traffic	V1 Stairs	11 m²	1st floor	32.04 m³	130.1163	28.37873	9.4
11	11	01.Mid.855	V Vertical traffic	V1 Stairs	3 m²	1st floor	19.11 m³	143.3339	41.41551	9.4
12	12	01.Oost.010	A Education	A2-4 drawing room	103 m²	1st floor	594.31 m³	100.4978	82.25135	9.4
13	13	01.Oost.050	A Education	A4 Study room / area	83 m²	1st floor	477.11 m³	101.4705	72.1554	9.4
14	14	01.Oost.110	A Education	A4 Study room / area	81 m²	1st floor	467.89 m³	100.8792	60.05702	9.4
15	15	01.Oost.150	S Sanitary	S1 Toilet room	4 m²	1st floor	25.05 m³	97.93495	54.39457	9.4
16	16	01.Oost.170	S Sanitary	S1 Toilet room	33 m²	1st floor	191.71 m³	101.9991	53.23953	9.4
17	17	01.Oost.180	S Sanitary	S1 Toilet room	23 m²	1st floor	69.55 m³	102.2508	49.16784	9.4

FIG. 9.5 The required information to create the indoor navigation graph

9.3 Network and path computation in Postgres/PostGIS

9.3.1 Creating the two tables Node (room) and Edge (network):

A database named BKNetwork was created within PostGIS, the spatial extension of PostgreSQL. Two tables to represent the navigation networks, Node and Edge, were created. Figure 9.6 shows the UML classes for the node and edge tables. The table Node has the following columns: nid, roomname, usagefunction, area, level, volume, x, y, z. The Node table was populated by using the CSV file that was extracted from Revit. The table was cleaned by removing any rows that have the value of NULL in columns x, y, and z, as shown in Figure 9.7. The Edge table has the following columns: ID, nodefrom, tonode, as shown in Figure 9.8. The edge table was populated by using the CSV file that was extracted from Revit.
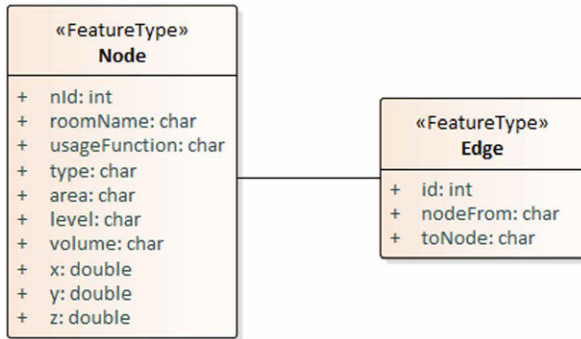
FIG. 9.6 The UML classes for the node and edge tables

	nid integer	roomname character varying	usagefunction character varying	type character varying	area character varying	level character varying	volume character varying	x double precision	y double precision	z double prec
1	50	01.Oost.812	H Horizontal traffic	H1 Times	32 m²	1st floor	97.71 m³	53.2716301	27.31427367	9.4
2	51	01.Oost.841	H Horizontal traffic	H1 Times	2 m²	1st floor	6.93 m³	15.43888744	31.54224556	9.4
3	140	01.West.854	V Vertical traffic	V1 Stairs	36 m²	1st floor	205.86 m³	171.8130161	43.54197619	9.4
4	141	01.West.856	V Vertical traffic	V1 Stairs	8 m²	1st floor	43.97 m³	191.8416078	51.40384239	9.4
5	142	01.West.857	V Vertical traffic	V1 Stairs	8 m²	1st floor	43.72 m³	191.8949443	38.14777315	9.4
6	143	01.West.858	V Vertical traffic	V1 Stairs	13 m²	1st floor	77.34 m³	196.9903548	34.78826502	9.4
7	144	01.West.859	V Vertical traffic	V2 Lift	7 m²	1st floor	42.07 m³	169.8503513	35.69532569	9.4

FIG. 9.7 Part of the node table

	id integer	nodefrom character varying	tonode character varying
1	1	01.Oost.812	D1
2	132	Room 6	D132
3	317	01.Oost.812	D317
4	474	01.West.806	D474
5	790	D34	Room 3
6	791	D35	Room 3
7	1262	D506	01+.West.410

FIG. 9.8 The edge table

9.3.2   Creating the geometry of the nodes and edges

In this phase, the table Node contained only alpha numerical information (including the separate x, y, and z attributes). Therefore, an additional column had to be created to store the node's geometry for each space. The 'geom' column was added and populated by using the function ST_MakePoint(x,y,z) for each space.

By having the geometry of the nodes in the node table, the edge_geom_view was created to store the geometry of the edges between the two spaces *nodefrom* and *tonode*. Figure 9.9 shows the concept of creating the edges between the nodes of the spaces and doors. The edge_geom_view was created by using the following function:

```
Create view edge_geom_vw as
select e.*, ST_Makeline (fr.geom, tt.geom) as geom
from edge e, node fr, node tt
where fr.roomname = e.nodefrom and tt.roomname = e.tonode;
```
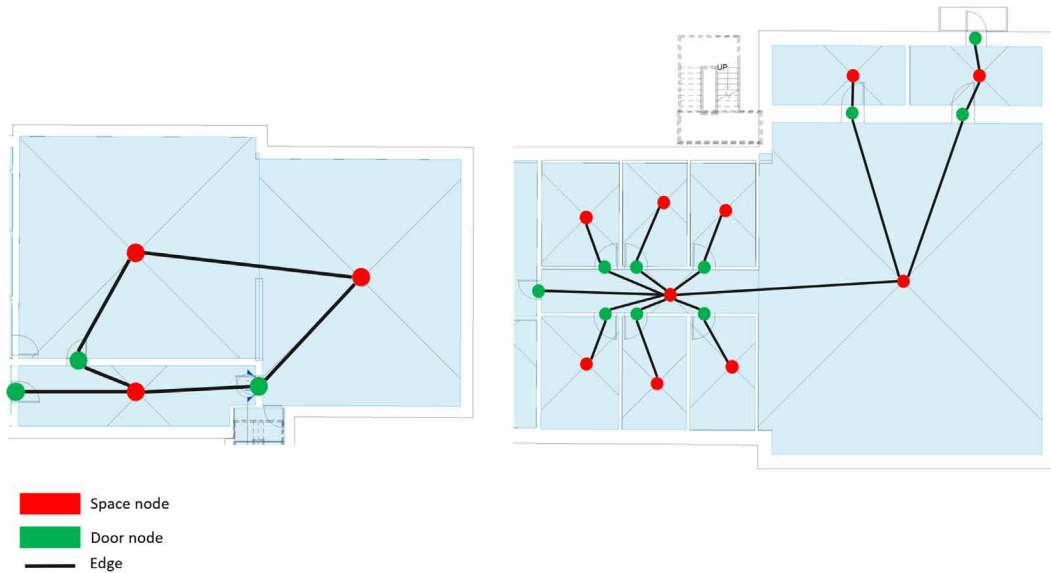

FIG. 9.9 The concept of creating the edges between the nodes

TOC

Conversion to pgRouting

The pgRouting is an extension for the PostgreSQL database that provides routing functionality for indoor and outdoor. Therefore, pgRouting will be used in our research to compute the navigation routes for the users. However, pgRouting does not support creating the network topology for 3D geometries (nodes and edges). It is only creating the topology for 2D geometries. With the nodefrom and tonode and geom columns in the edge_geom_view, there is no need to use pgRouting to create the topology because the edge_geom_view already contains the network between the spaces.

9.3.4 **The cost, source, and target columns**

As mentioned before, the pgRouting extension will be added to the database to include additional columns to the edge_geom_view to compute the navigation routes. The first column is the cost, and we use the length of the edge by using the function ST_3DLength(geom). Then, two additional columns were added to the edge_geom_view: *source* and *target*. The two columns have the value of the node ID of the *nodefrom* and *tonode* columns, as shown in Figure 9.10.

	id integer	nodefrom character varying	tonode character varying	geom text	cost double precision	source integer	target integer
1	1	01.Oost.812	D1	LINESTRING Z (53.2716301 27.31427367 9.4,52.65579435 15.35370002 9.28)	11.9764174822045	50	728
2	2	BG.Mid.803	D2	LINESTRING Z (137.4976237 30.88644468 3.7,136.5424089 28.34497224 3.7)	2.71505386271038	303	729
3	3	BG.Oost.600	D3	LINESTRING Z (9.193643505 8.50922468 3.7,5.644498332 7.123743106 3.7)	3.80998564970037	342	730
4	4	BG.Oost.560	D4	LINESTRING Z (26.15657016 6.573066581 3.7,12.14231164 11.75213829 3.7)	14.9406233347995	341	731
5	5	BG.Oost.808	D5	LINESTRING Z (37.74012175 10.05853868 3.7,36.27501858 8.426110472 3.7)	2.19347877879366	353	732

Data Output Explain Messages Notifications

FIG. 9.10 The cost, source, and target columns for the edge view (edge_wv)

9.3.5 Creating the party and right tables

As mentioned above, the integrated model LADM-IndoorGML defines the user access rights based on the user relationship to the indoor environment. Therefore, the LA_Party and LA_Right tables were created. Figure 9.11 shows the UML classes for the LA_Party and LA_Right tables. The LA_Party table includes the user ID (pID), name and the type of the user, as shown in Figure 9.12.
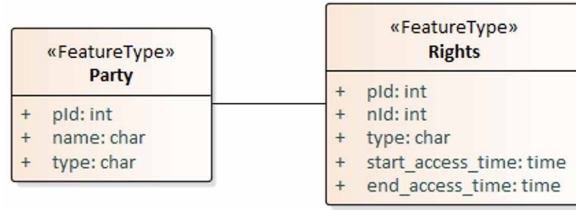
FIG. 9.11 Shows the UML classes for the LA_Party and LA_Rights tables

	pid integer	name character varying	type character varying
1	1	Liam	student
2	2	Noah	student
3	3	Oliver	student
4	4	William	teacher
5	5	Elijah	teacher
6	6	James	teacher
7	7	Benjamin	maintenance
8	8	Lucas	maintenance
9	9	Mason	visitor
10	10	Ethan	student

FIG. 9.12 The LA_Party table

According to the user access rights, the right table was created. The LA_Right table contains user ID (pID), node ID (nID), access type (type), start_access_time, and end_access_time. The LA_Right table has all the nodes ID where the users can access, as shown in Figure 9.13.

FIG. 9.13 The LA_Right table

9.3.6 Creating node and edge views based on the rights of user at given time

After creating the LA_Party table and LA_Right table, dynamic views for the node and edge tables have been created and they use the accessible spaces for a specific user (and at a specific time). Table 9.1 shows the total number of nodes and edges according to user's access rights. It is clearly visible that the teachers have access to most of the spaces. While the maintenance staff members have access rights to the basement and the corridors of the building only.

TABLE 9.1 Number of accessible spaces for each type of the users according to their rights

Users type	Node	Edge
Total	1394	2992
Student	860	1646
Teacher	906	1720
Maintenance	528	696
Visitor	324	442

The following queries have been used to create the node view and the edge view for a student **Liam** at **14:00:00** hours. Note that in the actual scripts to create the views we use parameters, and the values are obtained from the client GUI. Figure 9.14 shows the content node_vw view, and Figure 9.15 shows the edge_vw views for the student, together forming the (sub)network, which is accessible for Liam at 14:00:00 hours.

```
create view node_vw as
select node.nid, node.geom
from node n, LA_rights r, LA_party p
where p.name= 'Liam' and r.pid=p.pid and r.type= 'access' and r.nid=node.nid
and r.start_access_time <= '14:00:00' and '14:00:00' <= r.end_access_time;
create view edge_vw as
select edge_geom_cost_vw.*
from edge_geom_cost_vw, node_vw nf, node_vw nt
where nf.nid=edge_geom_cost_vw.source and nt.nid=edge_geom_cost_vw.target;
```

	nid integer	geom geometry	👁
1	50	01010000A0110F0000FB0D6EC6C4A2...	
2	51	01010000A0110F0000AFD9C2DAB5E...	
3	140	01010000A0110F0000E313573A047A...	
4	141	01010000A0110F0000DF217B73EEFA...	
5	142	01010000A0110F0000BB873A62A3FC...	
6	143	01010000A0110F0000F9AD8CFCB09F...	
7	144	01010000A0110F00008EF3ED13363B...	

FIG. 9.14 The node view for student

Data Output Explain Messages Notifications

	id integer	fromroomname character varying	toroomname character varying	nodefrom geometry	👁	nodeto geometry	👁	geom geometry	👁	cost double precision	source integer	target integer
1	1377	D621	01.0ost.812	01010000A0110...		01010000A0110...		01020000A0110...		9.64461422973641	1348	50
2	1378	D622	01.0ost.812	01010000A0110...		01010000A0110...		01020000A0110...		5.82067507391789	1349	50
3	1379	D623	01.0ost.812	01010000A0110...		01010000A0110...		01020000A0110...		1.20696761190692	1350	50
4	1071	D315	01.0ost.812	01010000A0110...		01010000A0110...		01020000A0110...		6.46242262927356	1042	50
5	2584	D316	01.0ost.812	01010000A0110...		01010000A0110...		01020000A0110...		5.62824864258055	1043	50

FIG. 9.15 The edge view for a student

9.3.7   Computing the shortest path

The Dijkstra algorithm has been used to compute the shortest path for the users of the building in pgRouting. The node and edge views of the user have been used to compute the indoor navigation routes as follows:

```
SELECT X.seq, Y.nid, Z.geom, X.Path_seq, X.edge, X.cost, X.agg_cost
FROM pgr_dijkstra(
'select id, source, target, cost from edge_vw',
(select nid from node_vw where roomname ='BG.Mid.802' limit 1),
(select nid from node_vw where roomname ='BG+.West.310' limit 1),
FALSE
) AS X
INNER JOIN
node_vw AS Y ON X.node = Y.nid
LEFT JOIN
edge_vw AS Z ON X.edge = Z.id
ORDER BY seq;
```

Figure 9.16 shows the path segments from the starting point (the main entrance of the building) to the destination point (office 'BG+.West.310'). Note, start and destination are parameters in the actual SQL scripts, as well as values, which are set via the client GUI.

seq integer	nid integer	geom geometry	path_seq integer	edge bigint	cost double precision	agg_cost double precision
1	1	302	01020000A0110…	1	1428	7.45921426018157	0
2	2	1399	01020000A0110…	2	2940	13.9334386831176	7.45921426018157
3	3	304	01020000A0110…	3	2339	10.0036920210965	21.3926529432991
4	4	798	01020000A0110…	4	827	5.88636732429947	31.3963449643957
5	5	436	01020000A0110…	5	2939	2.38394091739378	37.2827122886951
6	6	1398	01020000A0110…	6	1427	8.77123133838234	39.6666532060889
7	7	435	01020000A0110…	7	2413	6.0657029080525	48.4378845444713
8	8	872	01020000A0110…	8	901	10.5276410667169	54.5035874525237
9	9	434	01020000A0110…	9	2910	9.97536212444123	65.0312285192406
10	10	1369	01020000A0110…	10	1398	2.13231369360411	75.0065906436819
11	11	449	01020000A0110…	11	1416	1.92293623085794	77.138904337286
12	12	1387	01020000A0110…	12	2928	2.32544799273016	79.0618405681439
13	13	530	01020000A0110…	13	62	1.98794009252385	81.3872885608741
14	14	789	01020000A0110…	14	1574	1.80718695918744	83.3752286533979
15	15	532		15	-1	0	85.1824156125854

Data Output Explain Messages Notifications

FIG. 9.16 The path segments for a student

9.4 Visualization of the routes in Cesium JS

The routing with taking into account the access rights inside buildings of the different users (at different times) is exposed via a web-based 3D GUI. In this way end-users can use the functionality via their laptop, tablet or mobile phone web-browser via an easy to use interface where the start and destination are specified together with user (and time). At the server-side there is the PostgreSQL/PostGIS database (with pgRouting functionality), GeoServer implementing industry standard OGC protocols such as Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS), and Apache Tomcat as webserver. Figure 9.17 shows the system architecture of the system at http://pakhuis.tudelft.nl:8080/edu/cesium74/Apps/routing/.
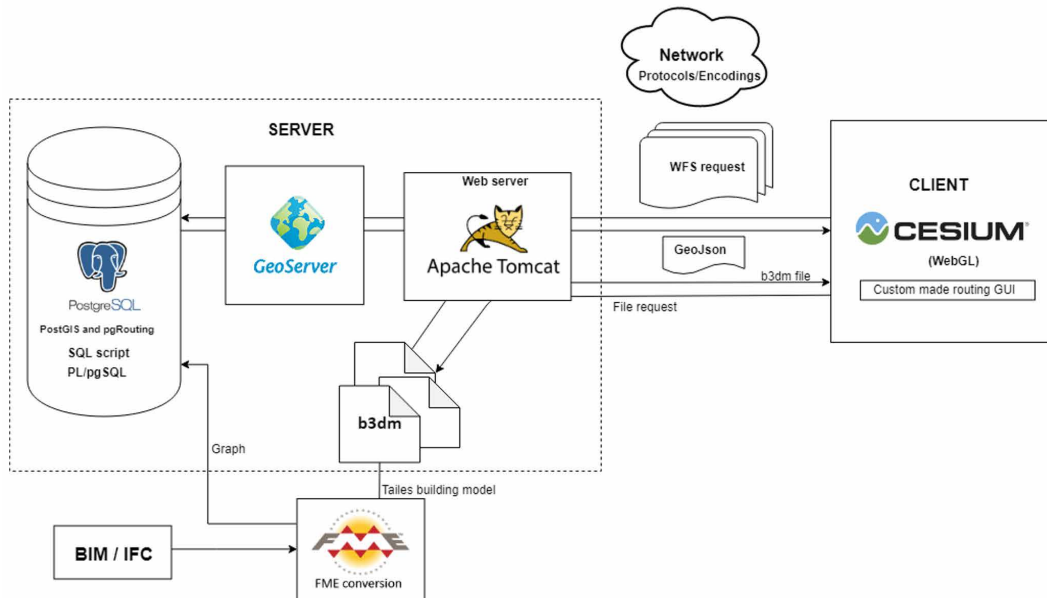
FIG. 9.17 The system architecture

The actual background images are in jpg form retrieved from another server (virtualearth.net) with HTTP requests such as:

```
GET http://ecn.t1.tiles.virtualearth.net/tiles/a1.jpeg?n=z&g=10184
```

The 3D building model is represented in a number of b3dm tiles with the geometry of the spaces. They are obtained by the client by the HTTP GET request to our pakhuis server:

```
http://pakhuis.tudelft.nl:8080/edu/cesium74/Apps/SampleData/cadastral3/tileset7/
data/data0.b3dm
```

Instead of using local coordinates, the building geometry has been transformed to geographic coordinates, which enables combinations with other (background) geographic information. As part of the geo-reference there is a coordinate transformation from our RD+NAP (EPSG 7415) to ECEF (Earth Centered, Earth Fixed, which s EPSG:4978) needed for Cesium JS.

9.4.1 Visualize & interact with the 3D building model

The Cesium JS based on a 3D web-client allows basic visualization and interaction functionality out of the box: a complete globe with earth imagery, zooming, panning (rotating over the Earth globe), adding additional map layers, hover-over (showing name), selecting a specific object (and showing more attributes), searching for specific locations via gazetteer (and fly to that location), etc. Cesium JS is using WebGL for high performance rendering by using the GPU at client side (when available).

JavaScript at the client side may be added to provide additional functionality. In our case a way to specify the user, the start and the target rooms, and to initiate the path computation and visualization. As stated, Cesium JS allows retrieving additional (3D) map layers and the best format for this is b3dm tiles, though other formats are supported, such as KML, but in our practice often leading to performance issues and/or bugs. "Batched 3D Model allows offline batching of heterogeneous 3D models, such as different buildings in a city, for efficient streaming to a web client for rendering and interaction. Efficiency comes from transferring multiple models in a single request and rendering them in the least number of WebGL draw calls necessary" (3D Tiles Specification, 2019).

A Cesium tile set consists of a tileset.json and b3dm with the geometry and other attributes. The tileset.json contains bounding boxes and other meta information, and has the urls of the 'tiles', in our case: b3dm files. B3dm files use gltf encoding for the geometry plus a 'batch table' that makes it possible to include non-geo attributes in the files. The 3D model of the Architecture (Bouwkunde) building is stored in b3dm files (these are the 'tiles' of the tileset) that are on the file system of the server.

FIG. 9.18 Definition of SQL view 'bkpath_party' (with three parameters: party_name, source_room, target_room) based on call of PL/pgSQL function 'fromtoname_party'

Computing the route is done in the database, by sending to the GeoServer a HTTP GET (WFS) request. For producing the response, the 'SQL View' possibility of GeoServer (extension of standard WFS) is used to define not the normal or typical database table as WFS layer, but a parameterized 'SQL View'; see Figure 9.18. When the map layer **bkpath_party** is requested via WFS to GeoServer at the server side, this results in the execution of the PL/pgSQL function **frontoname_party** with three parameters (party_name, source_room, target_room), which defines the proper SQL views, calls the dijkstra pgRouting and returns the resulting database table as new/dynamic map layer.

Below the PL/pgSQL code is shown that drops the old views (previous users), creates news views (based on rights of current users), and starts the Dijkstra routing. The returned table contains the computed route: room identifiers and the node geometry.

```
CREATE OR REPLACE FUNCTION frontoname_party(
party_name character varying,
source_room character varying,
target_room character varying)
RETURNS
TABLE(room_id integer, roomname character varying,
geom geometry, seq integer)
as
$$
declare
source_id int;
target_id int;
begin
execute 'drop view if exists node_vw cascade';
execute 'drop view if exists edge_vw cascade';
execute 'create view node_vw as
select room.id, room.roomname from room, rights, party where party.name = ' ||
quote_literal(party_name) || ' and rights.pid = party.pid and rights.type= ' ||
quote_literal('access') || ' and rights.nid=room.id';
execute 'create view edge_vw as select edge_geom_cost_vw.* from edge_geom_cost_
vw, node_vw nf, node_vw nt
where nf.nid=edge_geom_cost_vw.source and nt.nid=edge_geom_cost_vw.target';
execute 'select id from node_vw where node_vw.roomname = '|| quote_literal(-
source_room) into source_id;
execute 'select id from node_vw where node_vw.roomname = '|| quote_literal(tar-
get_room) into target_id;
return query
```

```
SELECT

X.Path_seq, X.edge, X.seq, Y.nid, Z.geom

FROM pgr_dijkstra(

'select id, source, target, cost from edge_vw', source_id, target_id,

FALSE

) AS X

INNER JOIN

node_vw AS Y ON X.node = Y.nid

LEFT JOIN

edge_vw AS Z ON X.edge = Z.id

ORDER BY seq; end;

$$ language plpgsql;
```

9.4.3 The navigation GUI

Using at the client-side JavaScript code the user is provided with a GUI sidebar added to Cesium JS (Figure 9.19), that contains setting transparency of walls, elevating the building, switching on/off the different floors (currently hardcoded for the example building, in the future a generic list of floors), specifying the user (group); e.g. staff or student, entering the names of the start and the target rooms, and finding the route. The result shows the shortest path as line (animated with movement) and highlights the relevant spaces.
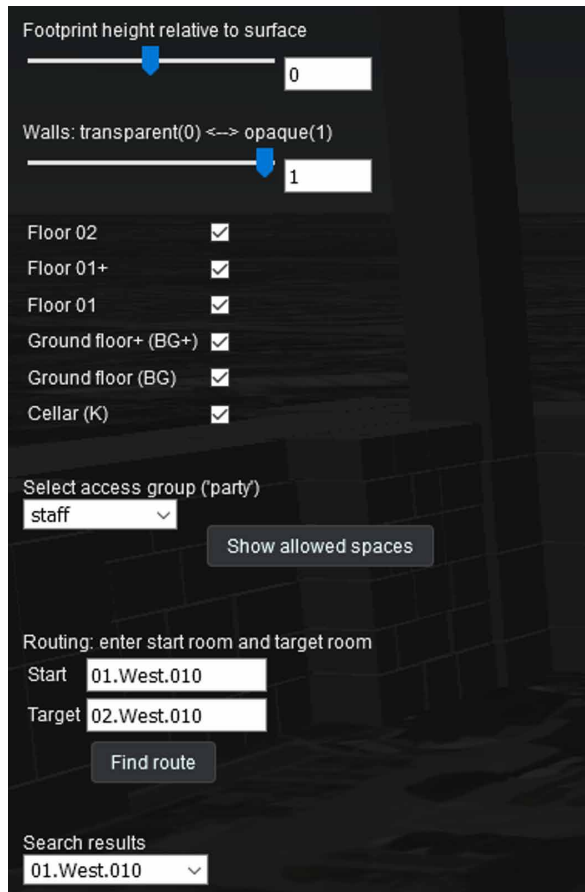
Before starting the actual routing, it is possible to check and visualize which rooms/spaces are accessible by a specific user (e.g. a student) with the following HTTP GET request:

```
http://pakhuis.tudelft.nl:8088/geoserver/nl/ows?service=WFS&version=1.0.0&re-
quest=GetFeature&outputFormat=application/json&typeName=nl:allowed_rooms&cql_fil-
ter=partyname='student'"
```

This request is constructed and sent to a WFS service (in our case GeoServer WFS implementation) that passes on the query to the database (in our case PostgreSQL). The response contains the map layer **nl:allowed_rooms** encoded in GeoJSON (in total 859 rooms/spaces):

```
{
    "type": "FeatureCollection",
    "totalFeatures": 859,
    "features": [
        {
                "type": "Feature",
                "id": "allowed_rooms.fid--7290fc9f_177e56c1fc7_7535",
                "geometry": {
                        "type": "Point",
                        "coordinates": [
                                3922993.57039708,
                                299849.38535691,
                                5003272.91050721
                        ]
                },
                "geometry_name": "geom_ecef",
                "properties": {
                        "id": 740,
                        "roomname": "D13",
                        "ecef_x": 3922993.570397083,
                        "ecef_y": 299849.3853569102,
                        "ecef_z": 5003272.910507206,
                        "partyname": "student"
                }
        },
        {
                "type": "Feature",
                "id": "allowed_rooms.fid--7290fc9f_177e56c1fc7_788f",
                "geometry": {
                        "type": "Point",
                        "coordinates": [
                                3923049.68503034,
                                299841.28404792,
                                5003236.92225268
                        ]
                },
                "geometry_name": "geom_ecef",
                "properties": {
                        "id": 1457,
                        "roomname": "D730",
                        "ecef_x": 3923049.685030338,
```

```
                    "ecef_y": 299841.2840479159,

                    "ecef_z": 5003236.922252683,

                    "partyname": "student"

            }

        }

    ],

    "crs": {

        "type": "name",

        "properties": {

                "name": "urn:ogc:def:crs:EPSG::404000"

        }

    }

}
```

The response is processed in the Cesium JS client. In this case to show the rooms with allowed access for a student. The 'match' between what comes back from the database via WFS and the units (rooms, parcels) in the b3dm model is done by looping over the batch tables of the b3dm tiles and finding the match between the identifier attribute in the b3dm batch tables ('LongName') and the identifier attribute 'roomname' in the database response. These spaces are highlighted.

The routing is started by sending the HTTP GET WFS request of the map layer nl:bkpath_party as follows:

```
http://pakhuis.tudelft.nl:8088/geoserver/nl/ows?service=WFS&version=1.0.0&re-
quest=GetFeature&outputFormat=application/json&typeName=nl:bkpath_party&view-
params=party_name:student;fromroom_name:01.West.010;toroom_name:02.West.010
```

When this routing fails, as no path exists, we get back a GeoJSON response without features:

```
{
    "type": "FeatureCollection",
    "totalFeatures": 0,
    "features": [],
    "crs": null
}
```

Indicating that there is no allowed route for a student to get from room 01. West.010 to room 02.West.010.

The same HTTP GET WFS request but now for a staff member:

```
http://pakhuis.tudelft.nl:8088/geoserver/nl/ows?service=WFS&version=1.0.0&re-
quest=GetFeature&outputFormat=application/json&typeName=nl:bkpath_party&view-
params=party_name:staff;fromroom_name:01.West.010;toroom_name:02.West.010
```

This gives a map layer containing the route encoded in the following GeoJSON result
(with 28 nodes in total):

```
{
    "type": "FeatureCollection",
    "totalFeatures": 28,
    "features": [
        {
                "type": "Feature",
                "id": "bkpath_party.fid--7290fc9f_177e56c1fc7_74fd",
                "geometry": null,
                "properties": {
                        "seq": 0,
                        "fromroomname": "01.West.010",
                        "ecef_x": 3923139.967637715,
                        "ecef_y": 299826.58231767156,
                        "ecef_z": 5003167.481330292
                }
        },
        {
                "type": "Feature",
                "id": "bkpath_party.fid--7290fc9f_177e56c1fc7_74fe",
                "geometry": null,
                "properties": {
                        "seq": 1,
                        "fromroomname": "D446",
                        "ecef_x": 3923137.5399089674,
                        "ecef_y": 299827.24866635184,
                        "ecef_z": 5003169.33252207
                }
        },
        {
                "type": "Feature",
                "id": "bkpath_party.fid--7290fc9f_177e56c1fc7_74ff",
                "geometry": null,
```

```
                        "properties": {
                                "seq": 2,
                                "fromroomname": "01.West.801",
                                "ecef_x": 3923135.6947698826,
                                "ecef_y": 299826.22960566,
                                "ecef_z": 5003170.830278884
                        }
                },
                ……
                {
                        "type": "Feature",
                        "id": "bkpath_party.fid--7290fc9f_177e56c1fc7_7517",
                        "geometry": null,
                        "properties": {
                                "seq": 26,
                                "fromroomname": "D567",
                                "ecef_x": 3923135.3362143203,
                                "ecef_y": 299822.50364835275,
                                "ecef_z": 5003178.817982247
                        }
                },
                {
                        "type": "Feature",
                        "id": "bkpath_party.fid--7290fc9f_177e56c1fc7_7518",
                        "geometry": null,
                        "properties": {
                                "seq": 27,
                                "fromroomname": "02.West.010",
                                "ecef_x": 3923138.395770645,
                                "ecef_y": 299815.0269162718,
                                "ecef_z": 5003176.880054299
                        }
                }
        ],
        "crs": null
}
```

The returned route is illustrated by highlighting the spaces that are passed and by drawing a path which can be visualized with the Cesium JS animation options. This can be (re)started by pusing the 'play' button, in the lower left corner of the GUI.

Routing example with visualization

In this subsection a routing example with visualization is given: same time, same source, same target, *different person* (example from section 9.4.3). The route in Cesium JS is not drawn by using the edge geometry, but by using a Cesium JS functionality to interpolate positions between given points (in our case the network nodes). This works much faster than adding linestring entities to Cesium (then Cesium uses the Entity API). The interpolation functionality also makes the animation possible: letting a symbol 'walk' along the interpolated route. The following example in Figure 9.20 shows the route for a staff member and a student for the same start and destination. While the staff member has a route as shown in Figure 9.20 top, the student, who does not have sufficient access rights for the same destination, obtains no route as shown in Figure 9.20 bottom (note the 'No results' waring in the interface).
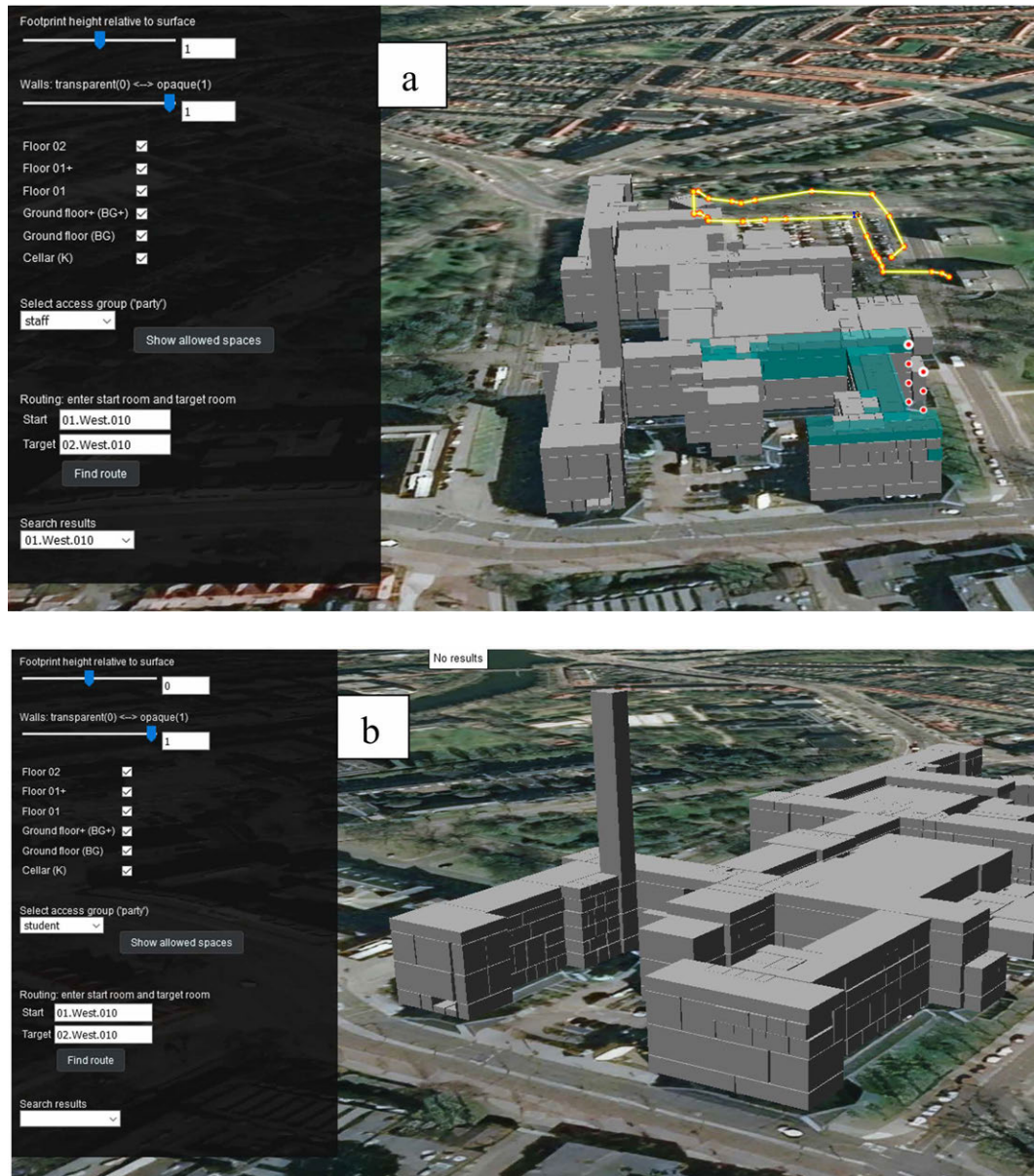
FIG. 9.20 The route for a staff member (above) and a student (below) that have different access rights for the same destination

9.5 Summary

This chapter presented the development of a 3D web-application for indoor navigation based on user access rights. This chapter has answered the sub-questions "T2. How to populate the database with the user information, access rights, geometric, and semantic information of the indoor spaces? and T3. What type of web-based user interface has to be used to manipulate/ visualize the data in the cases of selecting, updating, or routing?". The development of the application started by creating a 3D BIM/IFC model for an educational building, consisting of several floors and different types of spaces. By creating the 3D BIM/IFC navigation model, several types of information were attached to enrich the 3D model such as location (xyz) of spaces and doors to create the navigation network. The network was organised in PostgreSQL and pgRouting. Several navigation routes for the users with different access rights were computed. Finally, a web-client GUI based on Cesium JS was used to specify the parameters (user, time, start, destination) and to visualize the indoor navigation routes.

Each indoor environment has different access rights with respect to the user type. Users can be classified according to their access rights into different groups such as visitors, teachers, students, etc. The access rights are also time dependent. Each user can access several spaces based on these rights. This use case illustrates that having information about access rights makes the indoor navigation more accurate. The user obtains a navigation route based on his/her permission to access parts of the building.

TOC

10 Conclusion and Recommendation

This final chapter highlights the most important results of this PhD study and makes recommendations for future work to further the investigation. The primary conclusion, as well as the answers to the main and sub-research questions, are presented in Section 10.1. Recommendations for future study are provided in Section 10.2.

10.1 Conclusion

The research and development for indoor navigation applications that take into account the user's access rights, which are date/time-dependent, is presented in this thesis. To provide an indoor navigation route based on a user's access rights, the LADM and IndoorGML standards were integrated to establish the accessibility rights of indoor environment users. According to the result of this research, the relationship between users and the indoor environment can be determined by utilizing an integrated model to provide indoor navigation routes based on the user type. This research is organised at three levels: standard level, conceptual level, and technical level.

At the standard level, to support and validate the integration of LADM and IndoorGML, we examine the existing subdivision methods in indoor environments. In addition, the standards that cover 3D geometry, such as the BIM/IFC standard and facility information, such as Facility Management standard, were reviewed and utilized as a source of semantic information for the indoor spaces' functions. IndoorGML's conceptual model was proposed to be expanded because the version 1.0 UML class diagram did not contain some classes and attributes, which were included in the XML/GML schema. The proposed UML class diagram provides more accurate mapping of the standard classes, which helps better understanding IndoorGML and helps to prevent any misunderstandings throughout the process of using the standard.

Then, the property ownership regulations were examined in support to the development of the 2D LADM country profile for the Kingdom of Saudi Arabia. This is in support to improved and successful communication between all stakeholders involved in land registration. The spatial and non-spatial classes were developed following Saudi Arabian legislation. Additionally, we created the 3D country profile for the Kingdom of Saudi Arabia in order to facilitate the 3D registration of legal spaces. Saudi Arabia's 3D LADM country profile includes the identified concepts for multi-owner buildings and establishes a methodology for mapping from BIM/IFC to LADM, both conceptually and at the level of individual instances with their geometry and topology. The creation of the country profile revealed three distinct kinds of spaces in the context of buildings: private, common, and exclusive common.

At the *conceptual level*, the integration between LADM and IndoorGML has been proposed by investigating the functionality of all classes in both standards to determine which classes might be utilized to connect the two standards. The study then examines the connection between the interior space and the user by analyzing an educational facility in order to establish the rights of the indoor spaces. With LADM a connection can be establishes between the indoor spaces and the users by identifying the user type of the indoor environment. With LADM rights, restrictions, and responsibilities can be provided to each indoor space, and based on this information, the indication of which spaces are reachable to each type of user. Furthermore, the development of a refined LADM party package for application in an educational facility to depict various types of users in various indoor environments has been proposed. The development of the party package helps in defining the link between the users and the indoor environment. The integrated model of LADM and IndoorGML was then expanded to specify the access rights of users during a crisis.

At the technical level, we transformed the conceptual model into a technical model, followed by an implementation model, with the aim to uncover the capabilities and limits of the integrated model. Numerous problems arose, but they were solved. This step ensured the possibility of automating the transition from conceptual to technical models. The implementation model is then stored in a PostgreSQL database. Using the integrated model, a database schema has been designed to facilitate the computation of indoor navigation routes (using pgRouting). Furthermore, the development of a web-based application for the integration of LADM and IndoorGML has been proposed, which provides indoor navigation, which takes into consideration the user's access rights in an educational building. The GUI is web-based and can operate on various devices, including PCs, laptops, tablets, and mobile phones. All types of users can use the web-based application to obtain their path through the building according to their access rights and avoid all inaccessible spaces.

Throughout this thesis, all of the topics listed above are investigated in relation to the following main research question:

— **What is an optimal standard-based approach to enrich the IndoorGML semantic 3D model with LADM Rights, Restrictions, and Responsibilities in support to the accessibility of the indoor spaces in different types of building and for different purposes?**

The main research question is answered by subdividing into sub-research questions and categorized into three levels:

Standards level

— **Q1. What is the UML class diagram in IndoorGML, and how it should be improved?**

I have found that the UML class diagram of IndoorGML 0.1 has several issues that need improvement to develop the conceptual model of LADM and IndoorGML, as described in Chapter 3. The UML model of IndoorGML includes four distinct kinds of classes (GML, IndoorCore, IndoorNavi, and Not implemented). The majority of classes lack attributes, i.e., attribute names and attribute data types. Additionally, the relationships that connect the classes have names that are ambiguous to the user. The GeneralSpace and TransferSpace classes have the same code list values in their properties. The SpaceLayer class is associated with the CellSpace, State, and Transition classes, which causes confusion for the standard's user (since it is not immediately obvious from the model that CellSpace/State represents primal space and Transition represents dual space). The standard separates the geometry data into several classes, which enables the geometries to be applied to a variety of different objects (which could have been sharper typed). Additionally, separating geometry into several classes increases the model's implementation complexity.

As a result, this thesis proposed an enhancement to the IndoorGML standard's version 0.1 UML class diagram in Chapter 3. Therefore, I have proposed that the ExternalObject class, which is responsible for obtaining data (e.g., data from BIM/IFC) for the CellSpace and the CellSpaceBoundary, contains two subclasses: ExternalCellSpaceObject and ExternalCellSpaceBoundaryObject. Then, the CellSpace class is associated with the ExternalCellSpaceObject, and the CellSpaceBoundary class is associated with the ExternalCellSpaceBoundaryObject in order to clarify the ExternalObject class's concept. Moreover, the association multiplicity between CellSpace and CellSpaceBoundary is proposed to be rectified. NodeInDualSpace and EdgeInDualSpace are proposed to be replaced by State and Transition with Node and Edge since they better reflect the nature of these classes and therefore enhance

understanding. Geometry classes are proposed to be transformed to attributes of the classes that that are needed to simplify and facilitate user comprehension during implementation, as shown in Figure 10.1.
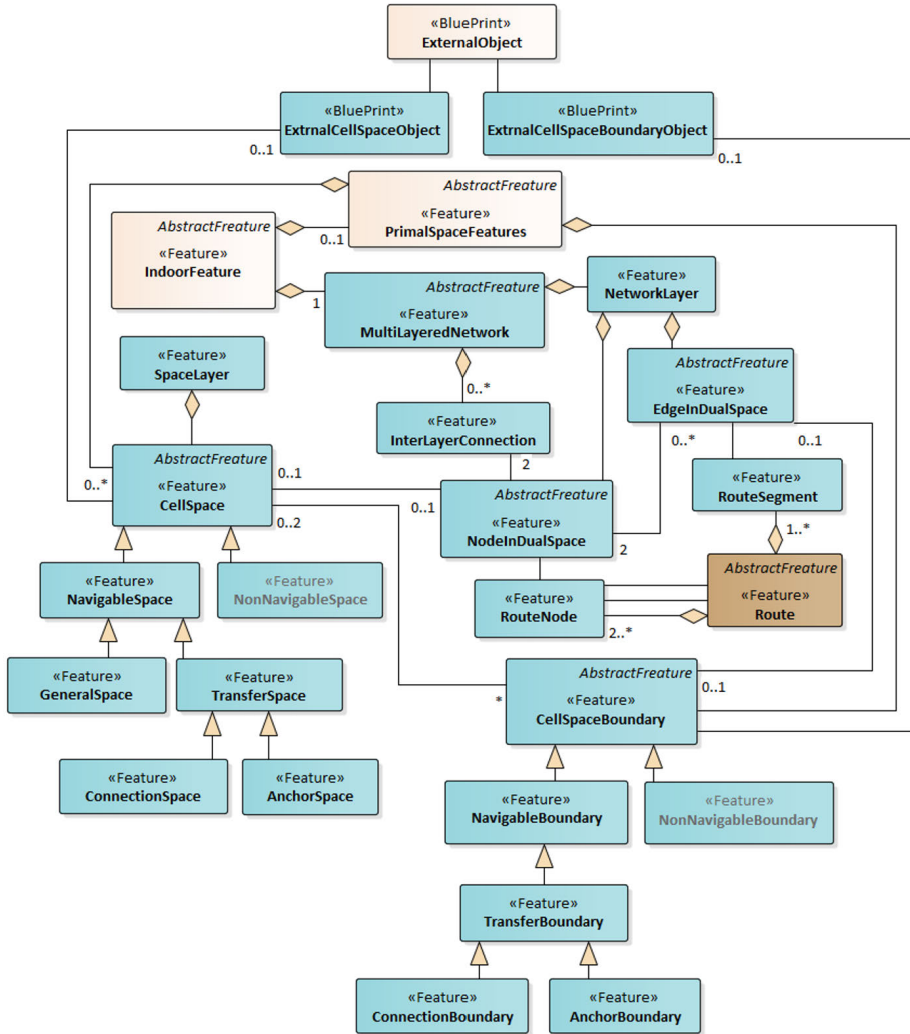

FIG. 10.1 The Enhanced UML class diagram of IndoorGML

Furthermore, the code list for the GeneralSpace and TransferSpace classes is named uniquely, and code list classes have been created to specify the values for each attribute. The DualSpaceNetworkLayer class is added as a collecting class for the

dual space's nodes and edges. In addition, the SpaceLayer class is proposed to be associated directly with the CellSpace class and serves as a collection class for the primal space's spaces. TransferSpace and CellSpaceBoundary are proposed to contain extra attributes with the value (virtual, real) that allow CellSpace aggregation and subdivision. This enhancement is a proposal to integrate the suggestions above into IndoorGML. It provides the first steps in creating a more complete and better conceptual model for IndoorGML.

— **Q2. What is the status of Land Administration in 3D indoor environment in Saudi Arabia?**

Four stakeholders are responsible for managing the land administration system (Ministry of Municipal and Rural Affairs, Ministry of Justice, Real Estate General Authority, and Ministry of Housing). They are responsible for all data connected to ownership registration, including technical and legal data. Saudi Arabia's land administration system is divided into two distinct parcel types: public parcels and private parcels. The existing system does not register public parcels, which are regarded to be the government's property. On the other hand, private parcels may have a variety of owners, including government ownership, business industry ownership, or induvial ownership (a group of private parties). The procedure of issuing the deed registration document varies according to the kind of property. Thus, the procedure of issuing these deed registration documents shows the stakeholder relationship.

Therefore, I recommended developing a 2D LADM initial country profile for Saudi Arabia, as described in Chapter 4. The process began with interviews with responsible stakeholders. The identified possible interconnection of all four stakeholders' activities resulted in the creation of the initial LADM country profile of Saudi Arabia. The country profile inherits all of its classes from the LADM's main classes. The Ministry of Justice is responsible for the SA_Party, SA_BAUnit, and SA_Mortgage classes. The information represented by these classes is recorded by the Ministry of Justice. The other classes are the responsibility of the Ministry of Municipal and Rural Affairs, the Ministry of Housing, and the Real Estate General Authority since they are in charge of geographical data. Additionally, they are linked to the RRR classes. As indicated in Section 4.3, the spatial and non-spatial data modelling classes include new code lists for the Saudi Arabia country profile, as shown in Figure 10.2.
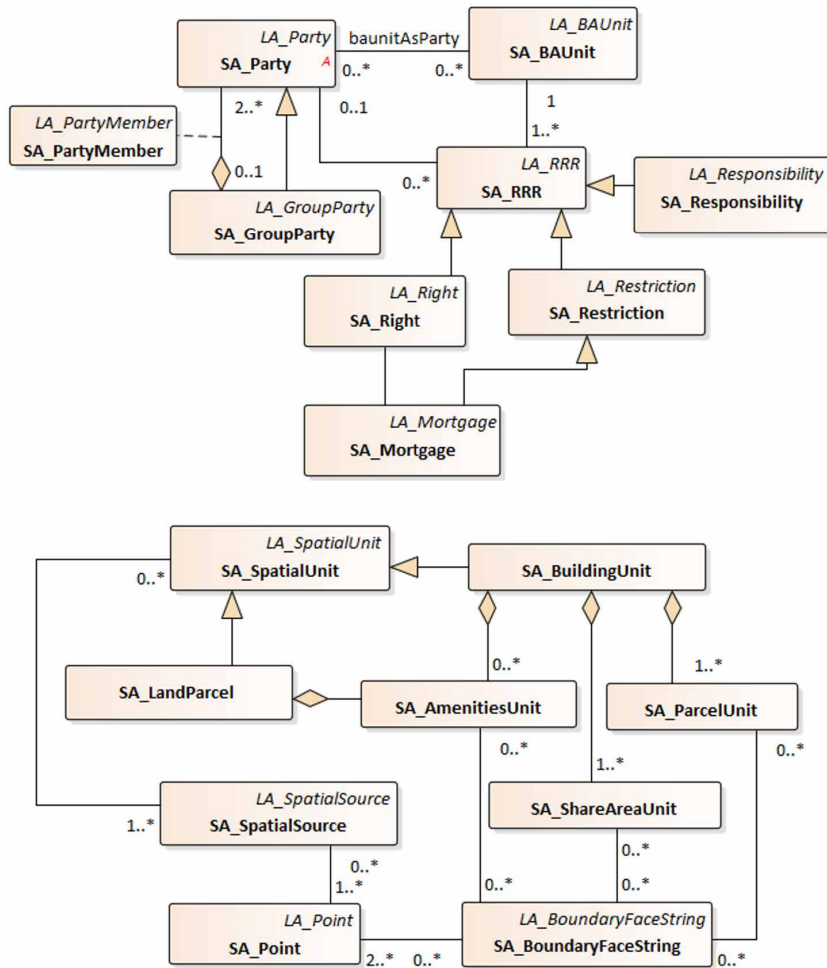
FIG. 10.2 Non-spatial (above) and spatial (below) UML class diagram for the initial country profile

When the initial country profile was tested and validated, the results revealed that just the most basic information about the land administration system was included. Consequently, I used a novel technique to extract all relevant information from the land administration system by collecting various deed registrations for different attributes and comparing them to extract the optional and non-optional attributes from the land administration system, as explained in Section 4.5. Next, all attributes have been divided into three separate groups depending on their classification (spatial information, party information, and administrative information). Finally, this classification system has been used to assign each attribute to the appropriate class in the country profile.

Then, using the 2D country profile, I created a 3D country profile of Saudi Arabia based on the building unit's subdivision procedures that focus on the indoor rights, restrictions, and responsibilities as indicated in Chapter 5. I developed an approach for refining 3D models with the spaces of the building to depict three primary categories of spaces: private spaces, common spaces, and exclusive common spaces. Therefore, building unit subdivision procedures have been established in 3D to cover more information during the registration of the building's legal spaces, and the subdivision procedures have been mapped to LADM concepts. Therefore, the first phase was to evaluate and analyze whether the subdivision techniques can be applied to a 3D IFC model of a real-world complex building, as shown in Figure 10.3. A number of challenges related to the 3D IFC model have been solved in order to apply the building unit's subdivision processes, including the following: 1) Issues with the building's spaces; 2) Issues with the building's floor walls, columns, and slabs; and 3) The 3D model did not contain the subsurface water tanks, as indicated in Section 5.3.

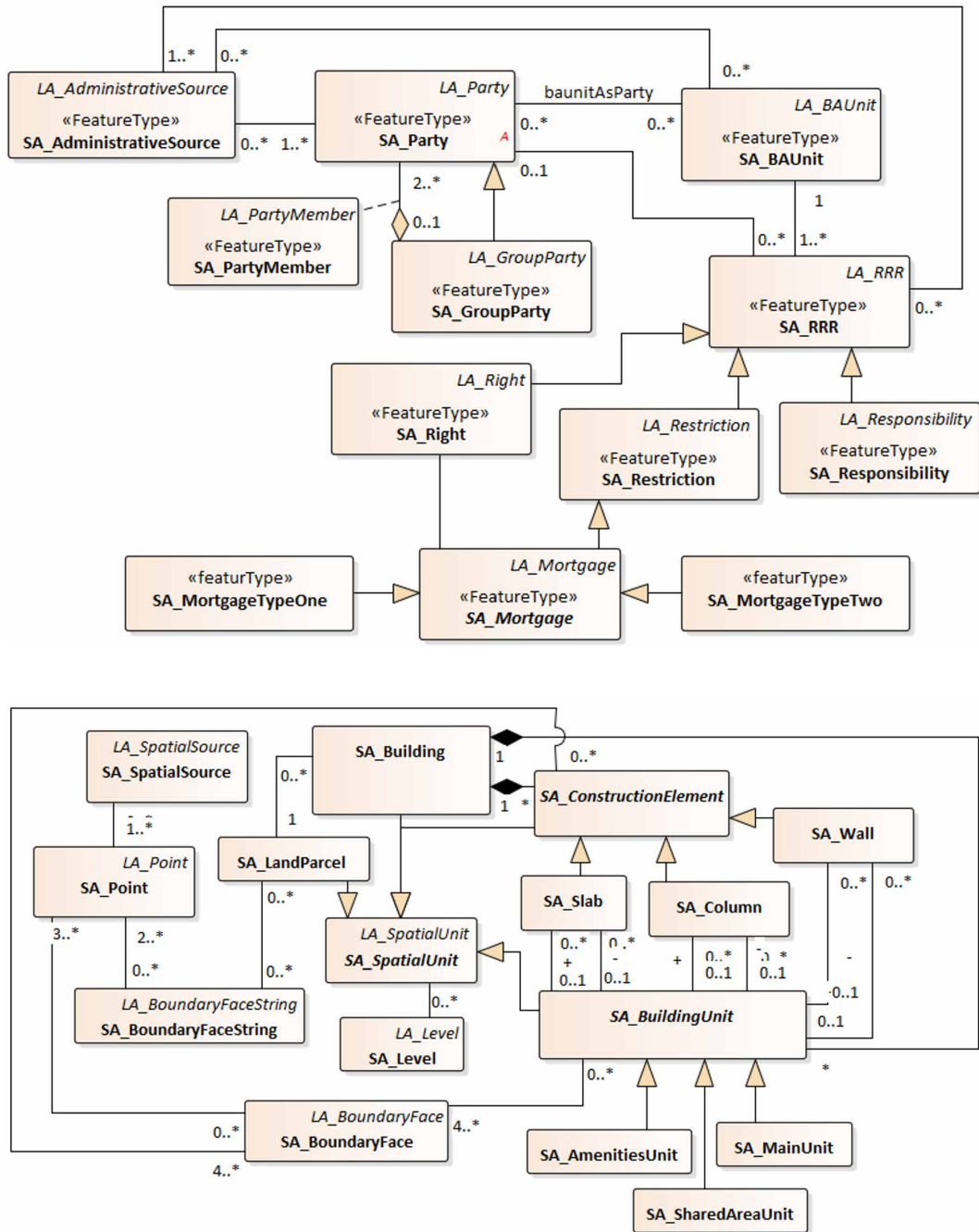FIG. 10.3 3D IFC model of a real-world complex building

FIG. 10.4 Non-spatial (above) and spatial (below) UML class diagram for the 2D country profile

By utilizing the enhanced 3D model, the country profile was expanded to include more attributes and associations for assigning ownership rights to spaces, such as 'property type,' 'property No,' 'ownership type,' 'service area type,' and 'ZoneName.' Furthermore, associations had been created within the building's spaces in order to distinguish the apartments that were adjacent to each other as shown in Figure 10.4. New attributes have been added to the building's construction elements, such as 'type,' 'ownership type,' and 'ZoneName,' which are used to determine the ownership of each element depending on its location. Other associations were also established to define the adjacent spaces of the construction elements. The inclusion of attributes and associations to the spaces and construction elements allows for the definition of various ownership types for the walls, columns, and slabs in both directions. As a result, it is determined that by visualizing the existing regulation of subdivision procedures in 3D, ownership rights are now more precisely defined, as they incorporate more information about each building space.

Conceptual level

— **C1. What is the proper way of linking LADM and IndoorGML conceptual models to define the access rights of use based on the party/user type?**

In order to determine the similarities and differences between the two standards, it is necessary to have a thorough grasp of the functioning of their different classes. In this way, as described in Chapter 6, both standards have been developed for different purposes; however, they are both concerned with the abstraction of spaces, both standards have a notion of primal space with geometrical and topological properties, and both models preserve relationships between objects. These similarities allow the two standards to be linked together without requiring any changes to the structure of each standard.

Therefore, I explored the role of each class in both standards in order to determine which classes could be linked together. Upon investigation, I discovered that the CellSpace class in IndoorGML is responsible for representing primal space and may be used to convey information about the indoor environment to LADM. LADM, on the other hand, has a subpackage called Spatial Source, which is responsible for providing spatial information to the other classes of LADM.

FIG. 10.5 The link between LADM and IndoorGML

Consequently, I created a connection between the CellSpace class in IndoorGML and the LA_SpatialUnit class in LADM, as shown in Figure 10.5. The association provides the cell ID as well as the cell function information. Following that, the spatial information about the cell is included in the LA_SpatialUnit and the cell function information collected by the LA_RRR. The Party Package contains the users' information from an external database by having spatial information of the indoor environment. Once this information has been collected, the LA_BAUnit groups LA_SpatialUnit with the same LA_Right (LA_RRR) class information to create the registration data. As described in Section 6.2, the LA_BAUnit and LA_SpatialUnit associate the subdivision of indoor spaces to the CellSpace class in IndoorGML based on the registration of information.

— **C2. What are the main types of indoor spaces according to the accessibility rights?**

By integrating the two standards, IndoorGML provides cell ID, cell function, and cell geometry to LADM, allowing it to generate a subdivision of the indoor space based on the user-space RRRs. In order to implement a subdivision of indoor spaces, an analysis of the indoor space must be carried out based on the kind of building and the type of users. The access rights are determined by the relationship between the indoor space and the users, as described in Chapter 6.

As a result, the LADM divides the IndoorGML GeneralSpaces and TransferSpaces into groups depending on the RRR of each cell. With LADM the indoor space can be categorised into distinct types of cells based on the LA_RightType and the parties associated with it. Each kind of cell has a different set of functional rights. As a result, two types of cells are classified based on the parties' rights: 1) cells that have private rights for individuals or groups of individuals, and 2) cells that have common rights for individuals or groups of individuals. The first category indicates that a specific individual or group of a party has access rights to the cell, while the second indicates that common rights may exist amongst the users. The LADM uses the same approach to subdivide each cell into smaller cells, each with private rights for the specific party.

— **C3. How the RRRs of the users will affect the indoor navigation during crisis situations?**

This study has explored the access rights of users during a crisis by utilizing the integrating model of LADM and IndoorGML, as described in Chapter 8. The integrated model of LADM-IndoorGML has been expanded to encompass a wider range of timeframes, including regular operations time/office hours, outside office hours, and crisis situations, as well as data that is critical for the Emergency Response Team (ERT). As a result, the LADM Party package has been expanded to include representation of those who utilize the indoor environment during times of crisis. In addition, the development of the party package allows for identifying the relationship between the users and the indoor environment. Consequently, I have created two scenarios and a 3D model that includes many sorts of information about each space, including the space number, use, type, specification, organization unit, cleaning frequency, floor finishing, chair information, department and section information, among other things.

The selected scenario has been tested, and two different outcomes have been achieved. The first result has been gathered by the observers, and it shows that the majority of users have decided to exit the building via the main entrance. The second result was acquired by analyzing and visualizing the users' movements using WiFi data collected throughout the exercise. As a result, I developed a database in

PostgreSQL utilizing the LADM-IndoorGML technical model and populating it with data obtained during an evacuation exercise.

For this aim, I manually digitized the positions of the WiFi access points in Revit and imported them into the database. The representation of access points in the 3D model allowed for monitoring the interaction between the building components and the users' movements. There were two main forms of analysis and visualisation: 1) tracking individual users and 2) monitoring the number of users connected to a single WiFi access point. According to the visualization of individual user movements, a new record was accessible every five minutes, which is a significant amount of time for a person who walks even on a regular day to complete their journey. This time period is sufficient for users to go to the other side of the building and back to their original location. The flow of users' movement as a group, on the other hand, was illustrated by counting the number of users who were connected to each WiFi access point. Therefore, the time allocated for the emergency exercise was split into eight-time frames, with each time frame representing one of the WiFi access points, depending on the number of devices that were connected to each access point throughout the exercise. The technique that has been provided an overview picture of the flow towards the main exit of the building.

The research has also shown that by establishing the position of the WiFi access point, it is feasible to depict the user's movements as an individual or as a group of users depending on the location of the WiFi access point. In this case, representing each WiFi access point as a sphere accurately represents the number of connected devices, which can be varied by altering the size of the sphere. Despite the fact that the research was unable to offer an exact trajectory of movement, it was able to accurately identify which places included more connected devices than other spaces. Eventually, this was used to analyze the flow of the users' movements. In order to achieve the best match between the number of users who were evacuated based on the reporting of the observers and the number of users who were evacuated based on the WiFi log data, it was necessary to take into account WiFi access points that are located near to the exits of the building in both vertical and horizontal directions.

The research results have clearly shown that the 2D representation of indoor environments does not offer a complete understanding of the indoor spaces and specific features such as building components. The concept that 3D representations provide faster and better results for evacuation then 2D representations has been proven correct. The findings of the investigation indicated that there were several gaps in the WiFi data. The temporal resolution of the WiFi log data, i.e., the fact that a new record was accessible every five minutes, is a key problem. Furthermore, due to privacy concerns, the WiFi data did not contain any information about the type

of user, such as student, employee, or other, and as a result, it was not possible to investigate the movements of the users depending on their RRR.

C4. What is the capability of LADM Party package to represent different types of users in several indoor environments?

The Party Package plays a critical function in the integrated model by representing the users of the indoor environment and attempting to establish the relationship between the users and indoor spaces. Therefore, as described in Chapter 6, I investigated several modelling possibilities for extending the Party Package to include additional features in the context of an educational building. The party information was classified into various categories based on the user types in the indoor environment, with each category requiring the addition of numerous required attributes to the Party Package.

As a result, I have presented two different approaches to developing the Party Package, i.e., adding attributes to the LA_Party class or introducing sub-classes. Adding additional attributes to the LA_Party class depending on the user type is the option that does not make any changes to the subclass LA_GroupParty. This option enables the representation of the particular party by providing the additional attributes to the LA_Party class. However, this simple extension may confuse the model since the same class will have multiple additional attributes for each type of user. This issue arises because of attempting to represent all types with a single class. When access rights are defined for each individual party, the same information will be repeated to all parties that are sharing the same information, resulting in an increase in the size of the data. A significant advantage of the first option is that it is straightforward.

On the other hand, the second option brings additional subclasses to the LA_Party and LA_GroupParty classes, as shown in Figure 10.6. The LA_GroupParty has been developed to represent each user category in a distinct subclass to prevent the categories' representation from being mixed in one class. The LA Party class has the same properties as the original class, and the rest of the information will be included in the subclasses of LA_GroupParty that depend on the kind of group party being presented, such as students, visitors, teachers, admin, and maintenance staff. This option enables for groups of groups to be formed, for example, a number of departments joining together to create a faculty. The second option demonstrates the potential to cover a variety of different types of parties via the use of LA_ GroupParty. Additionally, the second option was utilized to determine access rights in times of crisis, using the same procedure as outlined in Section 8.2.
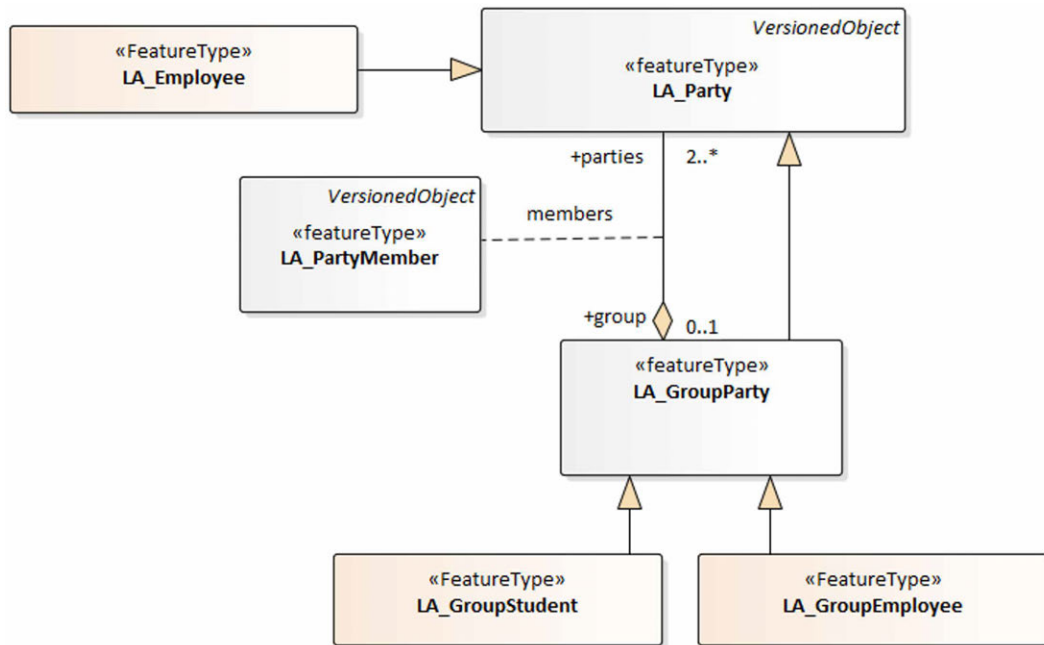
The second option of the Party Package

Technical level

— **T1. What specifications are needed to map a conceptual model to a technical model and then to an implementation model?**

To produce the indoor navigation route based on user-space RRRs, the conceptual model of LADM and IndoorGML have to be transformed into a technical model. I have demonstrated the conversion of the conceptual model into a technical model, which has subsequently been transformed into implementation in Chapter 7. I made use of the transformation tool in Enterprise Architect. I began the transformation process by transforming the class diagram into a table diagram. During that transformation phase, various issues were detected, and I manually corrected them as needed. These issues are summarized below.

Despite the fact that the class diagram has a unique ID attribute depicted in the UML class diagram, the translation tool added a new unique attribute allocated as PK to all tables. As a result, I manually adjusted the PK for all tables by deleting the relationship between the tables and then selecting the appropriate ID attribute.

The multiplicity of the association between the tables differs from that of the class diagram, and I had to adjust them after the transformation manually. For instance, in the UML model, the multiplicity of LA_GroupParty is 2..*; however, the transformation replaced it with 1, which must be manually adjusted. Besides, the transformation model does not convert the multiplicity of attributes to tables, and there is currently no method to resolve this problem. Furthermore, the transformation tool was incapable of dealing with the constraints imposed by the class diagram. Even when the appearance of the table was changed, the constraints were not included in the table diagram.

The LADM Oid and Fraction data types are not considered by the transformation model and thus are replaced with "varchar" in the table diagram. The spatial data types in the table diagram have also been changed to "varchar," and I have the option of changing them by choosing a different type from the list of spatial data types that the software has available. It is only possible to declare a spatial data type manually in SQL code if the type is not already included in the list of supported types. Furthermore, the present structure of the code list class has to be adjusted; as a result, I have created a new class for the code list in order to offer better semantic meaning throughout the transformation. Finally, the translation tool did not create a spatial index, which might be created manually in the SQL schema.

Then, using the code engineering tool in the Enterprise Architect program, I was able to produce an automatic SQL DDL from the UML table diagram. All tables in LADM-IndoorGML are converted by the code engineering. The SQL DDL code provides the comment that each attribute in the UML class has.

— **T2. How to populate the database with the user information, access rights, geometric, and semantic information of the indoor spaces?**

By converting the LADM-IndoorGML conceptual model to an implementation model, I have developed a database schema in PostgreSQL with the spatial extensions PostGIS and pgRouting used to generate an indoor navigation route depending on the user access rights, as detailed in Chapter 9. I began by establishing the Node and Edge tables and populating them with data from the CSV file that was retrieved from the 3D model that was built in the Revit software. Because the table Node included just alphanumerical information, I added an additional column to store the geometry data that was generated from the alphanumerical information. With nodes' geometries already included in the corresponding node tables, I created the edge_geom_view to 'store' the geometry of their edges.

Then, to further prepare for using the pgRouting extension, I added the cost, source, and target columns to edge_geom_view to compute the navigation routes. Then, I have created the LA_Party and LA_Right tables, which provide information on the access rights of the users. Following the creation of the LA_Party table and the LA_Right table, I developed dynamic views for the node and edge tables in order to represent the accessible spaces for a specific user at a specific time based on the access rights of the users in the database. Then, in pgRouting, I computed the shortest route for the specific groups of users using the Dijkstra algorithm. The indoor navigation route has been computed using the user's node and edge views.

— **T3. What type of web-based user interface has to be used to manipulate/ visualize the data in the cases of selecting, updating or routing?**

In this study, the Cesium JS-based 3D web client was used to visualize the indoor navigation routes that take the users' access rights into consideration. Cesium JS enables basic viewing and interaction capabilities by displaying a complete globe with earth imagery, zooming, and panning, providing additional map layers, choosing a specific object, and searching for certain places. Customers will have a simple online interface that allows them to use the capabilities wherever they have access to the web browser on their laptop, tablet computer, or smartphone.

The route is calculated in the database and sent to the GeoServer through an HTTP GET (WFS) request. Then, in order to generate the response, the GeoServer's 'SQL View' capability is utilized to construct a parameterized 'SQL View.' When a map layer with the optimal route is requested through WFS to GeoServer on the server-side, this results in the execution of a PL/pgSQL function with four arguments (party name, source room, target room, and time), which creates the appropriate SQL views, executes the Dijkstra algorithm, and returns the generated database table as a new/dynamic map layer.

Furthermore, I have utilized JavaScript code on the client-side to offer the user a graphical user interface (GUI) panel, which comprises controls for changing the transparency of walls, raising the building, switching on/off the various levels, specifying the user (group), for example, staff or students, inputting the names of the start and destination rooms, and discovering the route. The shortest route is shown as a line above the building, and the spaces the route is passing through are highlighted in the final result, as shown in Figure 10.7. It may be the case that a particular destination is not reachable for a specific user at a specific time, and then a warning will be generated. Additionally, the client-side JavaScript code enables users to verify and visualize which rooms/spaces are available to a specific user.

FIG. 10.7 the web user interface in Cesium JS (http://pakhuis.tudelft.nl:8080/edu/cesium74/Apps/routing/)

10.2 Recommendations for future research

This section provides an overview of recommendations in support to possible extensions of this PhD research in the future. The proposed enhanced UML class diagram of the IndoorGML standard proposed in Chapter 3 has been used as a basis for IndoorGML 2.0 by the OGC Standard Working Group on IndoorGML. This research work has been continued with clarifying some of the concepts and defining more attributes, and developing different implementations such as XML encoding, GeoJSON, SQL spatial schema. Appropriate applications with GUI to create the IndoorGML have been in the process of development as well.

In general, it is recommended that the Saudi Arabia authorities implement the LADM country profile as the basis for the new Land Administration System. Moreover, I recommend that the public parcels in Saudi Arabia are registered to have better quality control, check of possible overlaps, and unwanted gaps in the current registration system. Furthermore, the 2D and 3D country profiles that have been

proposed in Chapters 4 and 5 are recommended to be extended by including different types of information, such as indoor, subsurface, marine, valuation/taxation, and spatial planning information as now being developed by ISO TC 211 in LADM edition two (Lemmen et al., 2019). Then, a technical model and database is recommended to be developed for the management of data, and an appropriate user interface is recommended to be developed to visualize the ownership of lands and buildings. Moreover, the 3D country profile can also be extended to represent a mix-use building and other types of buildings with different sections, various functions, and ownership types based on the local subdivision procedures of Saudi Arabia. The Administrative Package is recommended to be further improved and enriched to support extending the country profile specifically for the elements that refer to the Rights, Restriction, and Responsibilities. Scaling up the implementation on the country profile of Saudi Arabia, the hybrid approach proposed in Chapter 5 is recommended to be tested in further country profiles and BIM/ IFC models for several types of buildings when registering the (ownerships) rights for a new building. In such follow-up research, useful conclusions could be drawn that will lead to the generic technical guidelines for an efficient structure of IFC files to facilitate 3D property registration.

The integrated model of LADM and IndoorGML that has been proposed in Chapter 6 is considered as the core of this research. In further research, it recommended that it be enhanced by investigating different types of buildings and parties, such as hospitals, hotels, train stations, and airports, to ensure the representation of all types of parties during their navigation activity in the indoor environment. Besides that, further research could investigate how to determine the accessible and non-accessible spaces in a more automated way and devise methods to increase the granularity of spaces inside rooms, e.g., around furniture. Also, the impact of LOD could be studied to estimate the complexity of indoor subdivisions. Furthermore, the conceptual model can be extended to be a part of a broader hierarchical framework of models for space subdivision based on the users' rights, restrictions, and responsibilities, as shown in Figure 10.8.
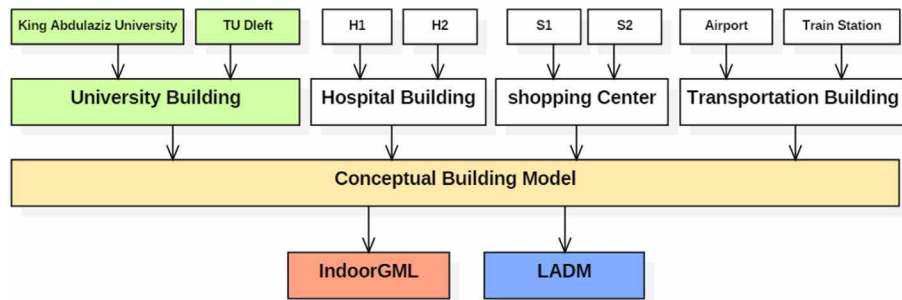
Hierarchical framework of conceptual models

Another direction of future work is expanding the current conceptual model of LADM-IndoorGML in order to cover trajectory data related to the cell spaces / spatial units of the indoor model. There are two main types of trajectory data. The first category covers suggested trajectories (so future evacuation routes) according to the user's preferences, such as fast path, slow route, shorter route, and longest route. The second category covers the recorded movements of the persons (so current and historic routes). For this purpose, two standards, ISO 19141 and ISO 19107, are recommended to be considered. ISO 19141 defines a method to describe the geometry of a feature that moves as a rigid body. ISO 19107 covers the feature moves within any domain composed of spatial objects. Based on ISO 19141, the feature may move along a planned route, but it may deviate from the planned route. By using an information model based on international standards (LADM/ISO 19152, OGC IndoorGML, ISO 19141, ISO 19107), we recommend that the information becomes a part of the 'building infrastructure' and applications all over the world can understand and use this data when entering or leaving a certain building during both normal and crisis situations. This does require not only technology but also rules and regulations. For example, future recommendations for building designers, constructors, maintainers, and permit authorities to make sure the standardized indoor routing support is provided in the building. We propose to include an annex to the new version of the LADM standard to present the integrated model of IndoorGML and LADM which support indoor navigation based on rights, restrictions, and responsibilities. Furthermore, it is recommended to define the legal spaces during the design phase of any complex building. In addition, the legal space of the utilities should be included in the model to detect any conflicting situations (both inside and outside LADM registration).

Different types of applications are anticipated to be based on this information model, e.g., mobile indoor routing app, crisis evacuation desktop (or browser-based) application for a command center, mobile indoor crisis app (supporting first

responders in the field), desktop of server application for analyzing the recorded trajectory data during crisis evacuation (study what did go well, and what did go wrong and should be further improved in the future). Furthermore, future research is recommended to focus on other types of sensors to detect the users' movement in the indoor environment based on their RRRs. For example, several types of buildings can be covered, such as residential, shopping malls, healthcare buildings, and during different indoor conditions such as normal operational time/office hours, outside office hours, and crisis situations; see Figure 10.1.

The web-based application that has been proposed in Chapter 9 can be further investigated and improved by extending the views and GUI to visualize the access time rights for all the users. The integrated model of LADM and IndoorGML is recommended to be used to develop indoor navigation applications for different indoor environments and conditions. I recommend further, more elaborated tests to be competed for large public establishments such as hospitals and airports, especially in emergencies scenarios.

Furthermore, follow-up research could concentrate on developing a mobile-based application that uses the real data of the users and environment and considers dynamic changes (including crowd 'too busy' status). Finally, an augmented reality application could be developed to show users the spaces with access rights and allow optimal navigation support for inside and outside buildings.

Bibliography

Diakité, A. A., & Zlatanova, S. (2018). Spatial subdivision of complex indoor environments for 3D indoor navigation. *International Journal of Geographical Information Science*, *32*(2), 213-235.

Afyouni, I., Ray, C., & Christophe, C. (2012). Spatial models for context-aware indoor navigation systems: A survey. *Journal of Spatial Information Science*, *1*(4), 85-123.

Alexander, K. (Ed.). (2013). *Facilities management: theory and practice*. Routledge.

Alrajhi, M., & Hawarey, M. (2010, June). Modernisation of Saudi Cadastre. In *72nd EAGE Conference and Exhibition incorporating SPE EUROPEC 2010* (pp. cp-161). European Association of Geoscientists & Engineers.

Aurenhammer, F. (1991). Voronoi diagrams—a survey of a fundamental geometric data structure. *ACM Computing Surveys (CSUR)*, *23*(3), 345-405.

Harvey, B. M. (2012). Perform+ function: A proposal for a healthy public housing community.

Bandi, S., & Thalmann, D. (1998, August). Space discretization for efficient human navigation. In *Computer Graphics Forum* (Vol. 17, No. 3, pp. 195-206). Oxford, UK and Boston, USA: Blackwell Publishers Ltd.

Becker, T., Nagel, C., & Kolbe, T. H. (2009). A multilayered space-event model for navigation in indoor spaces. In *3D geo-information sciences* (pp. 61-77). Springer, Berlin, Heidelberg.

Becker, T., Nagel, C., & Kolbe, T. H. (2009, May). Supporting contexts for indoor navigation using a multilayered space model. In *2009 Tenth International Conference on Mobile Data Management: Systems, Services and Middleware* (pp. 680-685). IEEE.

Sandoval, E. B., Li, B., Diakite, A., Zhao, K., Oliver, N., Bednarz, T., & Zlatanova, S. (2020, October). Visually Impaired User Experience using a 3D-Enhanced Facility Management System for Indoors Navigation. In *Companion Publication of the 2020 International Conference on Multimodal Interaction* (pp. 92-96).

Bhatt, M., Dylla, F., & Hois, J. (2009, September). Spatio-terminological inference for the design of ambient environments. In *International Conference on Spatial Information Theory* (pp. 371-391). Springer, Berlin, Heidelberg.

Boguslawski, P., & Gold, C. (2009). Construction operators for modelling 3D objects and dual navigation structures. In *3D geo-information sciences* (pp. 47-59). Springer, Berlin, Heidelberg.

Bon, M. P., den Duijn, X. A., Dukai, B., Griffioen, S. J., Kang, Y., & Vermeer, M. (2016). Identifying movement patterns from large scale Wifi-based location data: A case study of the TU Delft Campus. *Geomatics Synthesis Group Project*.

Boysen, M., de Haas, C., Lu, H., & Xie, X. (2014, May). A journey from ifc files to indoor navigation. In *International Symposium on Web and Wireless Geographical Information Systems* (pp. 148-165). Springer, Berlin, Heidelberg.

Brown, G., Nagel, C., Zlatanova, S., & Kolbe, T. H. (2013). Modelling 3D topographic space against indoor navigation requirements. In *Progress and new trends in 3D geoinformation sciences* (pp. 1-22). Springer, Berlin, Heidelberg.

buildingSMART International Ltd. (1996-2019). Industry Foundation Classes Version 4.2 bSI Draft Standard IFC Bridge proposed extension. https: //standards.buildingsmart.org/IFC/DEV/IFC4_2/FINAL/HTML/. Accessed December 17, 2019

BuildingSMART, Industry Foundation Classes (IFC). <http://www. buildingsmart.com/bim>, 2008.

BuildingSMART, The IFC-Compatible Implementations Database. <http:// buildingsmart-tech.org/ implementation/implementations>, 2011

CEN, C. E. D. N. (2006). Facility Management: Terms and definitions.

Howie, C., & Joel, B. (2000). Sensor-based exploration: the hierarchical generalized Voronoi graph [J]. International Journal of Robotics Research, 19(2), 96-125.

Coronel, C., & Morris, S. (2016). *Database systems: design, implementation, & management*. Cengage Learning.

Cozzi, P., Lilley, S., & Getz, G. (2019). 3D Tiles Specification 1.0. *Open Geospatial Consortium: Wayland, MA, USA.*

de Berg, M., Cheong, O., van Kreveld, M., & Overmars, M. (2008). Chapter 9: Delaunay Triangulations. *Computational Geometry: Algorithms and Applications (Springer-Verlag, Berlin, 2008)*, 191-218.

Demyen, D., & Buro, M. (2006, July). Efficient triangulation-based pathfinding. In *Aaai* (Vol. 6, pp. 942-947).

Diakité, A. A., Zlatanova, S., & Li, K. J. (2017). About the subdivision of indoor spaces in IndoorGML. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *4*(4W5), 41-48.

Abou Diakité, A., & Zlatanova, S. (2016). Valid space description in BIM for 3D indoor navigation. *International Journal of 3-D Information Modeling (IJ3DIM)*, *5*(3), 1-17.

Dürr, F., & Rothermel, K. (2003, October). On a location model for fine-grained geocast. In *International Conference on Ubiquitous Computing* (pp. 18-35). Springer, Berlin, Heidelberg.

Eastman, C. M., Teicholz, P., Sacks, R., Liston, K., & Handbook, B. I. M. (2008). A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators.

Eastman, C., Lee, J. M., Jeong, Y. S., & Lee, J. K. (2009). Automatic rule-based checking of building designs. *Automation in construction*, *18*(8), 1011-1033.

Elfes, A. (1989). Using occupancy grids for mobile robot perception and navigation. *Computer*, *22*(6), 46-57.

EuroFM (2011), available at: http://eurofm.org/about-us/what-is-fm/ (accessed 16 March 2018).

Fink, J., & Kobsa, A. (2002). User modeling for personalized city tours. *Artificial intelligence review*, *18*(1), 33-74.

Foerster, T., Stoter, J., & van Oosterom, P. (2012). On-demand base maps on the web generalized according to user profiles. International Journal of Geographical Information Science, 26(1), 99-121.

Franz, G., Mallot, H. A., & Wiener, J. M. (2005, August). Graph-based models of space in architecture and cognitive science: A comparative analysis. In *17th International Conference on Systems Research, Informatics and Cybernetics (INTERSYMP 2005)* (pp. 30-38). International Institute for Advanced Studies in Systems Research and Cybernetics.

Froese, T., Grobler, F., Ritzenthaler, J., Yu, K., Akinci, B., Akbas, R., ... & Kunz, J. C. (1999). Industry Foundation Classes for Project Management-A Trial Implementation. *J. Inf. Technol. Constr.*, *4*, 17-36.

Kang, H. K., & Li, K. J. (2017). A standard indoor spatial data model—OGC IndoorGML and implementation approaches. *ISPRS International Journal of Geo-Information*, *6*(4), 116.

Hevner, A., & Chatterjee, S. (2010). Design science research in information systems. In *Design research in information systems* (pp. 9-22). Springer, Boston, MA.

Housing program. (n.d.). Retrieved February 6, 2020, from https://vision2030.gov.sa/ar/programs/Housing.

Hu, H., & Lee, D. L. (2004, January). Semantic location modeling for location navigation in mobile environment. In *IEEE International Conference on Mobile Data Management, 2004. Proceedings. 2004* (pp. 52-61). IEEE.

IAI (1999a). Specification Development Guide. Ed. Wix J and See R. International Alliance Of Interoperability (IAI). Specification Task Force, pp. 47

IAI (1999b). IFC Object Model Architechture Guide. Ed. Liebich T and See R. International Alliance Of Interoperability (IAI). Specification Task Force, pp. 9

IAI (2000). IFC Technical Guide - Enabling Interoperability in the AEC/FM Industry. Ed. Liebich T and Wix J. Modeling Support Group. International Alliance Of Interoperability (IAI), pp. 46

IFMA-IT1 (2011), available at: http://ifma.com/about/ (accessed 3 March 2011).

Isikdag, U., Zlatanova, S., & Underwood, J. (2013). A BIM-Oriented Model for supporting indoor navigation requirements. *Computers, Environment and Urban Systems*, *41*, 112-123.

ISO 19152 (E), 2012, Geographic information- Land Administration Model (LADM), ISO 2012, ISO/TC 211 Geographic information/Geomatics, 128p.

Ivanov, R. (2010, June). Indoor navigation system for visually impaired. In *Proceedings of the 11th International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing on International Conference on Computer Systems and Technologies* (pp. 143-149).

Jeong, S. K., & Ban, Y. U. (2011). Computational algorithms to evaluate design solutions using Space Syntax. *Computer-Aided Design*, *43*(6), 664-676.

Kainz, W., Egenhofer, M. J., & Greasley, I. (1993). Modelling spatial relations and operations with partially ordered sets. *International Journal of Geographical Information Systems*, *7*(3), 215-229.

Kalogianni, E. (2016). Linking the legal with the physical reality of 3D objects in the context of Land Administration Domain Model.

Kalogianni, E., Dimopoulou, E., Quak, W., Germann, M., Jenni, L., & Van Oosterom, P. (2017). INTERLIS language for modelling legal 3D spaces and physical 3D objects by including formalized implementable constraints and meaningful code lists. *ISPRS International Journal of Geo-Information*, *6*(10), 319.

Kalogianni, E., Kalantari, M., Dimopoulou, E., & van Oosterom, P. (2019). LADM country profiles development: Aspects to be reflected and considered. In *LADM 2019: 8th FIG Land Administration Domain Model Workshop* (pp. 287-302). International Federation of Surveyors (FIG).

Kalogianni, E., van Oosterom, P., Dimopoulou, E., & Lemmen, C. (2020). 3D land administration: A review and a future vision in the context of the spatial development lifecycle. *ISPRS international journal of geo-information*, *9*(2), 107.

Li, K. J. (2016). IndoorGML-A standard for indoor spatial modeling. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, *41*.

Krūminaitė, M., & Zlatanova, S. (2014, November). Indoor space subdivision for indoor navigation. In *Proceedings of the sixth ACM SIGSPATIAL international workshop on indoor spatial awareness* (pp. 25-31).

Kuffner, J. J. (1998, November). Goal-directed navigation for animated characters using real-time path planning and control. In *International Workshop on Capture Techniques for Virtual Environments* (pp. 171-186). Springer, Berlin, Heidelberg.

Laakso, M., & Kiviniemi, A. O. (2012). The IFC standard: A review of history, development, and standardization, information technology. *ITcon*, *17*(9), 134-161.

LADM, 2017, ISO19152, LADM WIKI, available at (http://isoladm.org).

Lee, G., Won, J., Ham, S., & Shin, Y. (2011). Metrics for quantifying the similarities and differences between IFC files. *Journal of Computing in Civil Engineering*, *25*(2), 172-181.

Lee, J et al. (2015). OGC IndoorGML, Document No. 14-005r4. http :// docs.opengeospatial.org/is/14-005r5/14-005r5.html. Accessed February 09, 2021.

Lee, J. (2004). A spatial access-oriented implementation of a 3-D GIS topological data model for urban entities. *GeoInformatica*, *8*(3), 237-264.

Lee, J., K.-J Li, S. Zlatanova, T.H. Kolbe, C. Nagel, T. Becker, 2014, OGC IndoorGML, OGC 14-0051r1, http://www.opengeospatial.org/standards/indoorgml#downloads (15 May 2017)

Lemmen, C. H. J., van Oosterom, P. J., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., & Alattas, A. (2019, October). The scope of LADM revision is shaping-up. In *8th Land Administration Domain Model Workshop 2019*.

Lemmen, C.H.J., P.J.M. van Oosterom, R. Thompson, J. P. Hespanha and H. Uitermark, 2010, The Modelling of Spatial Units (Parcels) in the Land Administration Domain Model (LADM). In: Proceedings of the XXIV FIG International Congress 2010, April 2010, Sydney, 28 p.

Lemmen, C., Van Oosterom, P., & Bennett, R. (2015). The land administration domain model. *Land use policy*, *49*, 535-545.

Li, X., Claramunt, C., & Ray, C. (2010). A grid graph-based model for the analysis of 2D indoor spaces. *Computers, Environment and Urban Systems*, *34*(6), 532-540.

LIEBICH, T., ADACHI, Y., FORESTER, J., HYVARINEN, J., KARSTILA, K., AND WIX, J. Industry Foundation Classes: IFC2x Edition 3 TC1, technical corrigendum 1. International Alliance for Interoperability (Model Support Group) (2006).

Lin, Y. H., Liu, Y. S., Gao, G., Han, X. G., Lai, C. Y., & Gu, M. (2013). The IFC-based path planning for 3D indoor spaces. *Advanced Engineering Informatics*, *27*(2), 189-205.

Liu, L., & Zlatanova, S. (2011). A" door-to-door" path-finding approach for indoor navigation. *Proceedings Gi4DM 2011: GeoInformation for Disaster Management, Antalya, Turkey, 3-8 May 2011*.

Liu, L., & Zlatanova, S. (2012, November). A semantic data model for indoor navigation. In *Proceedings of the Fourth ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness* (pp. 1-8).

Liu, X., Wang, X., Wright, G., Cheng, J. C., Li, X., & Liu, R. (2017). A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS International Journal of Geo-Information*, *6*(2), 53.

Lorenz, B., Ohlbach, H. J., & Stoffel, E. P. (2006, December). A hybrid spatial model for representing indoor environments. In *International Symposium on Web and Wireless Geographical Information Systems* (pp. 102-112). Springer, Berlin, Heidelberg.

TOC

Lujak, M., Billhardt, H., Dunkel, J., Fernández, A., Hermoso, R., & Ossowski, S. (2017). A distributed architecture for real-time evacuation guidance in large smart buildings. *Computer Science and Information Systems*, *14*(1), 257-282.

Maas, G. and Pleunis, J. (2006), Facility Management, Strategie en Bedrijfsvoering van de Facilitaire Organisatie, Kluwer, Alphen aan den Rijn.

Makri, A., Zlatanova, S., & Verbree, E. (2015). AN APPROACH FOR INDOOR WAYFINDING REPLICATING MAIN PRINCIPLES OF AN OUTDOOR NAVIGATION SYSTEM FOR CYCLISTS. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences.*

Meijers, M., Zlatanova, S., & Pfeifer, N. (2005). 3D geo-information indoors: structuring for evacuation. *Proceedings of next generation 3D city models, Bonn, Germany*, *6*, 11-16.

Ministry of Housing, 2002. The Property ownership and subdivision system Act, (M/5 2002), Riyadh, KSA.

Ministry of Housing, 2020. Procedures for subdivision real estate units, Riyadh, KSA.

MOJ and MOMRA, 2002. The Property ownership and subdivision system Act, (M/5 2002), Riyadh, KSA.

Moravec, H., & Elfes, A. (1985, March). High resolution maps from wide angle sonar. In *Proceedings. 1985 IEEE international conference on robotics and automation* (Vol. 2, pp. 116-121). IEEE.

Munkres, J. R., 1984, Elements of Algebraic Topology, Addison-Wesley, Menlo Park, CA, 1984.

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., ... & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, *11*(3), 231-252.

Giudice, N. A., Walton, L. A., & Worboys, M. (2010, November). The informatics of indoor and outdoor space: a research agenda. In *Proceedings of the 2nd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness* (pp. 47-53).

Nicał, A. K., & Wodyński, W. (2016). Enhancing facility management through BIM 6D. *Procedia engineering*, *164*, 299-306.

Nutt, B. (2004). Infrastructure resources: forging alignments between supply and demand. *Facilities.*

Ozdenizci, B., Ok, K., Coskun, V., & Aydin, M. N. (2011, April). Development of an indoor navigation system using NFC technology. In *2011 Fourth International Conference on Information and Computing* (pp. 11-14). IEEE.

Pärn, E. A., Edwards, D. J., & Sing, M. C. (2017). The building information modelling trajectory in facilities management: A review. *Automation in construction*, *75*, 45-55.

Programs and initiatives. (n.d.). Retrieved February 6, 2020, from https://www.housing.gov.sa/ar/initiatives.

Quality of Life Program. (n.d.). Retrieved February 6, 2020, from https://vision2030.gov.sa/ar/programs/QoL.

Rajabifard, A., Atazadeh, B., & Kalantari, M. (2019). *BIM and urban land administration.* CRC Press.

Real estate ownership and sorting system. (n.d.). Retrieved February 3, 2020, from https://www.housing.gov.sa/ar/regulations.

Real estate ownership. (n.d.). Retrieved February 3, 2020, from https://www.moj.gov.sa/ar/SystemsAndRegulations/Pages/default.aspx.

Remolina, E., & Kuipers, B. (2004). Towards a general theory of topological maps. *Artificial Intelligence*, *152*(1), 47-104.

Renaudin, V., Yalak, O., Tomé, P., & Merminod, B. (2007). Indoor navigation of emergency agents. *European Journal of Navigation*, *5*(ARTICLE), 36-45.

Richter, K. F., Winter, S., & Santosa, S. (2011). Hierarchical representations of indoor spaces. *Environment and Planning B: Planning and Design*, *38*(6), 1052-1070.

Richter, K. F., Winter, S., & Rüetschi, U. J. (2009, May). Constructing hierarchical representations of indoor spaces. In *2009 tenth international conference on mobile data management: systems, services and middleware* (pp. 686-691). IEEE.

Rueppel, U., & Stuebbe, K. M. (2008). BIM-based indoor-emergency-navigation-system for complex buildings. *Tsinghua science and technology*, *13*(S1), 362-367.

Saudi Arabia Vision 2030. (n.d.). Retrieved from https://vision2030.gov.sa/ar.

Schaap, J. 2010. *Towards a 3D geo-data model to support pedestrian routing in multimodal public transport travel advices.* MSc Thesis. GIMA MSc. programme, Utrecht University, Netherlands.

Sime, J. D. (1984). *Escape behaviour in fires: panic or affiliation.* University of Surrey (United Kingdom).

Simon, H. (1996) The Sciences of Artificial, 3rd edn., MIT Press, Cambridge, MA.

Simpson, S.R., 1976, Land Law and Registration. Cambridge University Press.

Steenhuizen, D., Flores-Colen, I., Reitsma, A. G., & Ló, P. B. (2014). The road to facility management. *Facilities.*

Tang, F., & Ren, A. (2012). GIS-based 3D evacuation simulation for indoor fire. *Building and Environment*, *49*, 193-202.

Tang, SJ et al. (2015). "Automatic topology derivation from IFC building model for indoor intelligent navigation". In: The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 40.4, p. 7.

Tashakkori, H., Rajabifard, A., & Kalantari, M. 2015. A new 3D indoor/outdoor spatial model for indoor emergency response facilitation. Building and Environment, 89, pp. 170-182.

The organization of the General Authority for Real Estate. (n.d.). Retrieved February 3, 2020, from https://rega.gov.sa/AboutUs.

The system of municipalities and villages issued by the Royal Decree No. M / 5. (n.d.). Retrieved February 3, 2020, from https://www.momra.gov.sa/GeneralServ/Forms.aspx?id=2.

Visual scripting environment for designers: Dynamo. (2020, June 15). Retrieved March 17, 2021, from https://dynamobim.org/

Xiong, Q., Zhu, Q., Du, Z., Zhu, X., Zhang, Y., Niu, L., & Zhou, Y. 2017. A Dynamic Indoor Field Model for Emergency Evacuation Simulation. ISPRS International Journal of Geo-Information, 6(4), pp. 104.

Yuan, W. & Schneide, M. 2010. Supporting 3D Route Planning in Indoor Space Based on the LEGO Representation. In *proceedings of ISA'10*. New York: ACM.

Zhang, J. P., & Hu, Z. Z. (2011). BIM-and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies. *Automation in construction*, *20*(2), 155-166.

Zhiliang, M., Zhenhua, W., Wu, S., & Zhe, L. (2011). Application and extension of the IFC standard in construction cost estimating for tendering in China. *Automation in Construction*, *20*(2), 196-204.

Zlatanova, S., L. Liu, G. Sithole, J. Zhao and F. Mortari, 2014, Space subdivision for indoor applications, GISt Report, nr. 66, Delft, 2014 50 p.

Zlatanova, S., Li, K.J., Lemmen, C. and Oosterom, P. (2016). Indoor Abstract Spaces: Linking IndoorGML and LADM. In: Proceeding of the 5th International FIG 3D Cadastre Workshop (2016) Athens, pp.317-328

Zlatanova, S.; Van Oosterom, P.J.M.; Lee, J.; Li, K.-J.; Lemmen, C.H.J. LADM and IndoorGML for Support of Indoor Space Identification. In Proceedings of the 11th 3D Geoinfo Conference on ISPRS Annals of the photogrammetry, Remote Sensing and Spatial Information Science, Athens, Greece, 20–21 October 2016.

Zlatanova, S., Liu, L., & Sithole, G. (2013, November). A conceptual framework of space subdivision for indoor navigation. In *Proceedings of the fifth ACM SIGSPATIAL international workshop on indoor spatial awareness* (pp. 37-41).

Zulkifli, N. A., Abdul Rahman, A., Jamil, H., Teng, C. H., Tan, L. C., Looi, K. S., ... & Van Oosterom, P. J. M. (2014). Towards Malaysian LADM country profile for 2D and 3D cadastral registration system. In Proceedings of the 25th FIG Congress: Engaging the challenges, enhancing the relevance, Kuala Lumpur, Malaysia, June 16-21, 2014. FIG International Federation of Surveyors.

Zulkifli, N. A., Rahman, A. A., Jamil, H., & Hua, T. C. (2014). Development of a Prototype for the Assessment of the Malaysian LADM Country Profile. International Federation of Surveyors, FIG.

Zulkifli, N. A., Rahman, A. A., van Oosterom, P., Tan, L. C., Jamil, H., Teng, C. H., ... & Chan, K. L. (2015). The importance of Malaysian Land Administration Domain Model country profile in land policy. Land Use Policy, 49, 649-659.

Zulkifli, N.; Rahman, A.; Jamil, H.; Hua, T.C.; Choon, T.L.; Seng, L.K.; Lim, C.K.; van Oosterom, P.J.M. Towards Malaysian LADM Country Profile for 2D and 3D Cadastral Registration System. In Proceedings of the 10th 3D GeoInfo Conference, Kuala Lumpur, Malaysia, 28–30 October 2015.

Zulkifli, N.A., Rahman, A.A., Van Oosterom, P.J.M., 2013. Developing 2D and 3D Cadastral Registration System based on LADM: illustrated with Malaysian cases. In: Proceedings of the LADM Workshop, Kuala Lumpur, Malaysia, September 2013.

Curriculum Vitae

Abdullah Alattas was born in 1985 in Jeddah, Saudi Arabia. He received a bachelor's degree in architecture from the Faculty of Architecture and Planning at King Abdulaziz University in 2008. Afterward, he started working as a lecturer at the Geomatics department at the Faculty of Architecture and Planning in 2008. Then, he obtained a master's degree in Cartography from the international Master program that is a cooperation of: Technische Universität München (TUM), Department of Cartography, Technische Universität Wien (TU Vienna), Research Group Cartography, and Technische Universität Dresden (TU Dresden), Institute for Cartography in 2014.

Moreover, Abdullah joined the GISt section in 2017 at the Faculty of Architecture and the Built Environment, Technical University of Delft. Abdullah conducted his Ph.D. research on "The Integration of LADM and IndoorGML to Support the Indoor Navigation Based on the User Access Rights", funded by the Geomatics Department at the Faculty of Architecture and Planning, King Abdulaziz University.

The Integration of LADM and IndoorGML to Support the Indoor Navigation Based on the User Access Rights

Abdullah Alattas

Indoor navigation applications are actively investigated and developed due to their capacity to provide users with essential information in the modern extensive building complexes. Therefore, many researchers have developed a range of indoor navigation applications, which have focused on aspects such as localization, indoor route computation, and human spatial cognition. Unfortunately, current indoor navigation systems do not consider the user's access rights when it comes to navigating safely and effectively. This thesis delivers several contributions, which are based on international standards, to provide Indoor navigation aware of the user's access rights.

The thesis proposes:
1) a combined model of ISO's LADM and OGC's IndoorGML;
2) an enhancement of the UML class diagram of the conceptual model of IndoorGML;
3) a 2D LADM country profile of the Saudi Arabia;
4) a 3D LADM country profile of Saudi Arabia;
5) a conversion of the combined LADM and IndoorGML conceptual model to a technical model;
6) definitions of access rights for users of indoor environments during crisis based on the integrated model of LADM and IndoorGML;
7) a 3D web-based prototype application for indoor navigation making use of user access rights.

The developed concepts and implementation have been acknowledged by the standardization organization ISO and OGC and considered for amending IndoorGML and LADM.

A+BE | Architecture and the Built Environment | TU Delft BK