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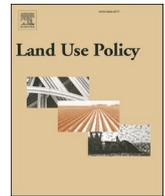
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Mapping private, common, and exclusive common spaces in buildings from BIM/IFC to LADM. A case study from Saudi Arabia

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ABSTRACT

This paper presents in detail 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 Land Administration Domain Model (LADM) country profile for Saudi Arabia must be able to represent the identified concepts for multi-owner buildings. Today, there is a trend to directly design these buildings in 3D. Within the spatial development lifecycle thinking, this design will be reused via Building Information Modelling (BIM)/ Industry Foundation Class (IFC) encodings in the subsequent phases, such as, obtaining permits, financing, constructing, etc. However, in order to support the next step, the cadastral registration, we present, at this paper, a mapping from the BIM/IFC to the LADM, both at conceptual modelling and at the level of the individual units 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 type of spaces are identified: private part, common part, and exclusive common part. A single property may contain multiple disconnected components, such as the main apartment, the storage in the basement, and a car park. In turn, a component, such as the main apartment, may contain multiple connected spaces, i.e. the various rooms of the main apartment. In addition to mapping the concepts at class level from IFC to LADM, we also extract rules for treating the spaces of various types of walls, slabs, roofs, and constructive elements, such as foundation and pillars. 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 IFC file which can be more easy 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. Though many of the presented findings are based on the legislation and case study in Saudi Arabia, we have the rather strong impression, that these findings will not be very different in other countries.

1. Introduction

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

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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 et al., 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 visualize complex buildings in more detail (Rajabifard et al., 2019). In this context, recent research focusing on extracting useful information from IFC files for cadastral registration, as presented in Section 2.

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 Industry Foundation Class (EN ISO 16739:2017) files to ISO 19152 Land Administration Domain Model:2012, 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. From the research carried out, the main conclusions are drawn, which can be translated to more general guidelines for structuring IFC files to extract 3D properties for registration purposes and, hence, move from country level to an international context. It is highlighted that the research uses two ISO standards, LADM and IFC, facilitating the generalization of its conclusions to a wider context that can be used, after further processing, by different jurisdiction types worldwide. LADM provides an international framework for the most effective development of 3D Cadastre and thus, it was used to develop the 3D

country profile of Saudi Arabia. What is more, the new regulations of building subdivisions in Saudi Arabia are well defined and very detailed, while a real-world IFC file for a complex apartments' structure was available for testing.

The methodology used in the research can be summarized as follows: Firstly, we reviewed the current research carried out on the discourse on BIM/LADM interoperability and the new regulations for building subdivision in our case study in Saudi Arabia. Then, we formulated those regulations in 3D expressions and defined three generic main types of spaces: private, common, and exclusive common. Next, we developed the 3D LADM-based country profile for Saudi Arabia, and a generic real-world 3D IFC model of a complex apartment building. Then a mapping between the 3D LADM country profile and the IFC model was established. The IFC model was evaluated and examined in terms of completeness and correctness and improved accordingly. The space subdivision procedures were completed to define the legal space of each ownership. After this step, the 3D spaces were created to represent the 3D legal boundary. Finally, each space is enriched with ownership information from the LADM country profile.

The rest of the paper is structured as follows: Section 2 briefly describes related work in the field of information reuse from BIM models for land administration. Section 3 presents an extensive overview of the building unit's subdivision regulations in Saudi Arabia, while Section 4 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, while the last Section are devoted to discussion and conclusions.

2. Related work

This section briefly presents related research that is carried out in the field of information reuse for land administration purposes, focusing on BIM/ IFC models as a source. As presented below, the first research studies were carried mostly at a conceptual level, trying to examine the usability of BIM/ IFC for such purposes, while later on, implementations using IFC models took place to validate the assumptions. Towards this implementation there are two directions, either to enrich IFC models with legal information, or to extend the legal model (usually based on ISO 19152:2012 LADM) with physical counterparts (Kalogianni et al., 2019).

The first researchers investigated the use of BIM in land administration were Clemen and Gründig (2006), as they indicated that IFC files could be enriched with (processed) surveying measurements and observations for indoor cadastre purposes. However, they did not proceed to implementations by enriching IFC files with cadastral information. Moreover, the cadastral extension of the Unified Building Model (UBM) was investigated by El-Mekawy and Östman (2012) and El-Mekawy et al. (2014), examining the capability of the IFC standard for dealing with 3D cadastral systems. The authors proposed that UBMs could be extended to include boundaries without physical objects or counterparts, which are necessary for representing above- and below-ground RRR spaces in the context of the Swedish jurisdiction. However, the enriched UBM does not model information about interest holders, and legal documents, and the authors did not present a BIM model enriched with 3D property information. Following, Isikdag et al. (2014) investigated connecting legal data models with 3D physical data models such as IFC, arguing that this could potentially facilitate current practices for evaluating properties in various countries, without presenting any implementation.

The first actual implementation attempts in using BIM/IFC data as a source for 3D land administration have been explored and presented by Oldfield et al. (2018) and Atazadeh et al. (2016, 2017) and Olfat et al. (2019). suggested that space objects (IfcSpace), and the grouping of these spaces as legal zones (IfcZone), could underpin the utilization of BIM models in 3D cadastres. To demonstrate the usability of BIM data for 3D land administration Model View Definition (MVD) was used,

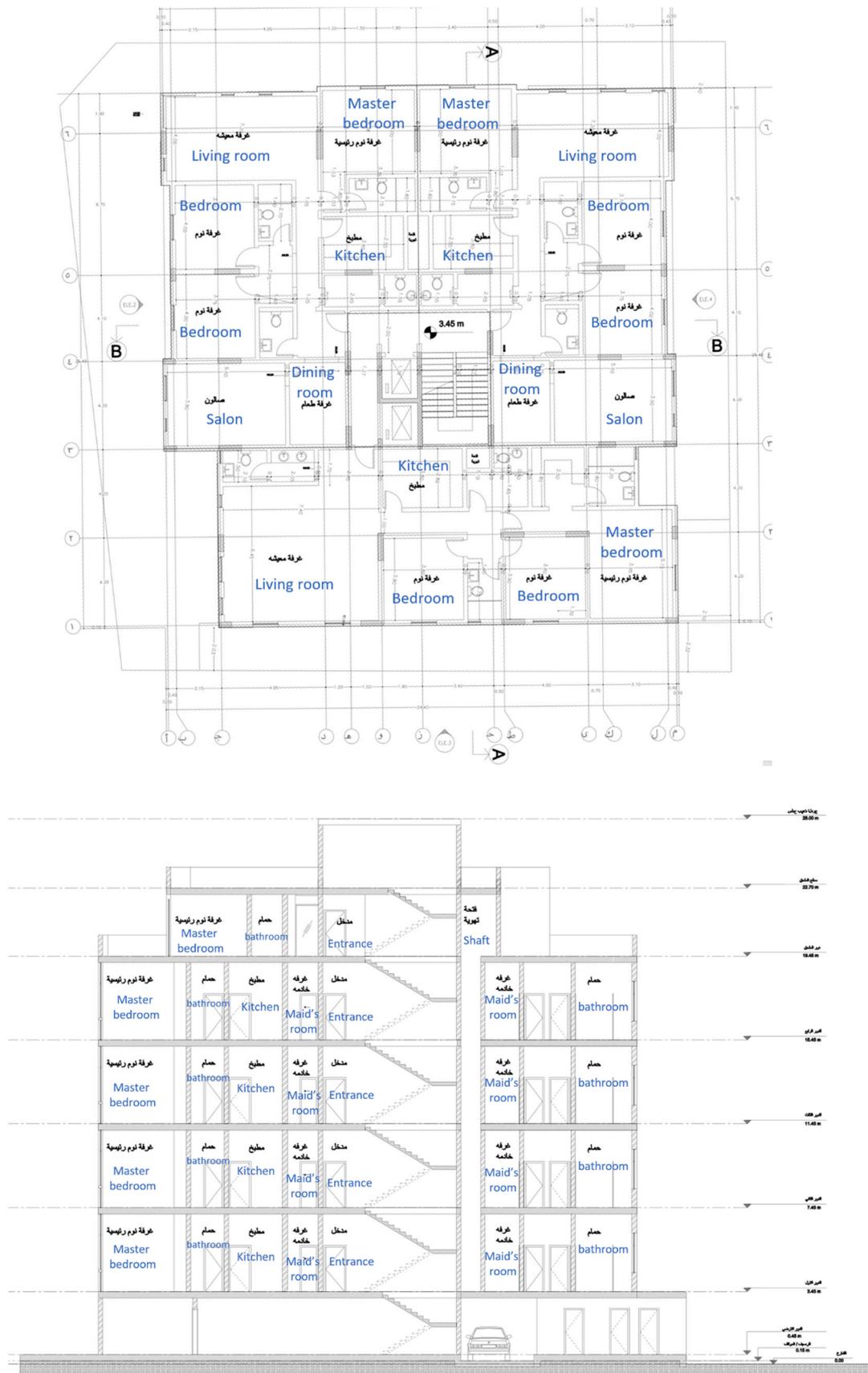


Fig. 1. Example of one of the required documents by the Ministry of Housing; the approved building floors plans from municipality (in the request of the subdivision).

Table 1
The subdivided units from the main types of real estate properties.

Construction types Functional unit 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						

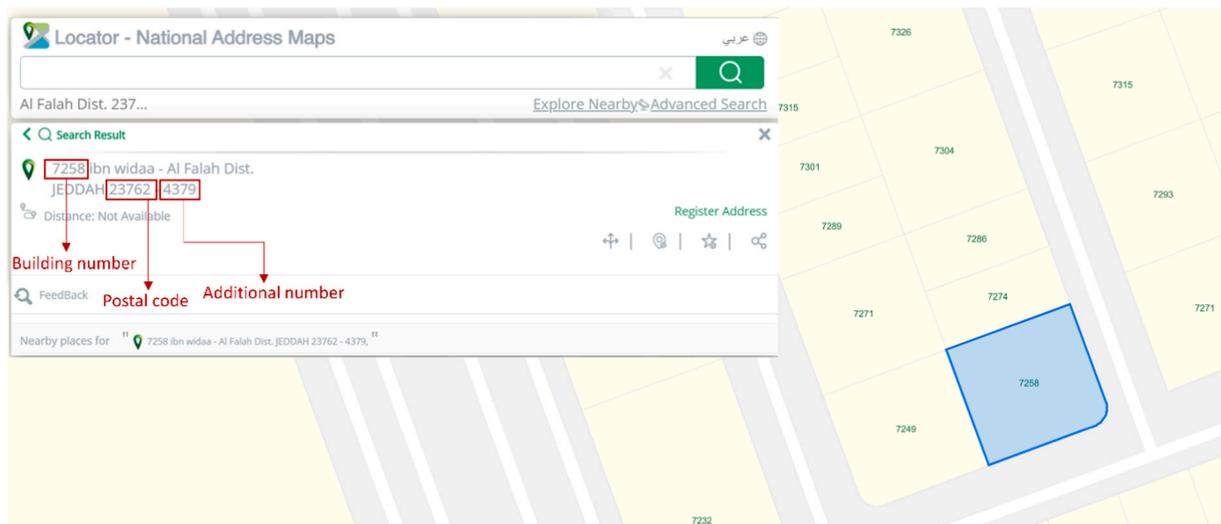


Fig. 2. the numbering approach system of the national address.

Table 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 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.	

aiming to stay within the resources of the IFC's common schema and not try to extend the model further. In the context of lifecycle thinking, the presented workflow described how land administration data requirements could be efficiently communicated between project stakeholders, which would, in turn, facilitate procedures for obtaining legal spaces from BIM models.

From a more technical perspective, Atazadeh et al. (2016) investigated the feasibility of BIM for urban land administration and, in particular, for 3D digital management of legal interests in multi-storey building developments. The IFC file was enriched with legal data, and a prototype BIM model for a multi-storey building development was implemented to demonstrate the viability of the extended IFC data model for 3D digital management and the visualization of data related to complex legal arrangements. From the results of this research, relevant entities suitable for modelling legal information were identified and proposed in the IFC standard. These entities have been extended to model legal information with the minimum change possible in the current IFC data structure. The adopted approach for extending relevant

IFC entities with legal data elements has mainly been predicated on using the extension mechanism provided within the current schema of the IFC standard. What is more, Atazadeh et al. (2018) presented the mapping between LADM and IFC concepts.

Focusing more on national regulations, Meulmeester (2019) proposes a proof of concept for a complete data processing chain for registering new apartment rights in 3D in the Netherlands, by enriching IFC files with minimal information enabling identification of legal spaces, by designing a user-defined property set with cadastral information (based on LADM), added to the 'IfcSpace' element.

From another perspective, and by recognizing that BIM and GIS models can be used as complementary input data for land administration systems, recent research by Sun et al. (2019) proposes to use both BIM and CityGML for such purposes, based on LADM.

From the aforementioned research studies, it is concluded that more and more studies focus on examining either the extension of IFC files or their simplification derive content-wise information for land administration purposes based on LADM. The result is either an extended/

enriched IFC file, or an LADM-based model visualised in UML at the conceptual level and implemented in a database at the implementation stage with both legal and physical/ structural information integrated.

3. Building unit's subdivision procedures in Saudi Arabia

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:
 - o 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.
 - o Then, the Municipality has to check all the documents to validate that all the requirements are met.
 - o 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 considered 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 standardizing the building's subdivision procedures, developing and organizing the systems, automate the processes, preserving and guaranteeing the unit owner's rights, activating the role of the building owner union, and reducing procedures time. The rest of the section is structured as follows: subsection 3.1 represents the condition and requirements for the property units' subdivision. Subsection 3.2 defines the types of real estate and sub-dividable units. The numbering approach of the real estate unit is represented in subsection 3.3. Subsection 3.4 presents common and private parts. The approach of defining a unit's area and its boundaries are presented in subsection 3.5. Finally, the construction elements ownership rights are described in Subsection 3.6.

3.1. Conditions and requirements for the subdivision of the property 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 have to 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 of the 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 Fig. 1.

3.2. 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:

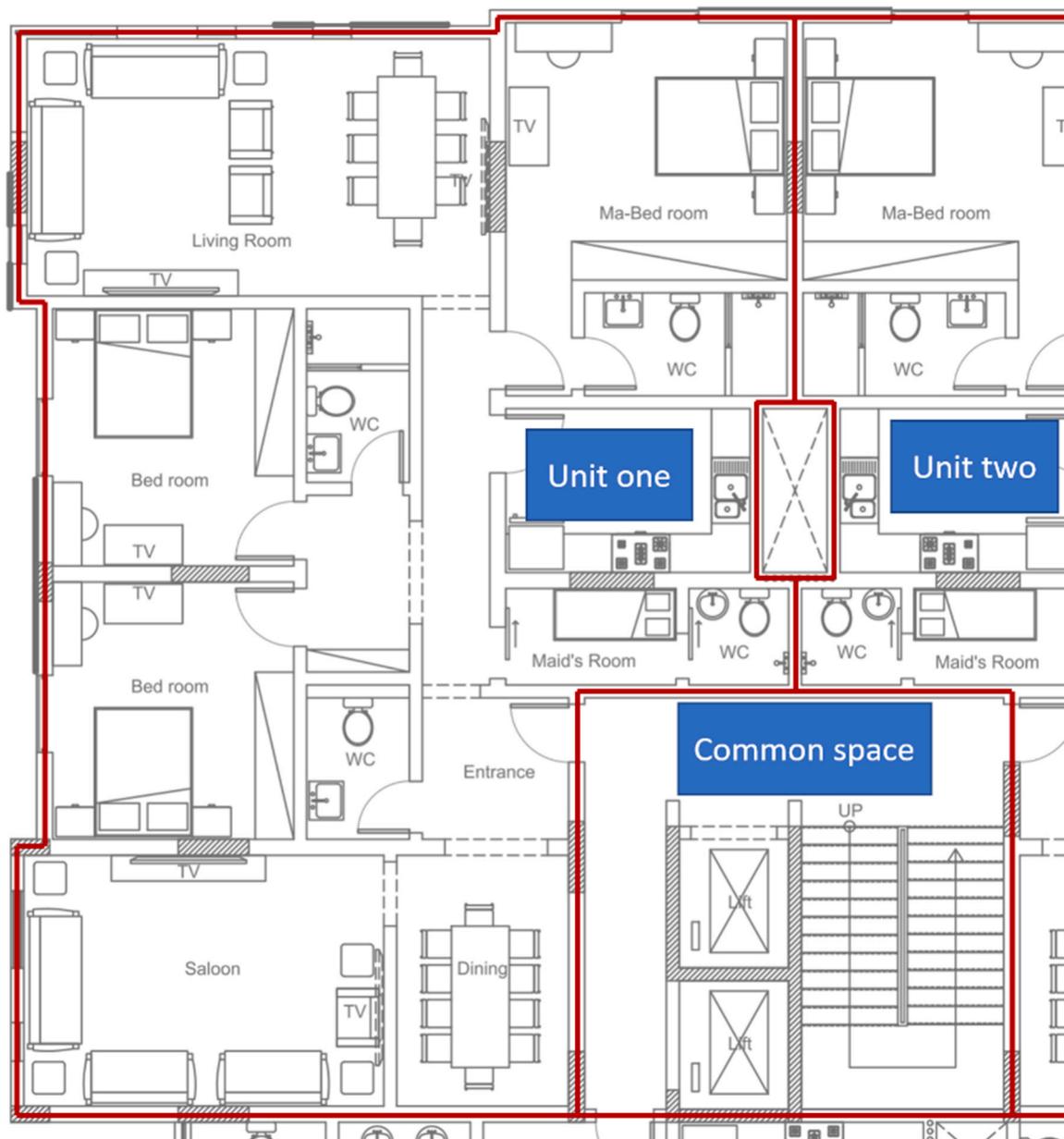


Fig. 3. Unit boundaries in middle of the walls.

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:** It 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.

The external façades of the building



Fig. 4. External façades of the building.

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 m, and their area not less than 200 m².
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 10 m, or it has a separated structure, and its area is less than 200 m², or the street width is less than 12 m.
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 m. The villa area is not less than 200 m², and the width of the street is not less than 12 m.
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 1](#).

3.3. 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 [Fig. 2 \(Ministry of Housing, 2020\)](#).

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 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 referred by a number that consist of the unit number and the floor number (unit /floor number). [Table 2](#) shows an example of the numbering system for a building consist 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 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.

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

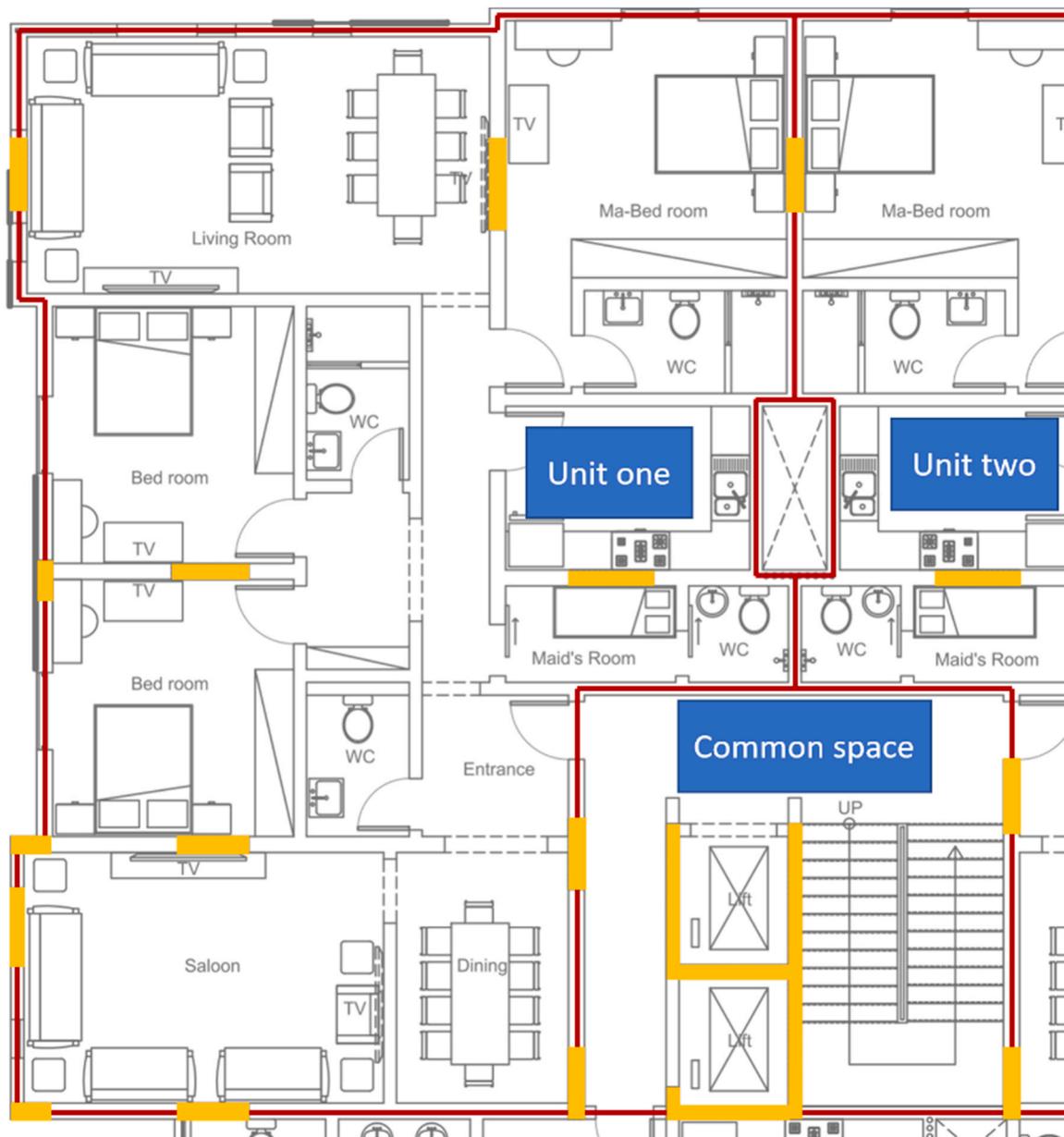


Fig. 5. The common ownership of columns.

property will have a separate deed registration.

3.4. Common, private, and exclusive common spaces

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 more 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.

3.5. 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 Fig. 3.



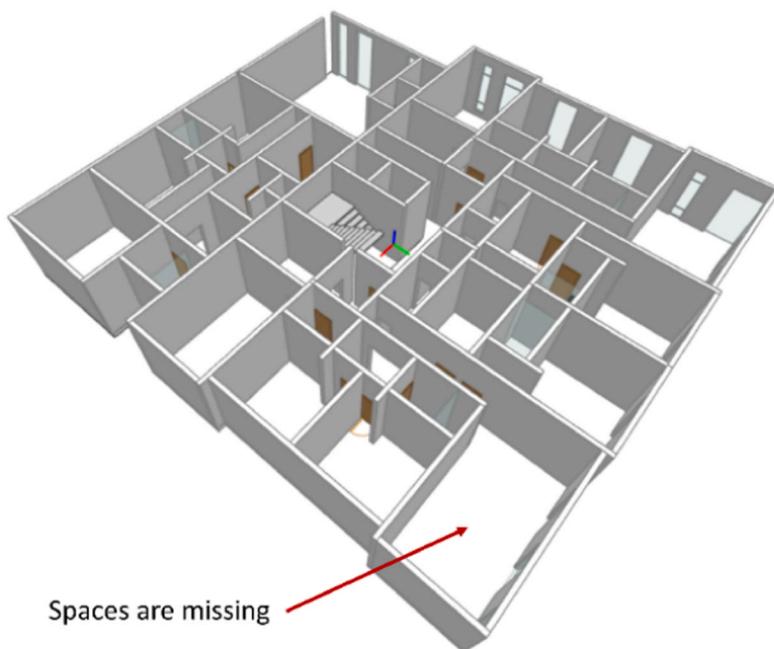
Fig. 6. A 3D model of an apartment building.

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 the indivual 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 of are considered as common space that is defined as half of the thickness of the outer wall of all the units, as shown in Fig. 4. All the elements of the façades are considered under common

ownership.

3.6. 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:



IFC Structure	
Type	
<input type="checkbox"/>	Building Storey
<input checked="" type="checkbox"/>	Building Storey
<input type="checkbox"/>	Walls
<input type="checkbox"/>	Annotations
<input type="checkbox"/>	Slabs
<input type="checkbox"/>	Doors
<input type="checkbox"/>	Curtain Walls
<input type="checkbox"/>	Others
<input type="checkbox"/>	Columns
<input type="checkbox"/>	Stairs

The content of the first floor

Fig. 7. Missing Spaces from the 3D model.

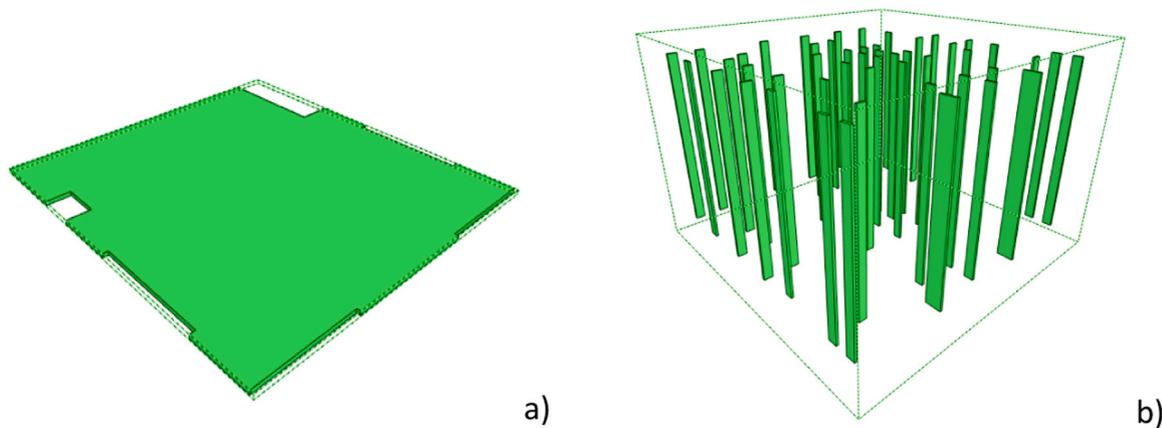


Fig. 8. The Slab and columns have been created as single object.

- 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 Fig. 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.

4. 3D representation of building unit's subdivision procedures in Saudi Arabia

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, it is expected that 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 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 Fig. 6. Each unit (apartment) has its own 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.

4.1. Modifying the 3D model based on the building unit's subdivision procedures in Saudi Arabia

From a brief research carried out, most of the architecture firms in Saudi Arabia create 3D models for most of their complex projects, and they use them for marketing purposes, while they create 3D perspective views to get the Municipality's approval. Therefore, the building's 3D model is 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 are 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 now briefly described. 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 3D spaces are missing, and there is some overlap in the slabs, several architecture elements are missing (windows and doors). Additionally, the construction elements of the building have some issues such as the columns have been created as one element and they will have the same information. In case of discovered errors, 'manual' corrections have been made to 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 unit's subdivision procedures. First, the 3D model is missing the 3D spaces as shown in Fig. 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.

Moreover, each floor slab has been initially created as one element for all apartments located on the same floor, and this will not allow assigning the ownership for each part that covers the units (apartment) are located above and under the slab as shown in Fig. 8a. Similarly, the columns have been created as a single object for the entire building, and that does not allow to add different ownership rights to each individual column as shown in Fig. 8b. Moreover, due to the purpose that the 3D model was created (marketing purposes), 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.

The 3D model assessment has shown several issues that have to be solved before implementing the subdivision procedures. 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 Fig. 9. Autodesk Revit was used to process and implement the 3D model, as it is one of the most used 3D modelling software worldwide, which supports IFC import/export, and the initial 3D model of this apartment building was modeled in Revit. Therefore, for interoperability reasons, Autodesk Revit was chosen. The software does not support creating one space for the entire apartment. Thus, it was decided that each apartment will

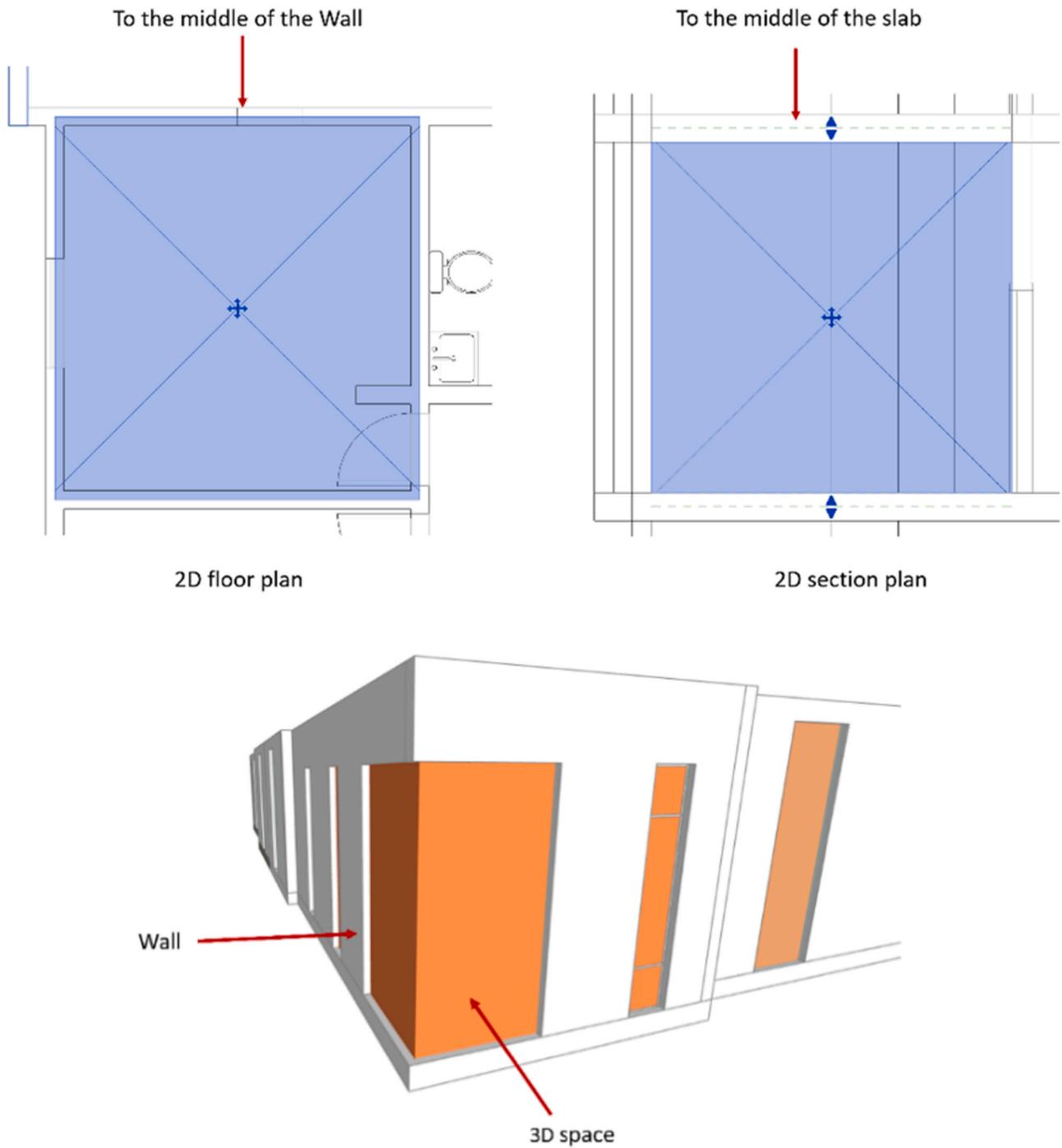


Fig. 9. Space representation.

Table 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	
Exclusive Common Ownership +	Name or number of the property or area that located in right side of the Exclusive Common space
Exclusive Common Ownership -	Name or number of the property or area that located in left side of the Exclusive Common space

consist of several spaces equal to the number of its rooms.

4.2. 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 4, which will be included accordingly in each building’s space based on its type/function.

By adding the attributes to the model and based on each space’s type, several types of spaces ownership are defined. Fig. 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 Fig. 11.

Apartment one has the following amenity/service spaces a parking spot and a driver’s room, and all of them have the same value

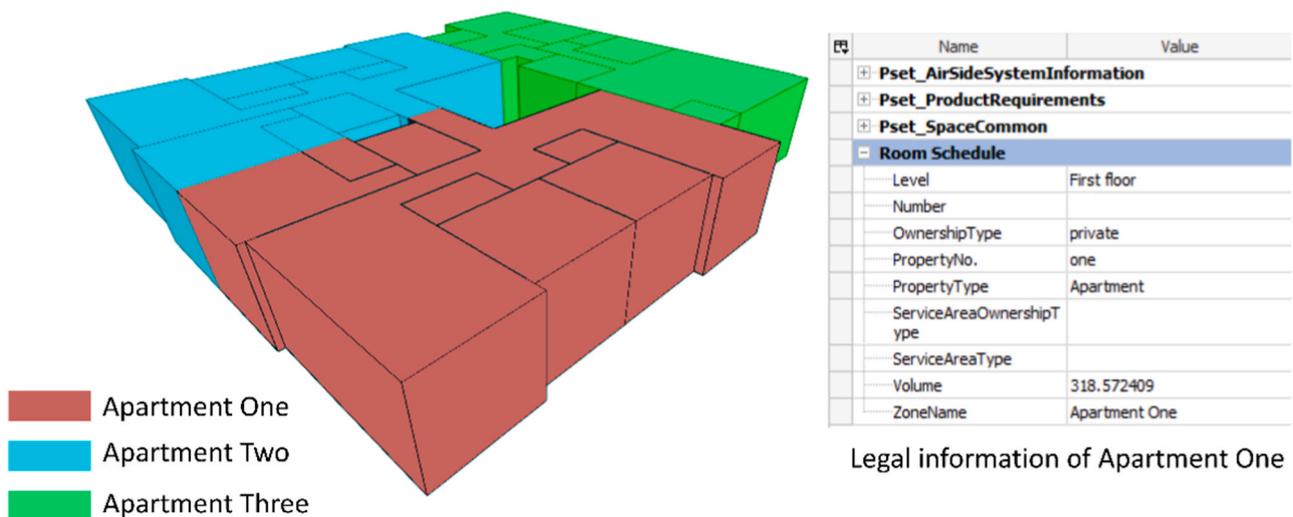


Fig. 10. The private ownership of apartment one.

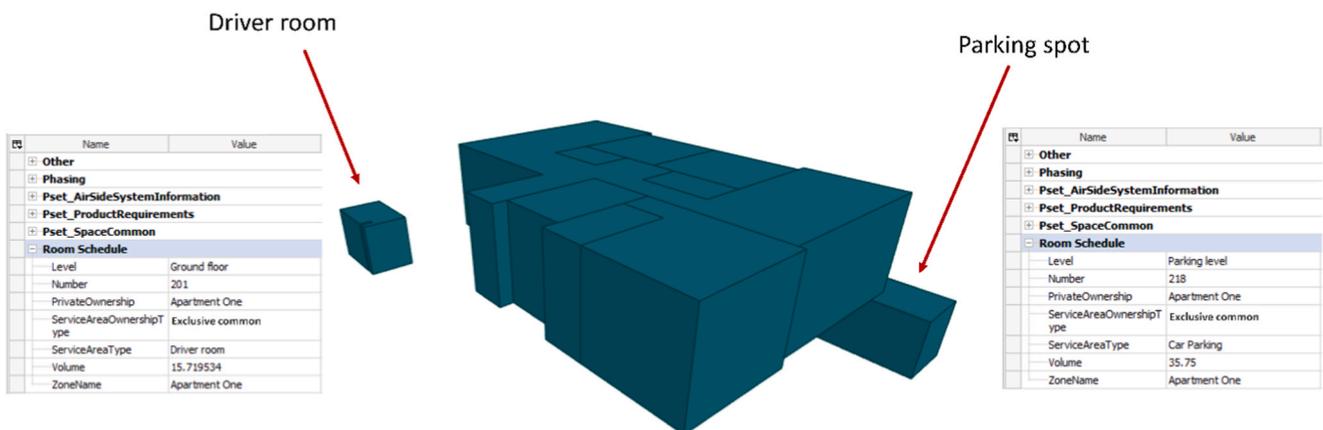
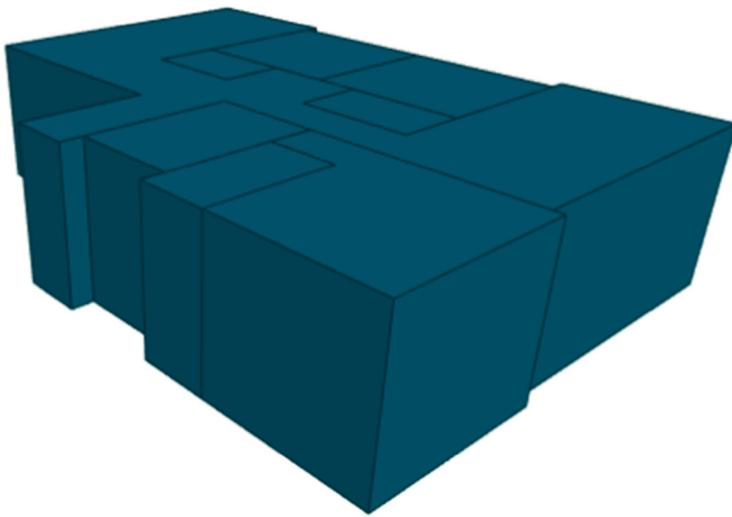
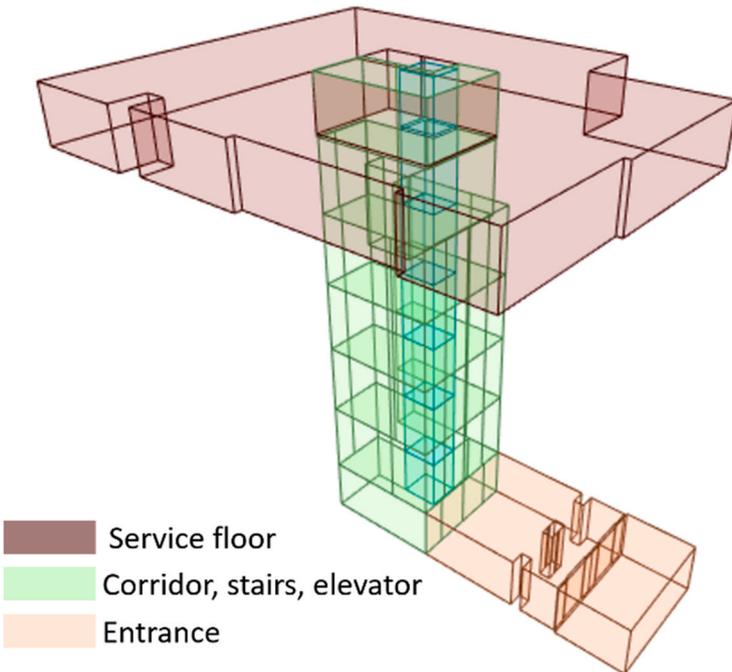


Fig. 11. The representation of the service spaces for apartment one (one zone of which the main one has many spaces, and the other two, driver room and parking spot, each have just one space).



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. 12. The representation of the private spaces for apartment one (as driver rooms and parking spots are common spaces in this option).



- Service floor
- Corridor, stairs, elevator
- Entrance

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

Legal information for the entrance

Fig. 13. The common spaces of the building.

(‘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). In that case, 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. Fig. 12 shows the representation of the private spaces of apartment one without the service spaces.

4.3. The common building units

Furthermore, the building has other spaces in 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 Fig. 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 Fig. 14.

4.4. The exclusive common building units

The last type of space ownership is the exclusive common ownership.

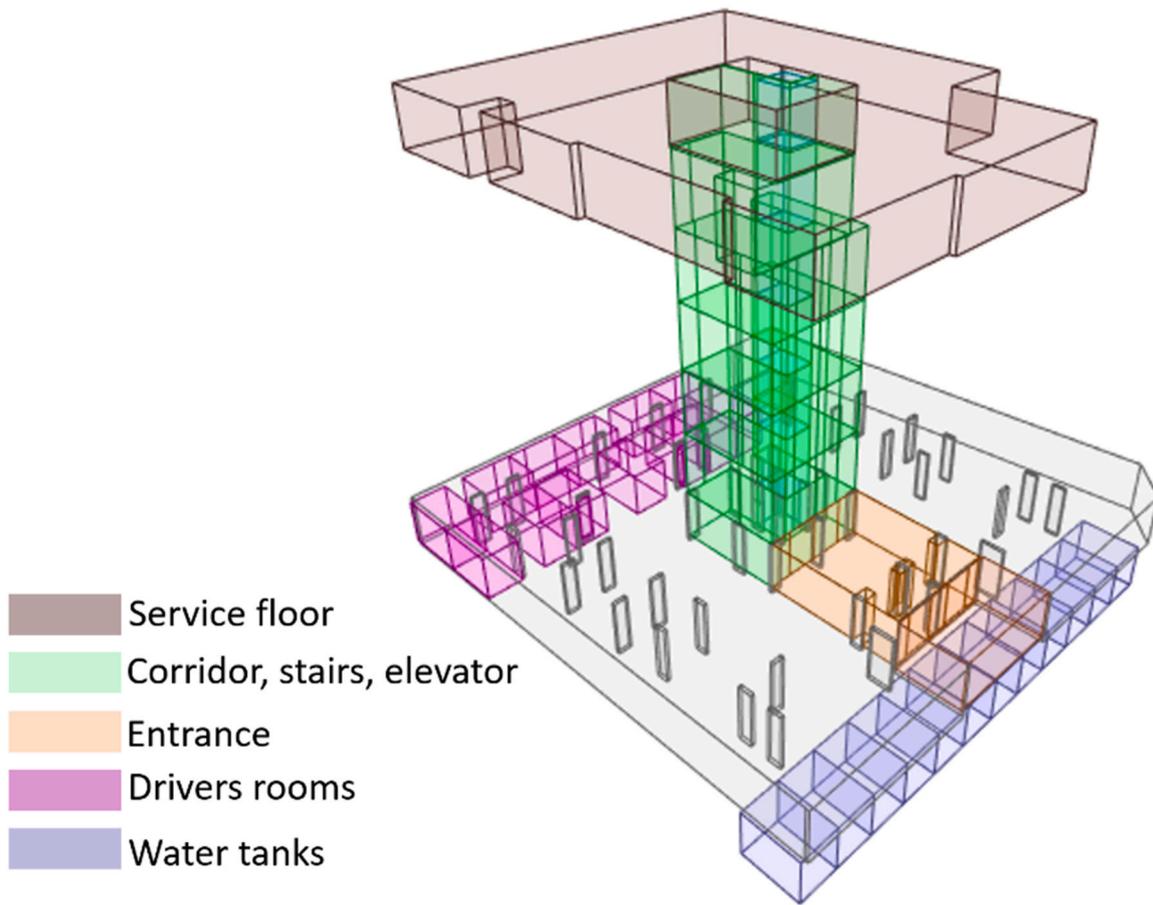


Fig. 14. The common spaces of the building including parking floor, drivers’ rooms, and water tanks.

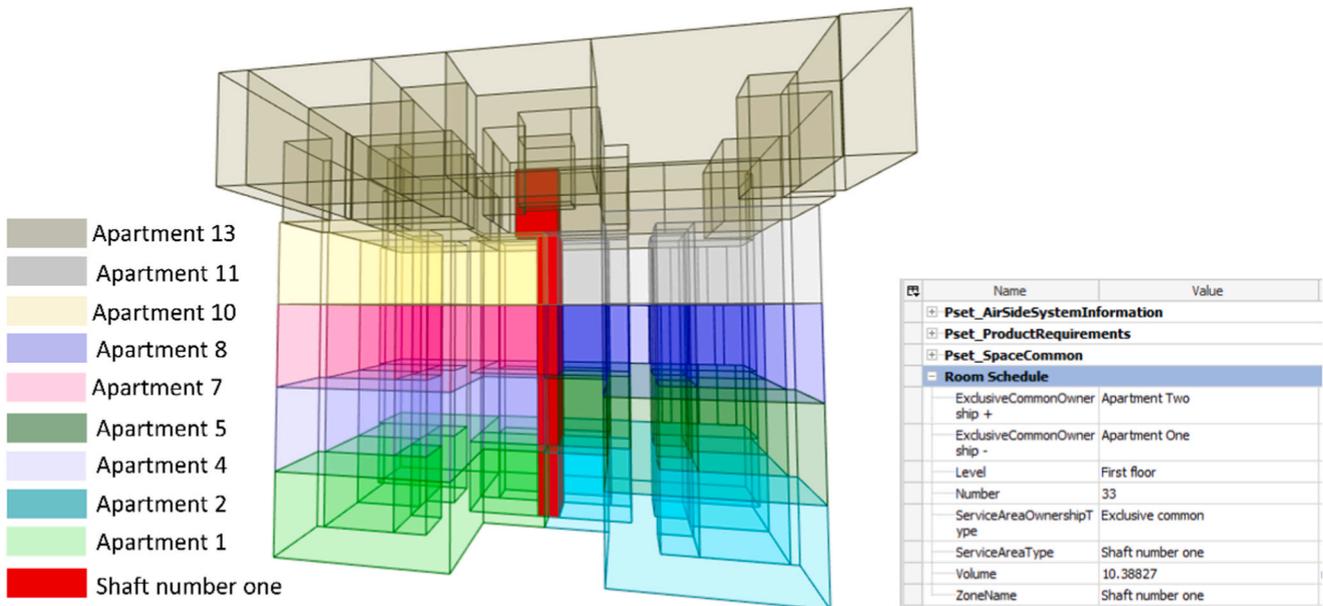


Fig. 15. 3D section of the building to represent the exclusive common ownership of the shaft.

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 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 2, to represent the spaces sharing the use of the shafts. The ‘Exclusive Common Ownership +’ and ‘Exclusive Common

Table 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
<i>Associations</i>	<i>Description</i>
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

Ownership –' associations have been used to represent for the right and left units, respectively. The model will only register the neighboring 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 Fig. 15.

4.5. 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 has included additional attributes to represent ownership. Table 5 shows the additional attributes that have been added to the walls of the 3D model.

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 Fig. 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 Fig. 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 Fig. 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 Fig. 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 Fig. 16e. The *last type* of wall ownership related to a wall located between two common spaces and the ownership type will be common ownership.

4.6. Construction elements of the building: columns

The second type of construction element is the columns, and they have common ownership rights. Additional attributes have been added to the columns to define the ownership, as shown in Table 5. Accordingly, the columns have to be created as detached columns to assign these attributes to each column separately, as shown in Fig. 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.

4.7. 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. Fig. 18 shows a slab with exclusive common ownership because it is located between two private ownership apartments.

5. Development of the initial 3D Saudi Arabia country profile for the representation of apartment unit's subdivision based on ISO19152:2012 LADM

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.

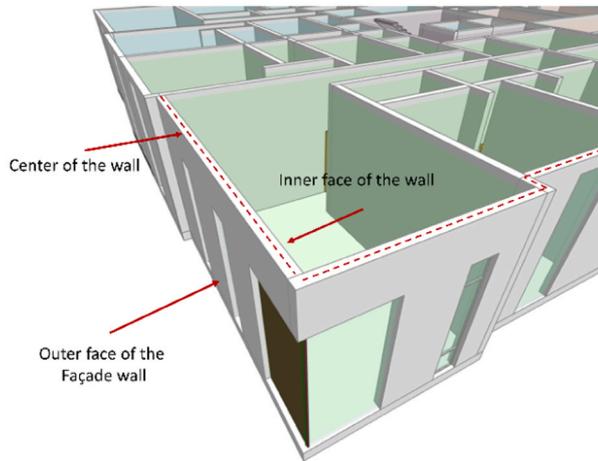
5.1. Initial 2D country profile based on LADM

As a *first step*, several interviews were conducted with the stakeholders to understand and investigate the local regulations of the property registration system. Then, a description of the current system was made to evaluate the current registration system, while numerous deed registration documents for the most common types of properties were studied to extract the primary information used during the registration. The information that has been identified during this research can be categorized in two groups: optional and non-optional information. These categories have been considered as attributes for the country profile, and there were three types of attributes: attributes related to party information, those related to spatial information, and those related to administrative/ legal information. Thus, by collecting all the information about the local registration system, the *next step was to map the local registration system's main elements to LADM concepts* by assigning each attribute to the related LADM class.

The *UML diagram of the 2D country profile* is split into a spatial and a non-spatial diagram. The party package and the administrative package are in the non-spatial diagram as presented by Alattas et al. (2020). The party package includes the following classes: SA_Party, SA_GroupParty, and SA_PartyMember. At the same time the administrative package includes the classes: SA_BAUnit, SA_RRR, SA_AdministrativeSource class, and SA_Mortgage class. The SA_RRR is an abstract class and three subclasses: SA_Right, SA_Responsibility, and SA_Restriction. The SA_Mortgage is an abstract class and it has two subclasses to represent different mortgage sources: SA_MortgageTypeOne and SA_MortgageTypeTwo.

The spatial package has the abstract class SA_SpatialUnit class with its two subclasses SA_LandParcel and SA_BuildingUnit (with subclasses for the different types) as presented by Alattas et al. (2020). The surveying and representation sub-package includes the following

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

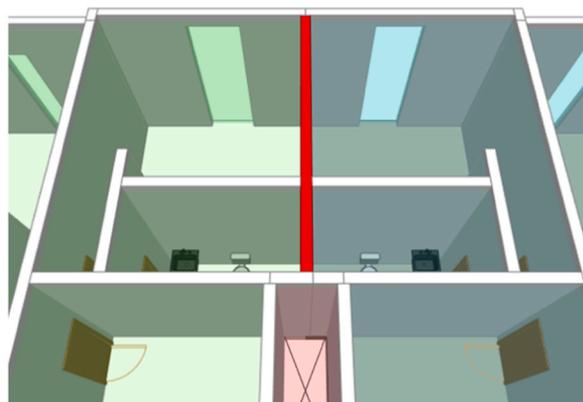
b) A wall is located inside a unit and has private ownership:



- Inner wall
- Apartment One
- Apartment Two

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

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

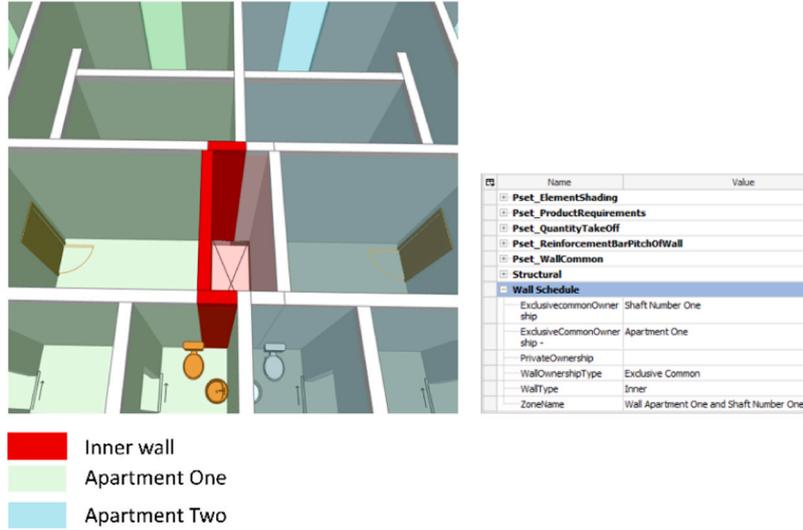


- Inner wall
- Apartment One
- Apartment Two

Name	Value
Pset_ElementShading	
Pset_ProductRequirements	
Pset_QuantityTakeOff	
Pset_ReinforcementBarPitchOfWall	
Pset_WallCommon	
Structural	
Wall Schedule	
ExclusiveCommonOwner ship	Apartment One
ExclusiveCommonOwner ship -	Apartment Two
PrivateOwnership	Apartment Two
WallOwnershipType	Exclusive Common
WallType	Inner
ZoneName	Wall Apartment One and Two

Fig. 16. The ownership types of the walls.

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



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

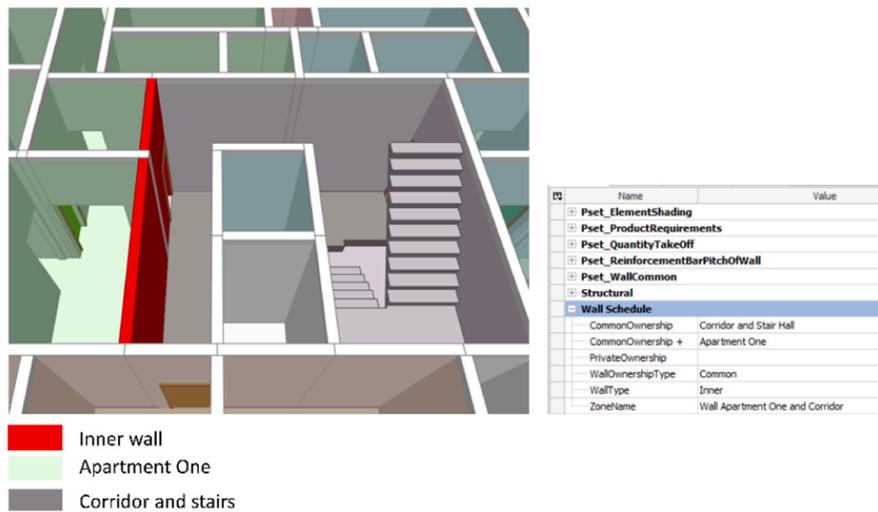


Figure 16: The ownership types of the walls

Fig. 16. (continued).

classes: SA_Point, SA_SpatialSource, and SA_BoundaryFaceString. Each class has its additional attributes based on the local registration system. Furthermore, the party package classes, and the administrative package classes inherit additional attributes from their original classes of LADM.

5.2. Initial 3D country profile based on LADM

The authors have developed the 3D country profile based on the update of the earlier developed 2D profile (Alattas et al. 2020) 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 profiles and others that should be added to address the needs of the country. Therefore, Table 6 represents the main classes of LADM that have been used for the development of the 3D country profile.

According to the new attributes that have been proposed in Sections 4.1 and 4.5 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 Fig. 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 Fig. 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

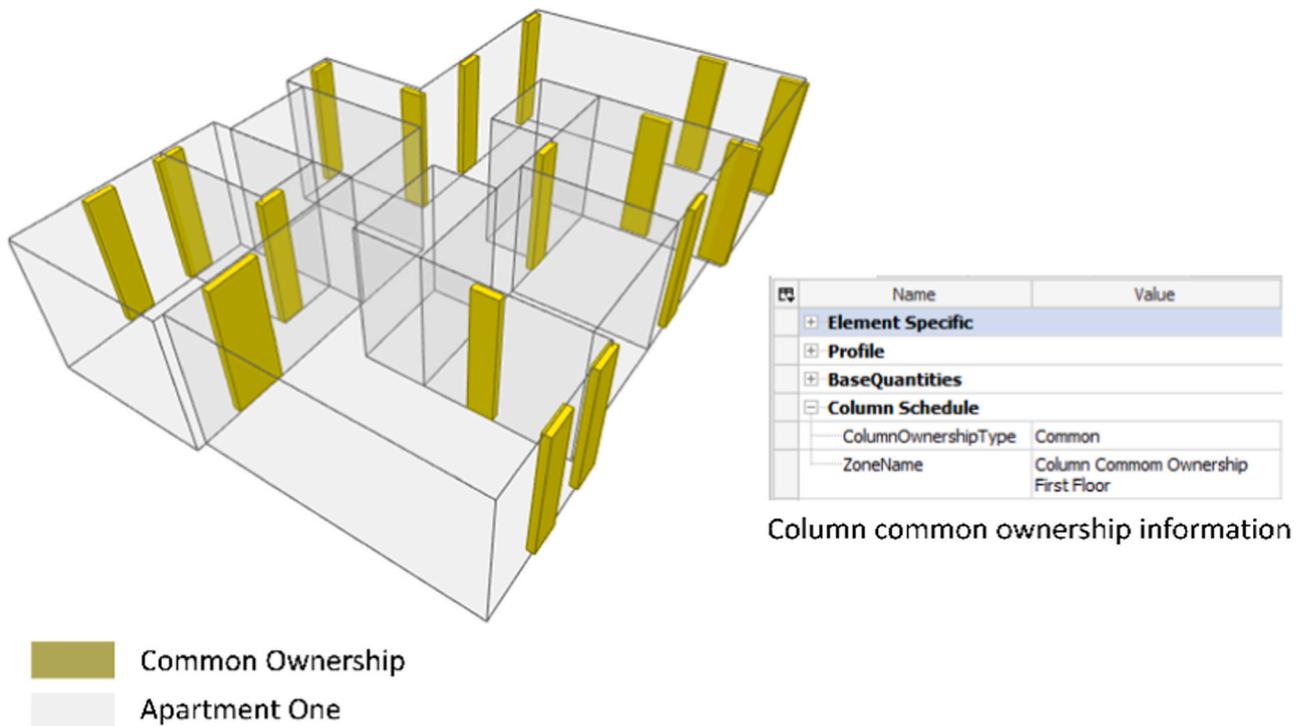


Fig. 17. The ownership types of the columns.

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,

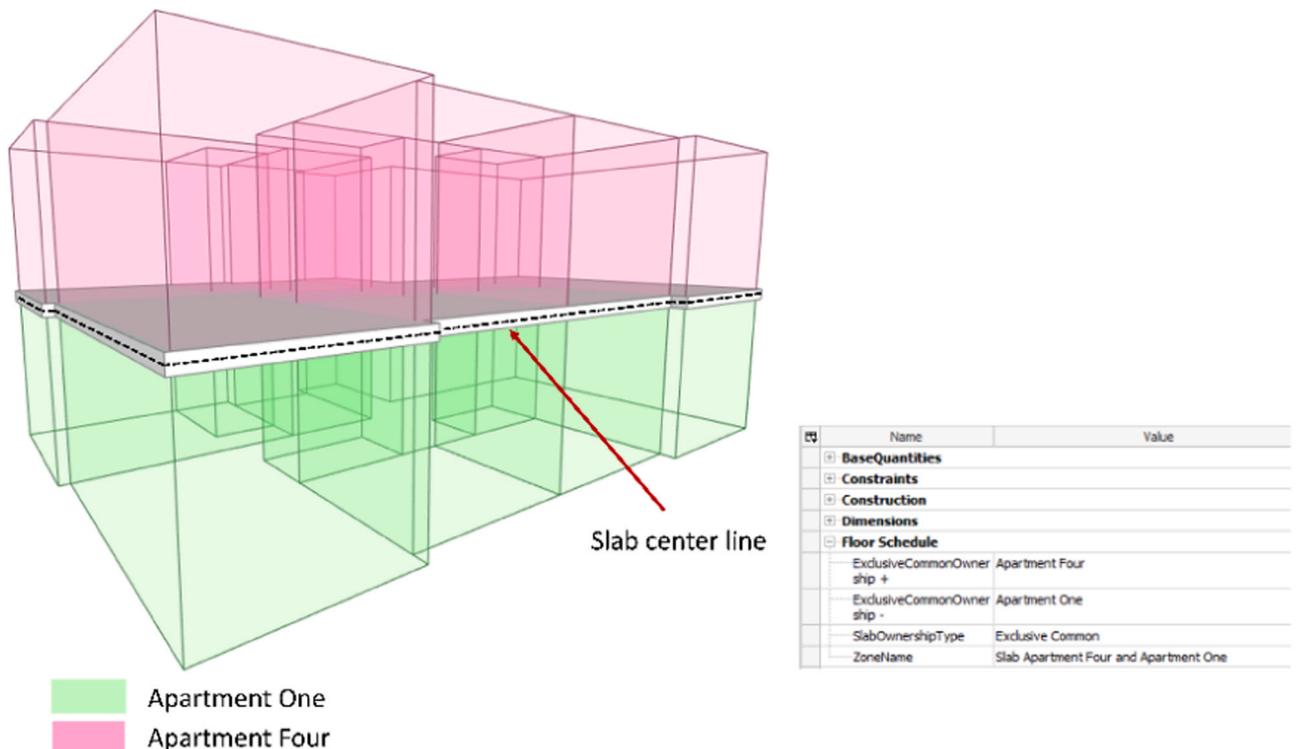


Fig. 18. The ownership type of the slab.

Table 6
The LADM classes that have been used for the development of the 3D country profile.

LADM package	LADM class	Included or not Included
Party Package	VersionedObject	Included
	LA_Source	Included
	LA_Party	Included
	LA_GroupParty	Included
Administrative Package	LA_PartyMember	Included
	LA_RRR	Included
	LA_Right	Included
	LA Restriction	Included
	LA_Responsibility	Included
	LA_BAUnit	Included
	LA_Mortgage	Included
	LA_AdministrativeSource	Included
	LA_RequiredRelationshipBAUnit	Not Included
	LA_SpatialUnit	Included
Spatial unit Package	LA_SpatialUnitGroup	Not Included
	LA_LegalSpaceBuildingUnit	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

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. Fig. 21 presents the code lists of the 3D country profile.

6. Discussion and conclusions

This paper deals with the mapping of 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 4, and

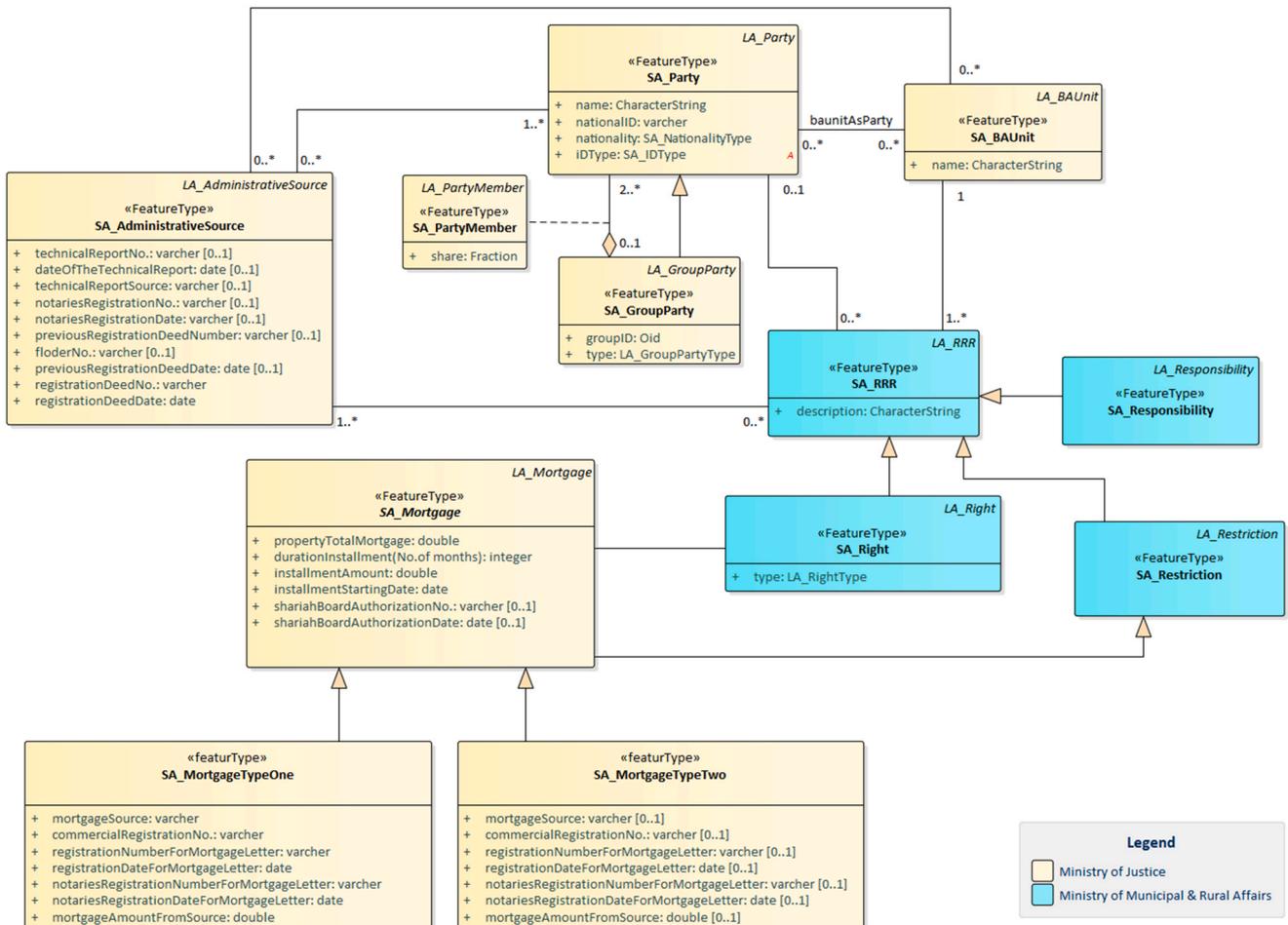


Fig. 19. Party and administrative package of the 3D LADM-based country profile.

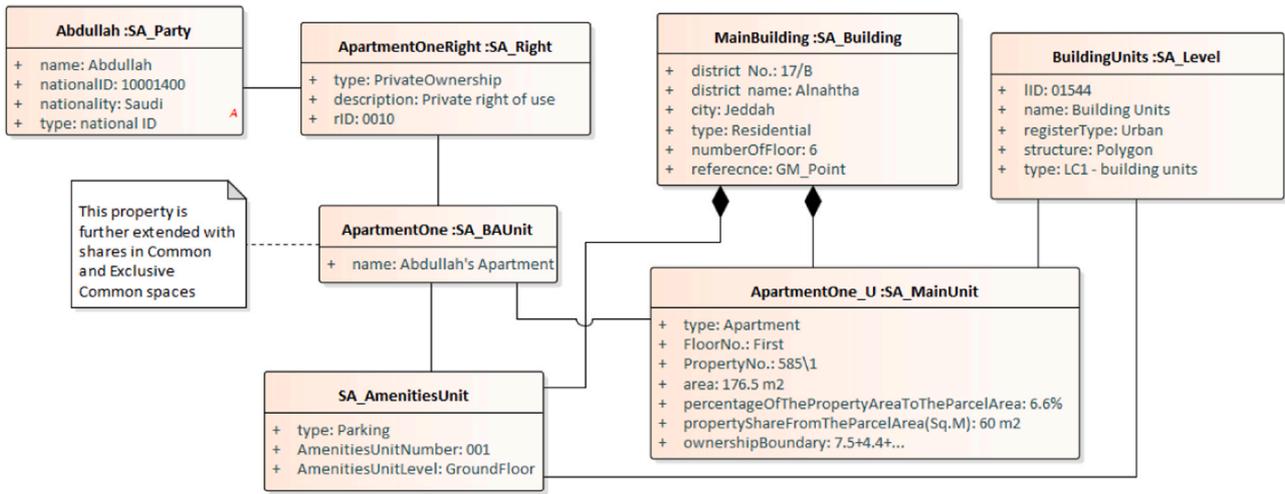


Fig. 22. Instance level diagram for private ownership for apartment one.

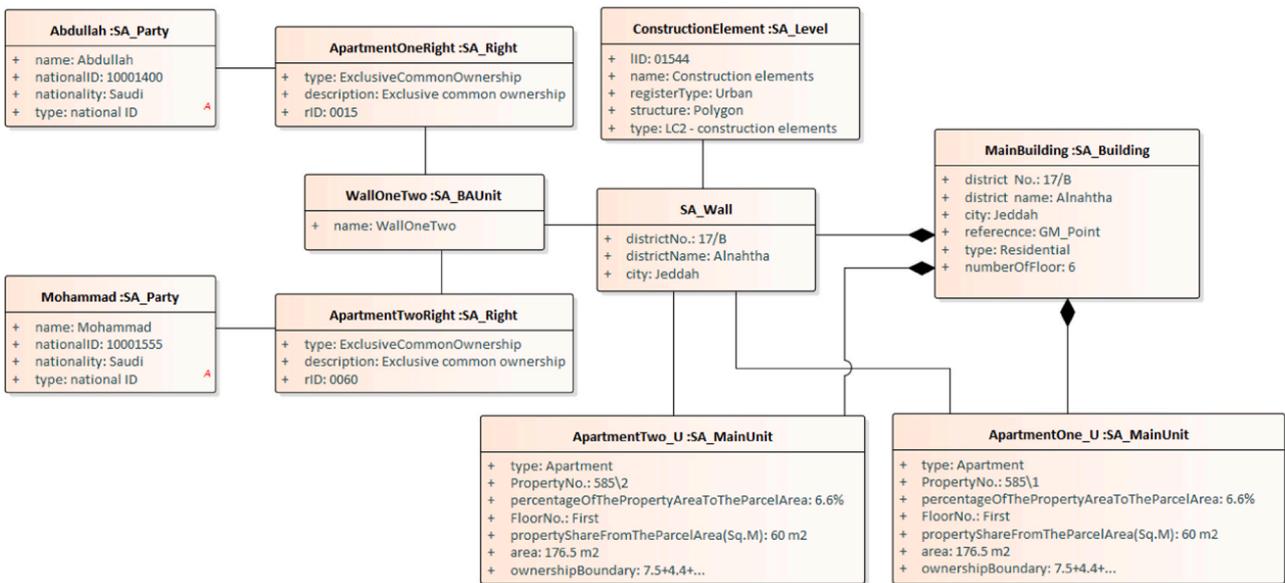


Fig. 23. Instance level diagram for exclusive common ownership for wall.

counterparts. The work presented in this paper is a hybrid approach, in-between the two afore-mentioned 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 work starts by presenting 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).

Specifically, the current regulations do not describe the relationships between the units in detail, affecting the quality of the subdivision procedures. Therefore, in the context of this research, the 3D representation of the building unit's subdivision procedures has been developed and it is proposed 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 analyse a 3D IFC model for a real-world complex building to implement the current subdivision procedures.

The IFC file used corresponds to the 'as-designed' model, however no changes are expected in the procedure if 'as-built' 3D model will be used. Currently, in Saudi Arabia, neither 'as-designed' nor 'as-built' 3D models are requested, as the existing situation covers only 2D representation of legal spaces. What is more, the proposed approach is tested on a residential building, although, in general, the residential buildings have limited types of spaces, and that narrows down the possibility to examine and represent different types of ownership rights concerning the users. Nevertheless, it is noted, that this paper is the first attempt to represent the subdivision procedures of Saudi Arabia in 3D, considering a dedicated 3D country profile.

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 and are briefly presented at the following paragraphs. The first issue was related to the spaces of the building. In the IFC model, only the building's construction elements were modeled, while the spaces of the building were not included and

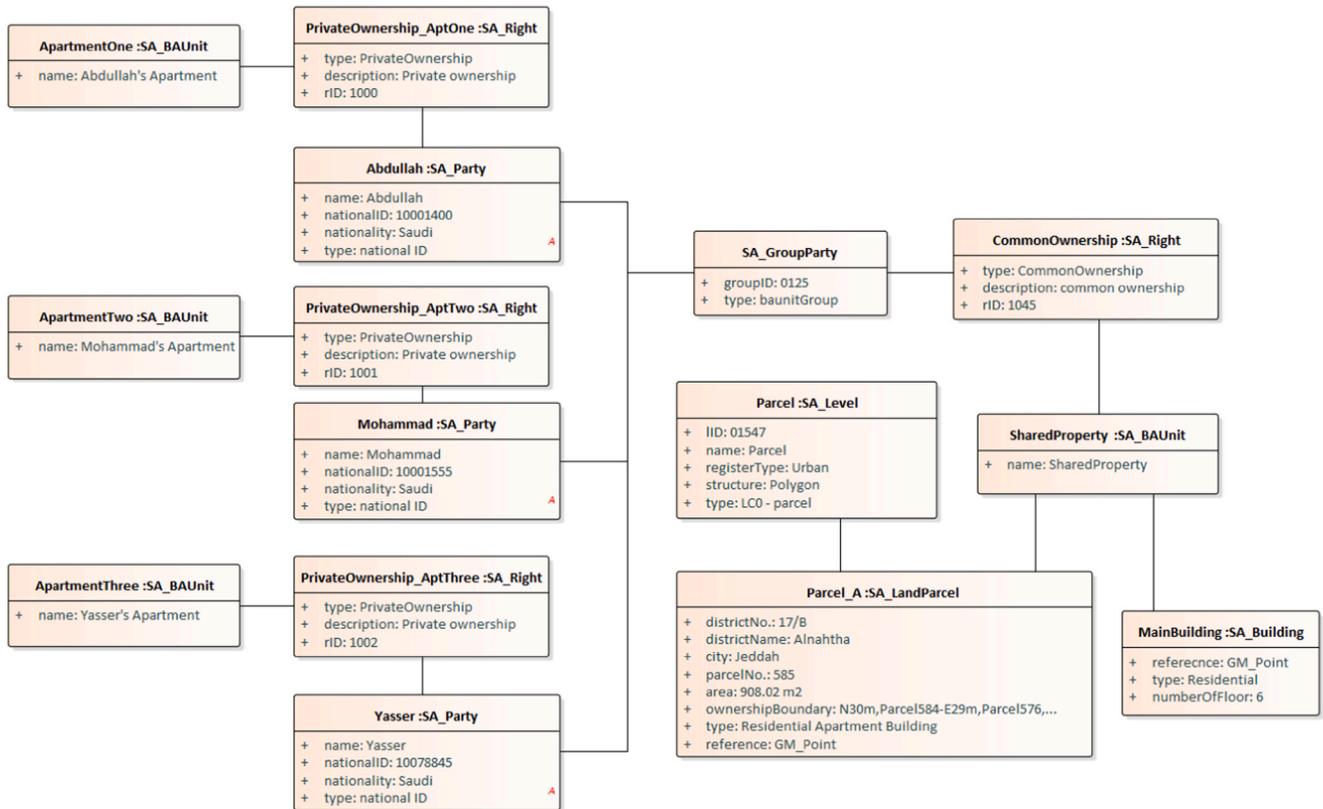


Fig. 24. Instance level diagram for direct common ownership for a shared parcel for multiple parties.

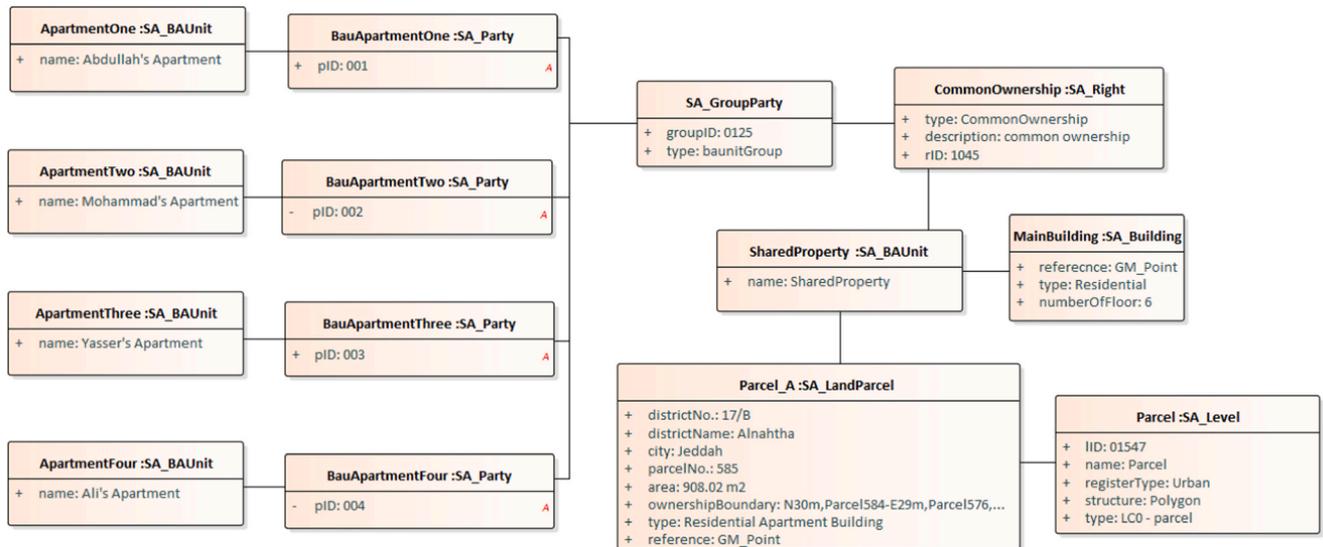


Fig. 25. Instance level diagram for a common ownership for a parcel where the BAUnit is a party.

were added to provide the volume of the spaces. Without the spaces, it is impossible to define the boundary of units and areas, meaning that it is impossible to define each unit's Right and the corresponding area such as private ownership, exclusive common ownership, or common ownership. By adding the spaces to the building, each space's boundary was defined both in the horizontal and vertical direction, and that improved the way of defining the rights based on the relationship between 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 of the

boundary of the private units and the common spaces. It was crucial to split the slab into several parts, so each part's right can be defined based on the unit's type that is located above or below the slab. 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, the building walls had to be modified to follow the units' legal boundaries or shared areas.

Furthermore, additional attributes and associations were introduced to attach the ownership rights to the spaces and the building's construction elements, such as 'property type', 'property No', 'ownership

'type', 'service area type', and the 'ZoneName'. The reason for adding the 'ZoneName' attribute was that the Autodesk Revit software does not create one space for each private unit, but it creates several spaces similar to the number of rooms that belong to the same private unit. Additionally, the spaces of the building had been included associations to define the adjacent units. By using all the new attributes and associations, all the building's spaces types had been defined, and that led to attach the correct type of ownership based on the location of the space. What is more, 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. Additional 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 are now better defined, as they include more information about each space of the building.

The next step was to develop the 3D LADM-based country profile of Saudi Arabia according to the 3D representation of the building unit's subdivision procedures by mapping the subdivision procedures to ISO19152 concepts. Following the development of the profile and the creation of UML diagrams, its efficiency is validated by creating instance-level diagrams for different ownership types.

Based on the main findings of the research, the following recommendations to the building subdivision authorities in Saudi Arabia are proposed, that concern both subdivision procedures and the development of the 3D model:

- Using a 3D 'as-built' model during the subdivision procedures will improve the quality of registration for legal boundaries ownership.
- Providing more clear regulations and examples for the private, common, and exclusive common spaces will bring a better understanding to the users.
- Registering the ownership rights of the construction elements of the building.
- Providing additional regulations about the Rights, Restrictions, and Responsibilities for each type of space (private, common, and exclusive common spaces) will improve spaces' use.
- Defining the type of information (attributes and associations) that has to be added to each space and construction element of the building to represent the rights of ownership.
- Providing a guideline for the creation and preparation of the 3D model based on the regulation will improve the quality of the 3D model, such as:
 - o The 3D volume of the spaces shall be added to the 3D model.
 - o The building's construction elements (walls and slabs) to be modeled with respect to the ownership boundary in the horizontal and vertical directions.
 - o The building's structural elements should be created as separate objects to allow assigning the ownership rights to the corresponding object.

To conclude, from the research carried out, main conclusions are drawn, which can be translated to more generic guidelines for structuring IFC files in such a way that allow extracting 3D properties for registration purposes and hence, moving from country level to an international context. It is highlighted that the research uses two ISO standards, LADM and IFC, facilitating the generalization of its conclusions to a wider context that can be used, after further processing, by different jurisdiction types worldwide. Future research directions shall include the following:

- The 3D country profile to be extended to represent a mix-use building (or other types of buildings) with different sections,

various functions, and ownerships types based on the local subdivision procedures.

- Improving and enriching the 'Administrative Package' of the country profile specifically the elements referring to the Rights, Restriction, and Responsibilities.
- The 'SA_ConstructionElement' class to be developed for better representation of the construction elements for different type of buildings.
- Scaling-up the implementation on the country profile of Saudi Arabia, the hybrid approach proposed in this paper, shall be tested in further country profiles and BIM/ IFC models for several types of buildings. Thus, 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.
- IFC files as actually submitted to municipalities for building request could be used and if needed, to be upgraded to be used for 3D Land Administration purposes.
- Following this approach, as a next step, develop a database based on LADM to store the country profile and a 3D web prototype to visualize and query the models.

Author statement

All authors contributed to the ideas and concepts in this paper. Abdullah Alattas was the main author; the other authors conducted thorough internal reviews.

Annex.

This Annex presents the instance-level diagrams for the 3D country profile of Saudi Arabia. At the four diagrams depicted below, three types of ownership are represented: private, exclusive common and common ownership (two options given).

The first instance level diagram represents private ownership for apartment one and their amenities unit, as shown in Fig. 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.

The second instance level diagram shows exclusive common ownership for the wall located between two private units, as shown in Fig. 23. Each party has individual 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 from 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 Fig. 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 Fig. 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.

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