GEOCARTO INTERNATIONAL
https://doi.org/10.1080/10106049.2022.2142960

How to exploit BIM/IFC for 3D registration of ownership rights in multi-storey buildings: an evidence from Turkey

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ABSTRACT
The condominium rights, which is a special ownership type that can only exist in the buildings that have an occupancy permit, are needed to be examined and depicted as three-dimensional (3D) in order to prevent misinterpretations and disputes regarding Rights, Restrictions, and Responsibilities (RRRs). This paper, therefore, aims to provide the model that extends the Industry Foundation Classes (IFC) schema by referencing Land Administration Domain Model (LADM) in the sense of reusing the Building Information Modeling (BIM)/IFC model of the building for 3D registration of condominium rights in Turkey. The results of the study show that there is a solid potential to benefit from BIM/IFC model in order for both 3D representation of the ownership rights in the multi-storey buildings and obtaining the semantics of the condominiums in terms of wide ranges of attributes such as area, volume, land share, and RRRs.

ARTICLE HISTORY
Received 4 May 2022
Accepted 28 October 2022

KEYWORDS
Condominium rights; 3D land administration; Industry Foundation Classes (IFC); Building Information Modeling (BIM); Land Administration Domain Model (LADM)

1. Introduction

Land management is of pivotal importance for ensuring the sustainability of the urban and rural areas as it has a significant effect on the countries or jurisdictions in terms of societal, economical, and legislative angles (Yomralioglu and McLaughlin 2017). The Land Administration Systems (LASs) that deal with the organizational and technical issues in terms of Rights, Restrictions, and Responsibilities (RRRs) in efficiently maintaining the land management are commonly based on two-dimensional (2D) data and representations (Kalogianni et al. 2020c). However, LASs might be insufficient in governing the ownership rights with their current forms since the complexity of the built environment is increasing due to the inevitable, various reasons such as population growth and urban sprawl (Williamson et al. 2010; van Oosterom 2018). In this connection, the multi-storey buildings require considerable attention in the sense of the ownership rights that can be established within them because the apartment owners are able to have accurate, detailed information on their apartment rights that encompasses a large number of physical objects and their related logical spaces. The 2D data might be unsatisfactory for representing this information owing to the complex situations that require 3rd dimension. Three-

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dimensional (3D) delineation of ownership rights within buildings is therefore a timely topic in the context of 3D cadastre (van Oosterom et al. 2020; Guler and Yomralioglu 2021a). Noteworthy to mention that the 3D cadastre notion is being replaced by the term 3D land administration since this term wholly represents the cover of land registry and cadastre activities (Kalogianni et al. 2020c).

On the other side, the adoption of Building Information Modeling (BIM) that provides a highly detailed digital depiction of physical objects together with their semantics is continuing to grow (McGraw Hill Construction 2014; Teicholz et al. 2018; BIMgenius 2020; NBS 2020). There hence exists an important opportunity to create the 3D representation of condominium rights in the buildings in the sense of benefiting from the interrelation between Architecture, Engineering, and Construction (AEC) industry and land administration sectors (Rajabifard et al. 2019). This paper thus focuses on the model that exploits two International Organization for Standardization (ISO) standards namely Land Administration Domain Model (LADM) ISO 19152:2012 (ISO 2012) and Industry Foundation Classes (IFC) ISO 16739-1:2018 (ISO 2018) for unambiguously depicting the apartment rights as 3D in Turkey context. This is because the realization of 3D cadastral registration within the buildings as a part of 3D land administration can be achieved in this way. Considering the condominium rights can only exist in the lifecycle of the buildings, it can be highlighted the close relationship of land administration with the buildings. It is important to note that this study concentrates on the buildings only even though 3D land administration covers the registration of wide ranges of physical objects within the built environment such as tunnels, mining, and utilities (Saeidian et al. 2021).

The present paper continues with the background section that informs readers on related standards, previous works, the current state in Turkey in terms of the legal documents and developments and strategies, and contributions of the paper. After, Sec. 3 detailedly presents the integrated model for 3D delineation of condominium rights in Turkey. In Sec. 4, the integrated model is demonstrated by using BIM/IFC data of a building. Subsequently, Sec. 5 provides a discussion on the integrated model in terms of various aspects. Lastly, Sec. 6 concludes the paper.

2. Background

2.1. Related standards

2.1.1. Land administration domain model (LADM) ISO 19152:2012

Although land administration practices differ among countries because of the differences in legal systems of the countries, the common basis that LASs are based on is highly similar for implemented regions. LADM is therefore created to provide a common ontology for efficient implementation of LAS through enabling a conceptual model that encompasses a large number of occasions within the land administration practices. The first edition of LADM contains the three main packages as *Party*, *Administrative*, *Spatial Unit*, and one sub package of *Spatial Unit* as *Surveying and Representation*. This edition is approved as an official standard by ISO in 2012.

Party package is suitable to model the various parties involved in the different parts of the land administration practices. The classes of the *Administrative* package enable the detailed representation of specific elements and occasions regarding RRRs. The features that should be depicted spatially are provided through the *Spatial Unit* package with necessary relationships. A wide range of spatial objects and RRRs pertaining to these objects can be modeled within this package, for example, land parcels, buildings, and utilities. It is aimed to provide a basis in terms of spatial modeling concept for features of *Spatial Unit* package by means of the *Surveying and Representation* sub package. Within this sub package, *LA_BoundaryFaceString*, *LA_BoundaryFace*, and *LA_Point* are utilized to depict the instances of *LA_SpatialUnit*. These classes have geometries as *GM_MultiCurve*, *GM_MultiSurface*, and *GM_Point*, respectively. To include the geometry specifications in the conceptual model, these geometry types come from ISO 19107 'Geographic Information—Spatial schema' (ISO 2003) standard that encompasses the spatial schema for the representation of geographic objects.

With the publication of the LADM as a standard, a large number of scholars developed country profiles for various jurisdictions such as Croatia (Vucic et al. 2017), Serbia (Radulović et al. 2019), Morocco (Adad et al. 2020), and China (Zhuo et al. 2015). In this regard, Kalogianni et al. (2021) proposed a strategy consisting of three phases namely scope definition, profile creation, and profile implementation for developing a country profile based on LADM.

Noteworthy to mention that there is an ongoing activity for revision of LADM. The second edition of the LADM will cover the parts with regards to Valuation Information (Part 4) (Kara et al. 2020) and Spatial Plan Information (Part 5) (ISO/TC 211 2021) and hence the standard will be providing a conceptual model for the main counterparts of land administration paradigm. Improving the modeling of 3D spatial units is also considered in the scope of the revision. As it is known, the implementation of the conceptual models is crucial to demonstrate the applicability of the developed conceptual model and improve the current system as well. For this reason, there is a strong ambition for providing fundamental steps for implementations for LADM-based conceptual models in the context of the next edition of the standard, that is Implementation (Part 6) (Kalogianni et al. 2020b).

2.1.2. Industry Foundation Classes (IFC) ISO 16739-1:2018

It is important to note that interoperability is of great significance for data-driven application fields such as the AEC industry. In this sense, there is a vivid need for internationally recognized standards within the BIM domain. IFC is therefore started to develop and approved as an ISO standard in 2013 (ISO 2013) and then revised to its latest version in 2018 (ISO 2018). It is also an open standard that is managed by the buildingSMART (2020). The main aim of developing the IFC is to allow different stakeholders to exchange interoperable data between applications or software in the construction or facility management. IFC schema encompasses 3D digital representations and semantics of the elements, events, and parties regarding the whole lifecycle of the buildings and facilities in utter detail through an object-oriented modeling approach. Figure 1 illustrates the summarized representation of the whole IFC schema such that it covers the entities that can be used to depict the condominium rights as 3D. It can be seen from Figure 1 that *IfcRoot* is the main entity in the schema and other entities are subtypes of it except those are included in the resource schema.

IfcProject as a subtype of *IfcContext* covers all the necessary information besides root instance regarding the product. The default units and geometric representations are examples of this kind of information. *IfcActor* stores the information with regards to the participants and stakeholders involved in a project lifecycle from design to maintenance. It is important to mention that a person or organization can be an actor. *IfcProduct* entity contains a large number of entities, and *IfcSpatialElement* and *IfcElement* entities are two of them. Whereas *IfcElement* is a generalization of entities that provides information for all types of elements that can take a part in a product, *IfcSpatialElement* is a supertype of

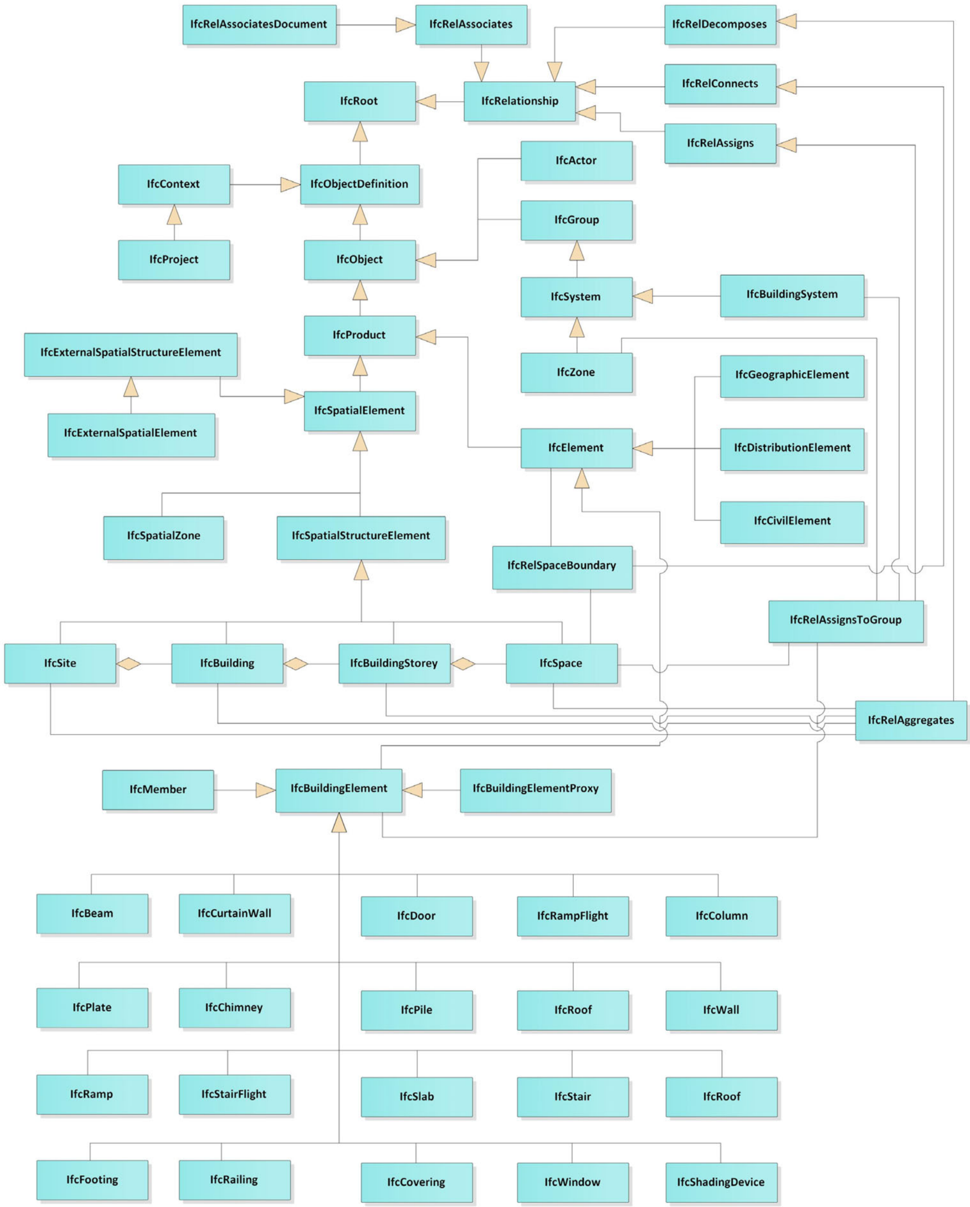

Figure 1. Summarized representation of the IFC schema (the authors' adaptation from (buildingSMART 2020)).

the entities that are used to store the necessary information regarding spatial elements that might be utilized for defining spatial structures or spatial zones. More specifically, *IfcGeographicElement*, *IfcDistributionElement*, *IfcCivilElement*, and *IfcBuildingElement* are examples of subtypes of *IfcElement* and they encompass the modeling specifications for elements from different sub-fields. For example, *IfcGeographicElement* is the suitable entity that can be used to model the features pertaining to landscape in the construction project. *IfcBuildingElement* is the primary entity that enables storing the models regarding multifarious types of elements such as beam, door, wall, railing, column, roof, stair, slab, chimney, and window. *IfcBuildingElementProxy* as a subtype of *IfcBuildingElement* can be used to delineate the elements related to buildings that are not predefined, for example, lifts and water tanks. *IfcExternalSpatialStructureElement*, *IfcSpatialStructureElement*, and *IfcSpatialZone* are the subtypes of *IfcSpatialElement* entity. *IfcExternalSpatialElement* as a subtype of *IfcExternalSpatialStructureElement* can be utilized for logical or physical modeling of the external regions of the building site. To depict the different detail or structure levels of the building, *IfcSpatialStructureElement* has four subtype entities as *IfcSite*, *IfcBuilding*, *IfcBuildingStorey*, and *IfcSpace*.

As illustrated in Figure 1, the aggregation relationship between these entities is enabled through *IfcRelAggregates*, which is a subtype of *the IfcRelDecomposes* entity. Noteworthy to mention that *IfcSpace* can be associated with a building storey if it is specified, and the exterior of the building as well. Furthermore, it is possible to define the relationships between spaces and other elements by using *IfcRelSpaceBoundary*. It is also significant to note that multiple *IfcSpace* instances can be collected in an *IfcZone* instance, and multiple *IfcBuildingElement* instances can be grouped to an *IfcBuildingSystem* instance by means of *IfcRelAssignsToGroup*, which is a subtype of *IfcRelAssigns* entity.

Property sets that are composed of properties are utilized to preserve detailed semantic information regarding entity instances. The properties are defined by different entities such as *IfcPropertyTableValue* and *IfcPropertyListValue* based on the values that they contain. IFC schema also provides numerous defined types so as to efficiently store the data in the properties. For example, whereas *IfcIdentifier* is suitable for storing data that does not need to be understood by humans, *IfcInteger* can be used to store integer data. The current version of IFC is IFC4 ADD2 TC1; however, the development of the next version (IFC 4.3) is still ongoing.

2.2. Literature review

3D cadastre notion was started to study and investigate twenty years ago approximately since it was aware that the 2D representations cannot realistically show the ownership rights regarding buildings for different cases. For instance, it is hard to depict the right to use through only 2D delineations if one part of a building is located below of one part of another building. It is also important to represent the rights in the 3rd dimension because legal documents of the countries or jurisdictions commonly define the ownership rights below and above of the land or water. Creating a conceptual model that covers all components of land administration activities is necessary and advantageous for implementing any 3D cadastral registration since the requirements are able to be determined in this way. In this connection, LADM has gained considerable attention internationally as it provides a common basis that covers the representation of 3D spatial units as well.

On the other side, the development of the standards that focus on the 3D representation and modeling of physical objects in the built environment accelerates because of the need for more detailed digital models in order to conduct better analysis and make holistic decisions pertaining to the built environment. Publication of the CityGML (2.0) contributes to the creation of 3D city models worldwide. At this point, the idea with regards to 3D representation of ownership rights is to integrate the LADM and CityGML so as to benefit from both detailed conceptualization of LADM and rich physical depiction capabilities of CityGML (Góźdź et al. 2014; Rönsdorff et al. 2014; Li et al. 2016). It is however that the representation of logical spaces that do not need to be certainly depicted through physical object type is not at a sufficient level. This is improved by the publication of the new version of the CityGML (3.0) (OGC 2021) that exploits *spaces* in modeling approach because, for example, logical spaces such as apartments within buildings are able to be represented by using the *AbstractBuildingSubdivision* feature that has two subclasses namely *BuildingUnit* and *Storey*. On the other hand, even though the idea that concentrates on the usability of IFC data for 3D cadastre goes back to 2006 (Clemen and Gründig 2006), utilizing the Building Information Models (BIMs) and their IFC data in the 3D depiction of apartment rights has gained significant attention globally at the last years (e.g. El-Mekawy et al. 2014; Olfat et al. 2019; Kalogianni et al. 2020a; Shin et al. 2020; Ramlakhan et al. 2021). This is because not only BIM provides highly detailed semantic and physical information belonging to buildings and facilities but also there is a growing global adoption for BIM. For example, Atazadeh et al. (2017a) produce a BIM model from CAD drawings of an example building and show the legal rights within this building. Atazadeh et al. (2017c) present adding the possible properties to IFC data for representation of ownership rights in Australia. Atazadeh et al. (2017b) propose to extend the IFC schema by adding new entities such as *IfcRelReferencedInPrivateProperty* and *IfcRelReferencedInCommonProperty* to better delineation of legal rights as 3D using BIMs. Afterward, integrating the LADM and IFC is widely researched by a large number of scholars from different countries. For instance, Oldfield et al. (2016, 2017) match the features of LADM and entities of IFC with the aim of 3D cadastral registration. Meulmeester (2019) zooms in on the case of the Netherlands for 3D representation of apartment rights using BIM and LADM. Cemellini et al. (2020) develop a web-based prototype that enables to the representation of legal spaces as 3D using BIM and investigate user requirements for such prototypes. Ying et al. (2021) present how easement rights in the buildings can be represented by using LADM and BIM. Atazadeh et al. (2021) map the features of LADM with entities in the IFC schema for 3D land administration purposes. Petronijević et al. (2021) extend the IFC schema by adding a new entity namely *IfcBuildingPropertyUnit* as a subtype of *IfcSpatialStructureElement* for representing the legal spaces in the complex buildings. Alattas et al. (2021) enhance the IFC data of a building by adding new property sets that cover ownership rights with respect to apartments and several building elements such as the wall, column, and slab in the Saudi Arabia context. Barzegar et al. (2021a) develop an IFC-based database that provides 3D querying for 3D land administration purposes using PostGIS[1] and SFCGAL[2] extensions within PostgreSQL.[3] Gkeli et al. (2021) propose a BIM-based solution that benefits from crowdsources data and visualizes BIMs that show legal spaces in the web platform. Barzegar et al. (2021b) propose an approach on how the boundaries of legal spaces can be identified to store in a spatial database. Hajji et al. (2021) propose converting BIMs to CityGML data that is enriched with cadastral semantic information in order to provide 3D database that enables querying as the case of Morocco. Sun et al. (2019) exemplify how LADM and CityGML 3.0 can be integrated for depicting the cadastral rights in buildings by using a IFC model.

Recently, Broekhuizen et al. (2021) compare the IFC data of different buildings to express how much the as-built BIMs are suitable for representing legal spaces, and then develop a web prototype for a conceptual model that integrates IFC and LADM. Einali et al. (2022) developed BIM-based approach for 3D land administration purposes in Tehran, Iran. Moreover, Alattas et al. (2017) propose an approach that benefits from IndoorGML (OGC 2020) and LADM for representing the ownership rights in terms of indoor positioning and navigation. Tekavec et al. (2021) propose an conceptual schema that connects IndoorGML, IFC, and CityGML standards based on the LADM in representing the legal spaces within buildings. The approach that provides a complete lifecycle of spatial data in a way that contains building permit issuing and cadastral database updating is also proposed (Oldfield et al. 2018).

Regarding Turkey, research with regards to 3D cadastre started approximately ten years ago. For example, Döner (2010) examines the possibility of 3D representation of cadastral rights and develops a spatial database that allows visualizing various ownership rights in 3D. Ayazli et al. (2011) propose a Unified Modeling Language (UML)-based conceptual schema for storing the cadastral rights as 3D in the Turkey context. Cagdas (2013) develops a CityGML ADE that encompasses the features and relationships regarding condominium rights for taxation purposes in Turkey. The approach in this ADE is further used in LandInfra/InfraGML (OGC 2016) standard. Döner and Şirin (2020) examined the current developments with respect to the 3D registration of apartment rights in Turkey. Alkan et al. (2021) develop a conceptual country profile based on LADM that covers 3D RRRs for Turkey. Kara et al. (2021) demonstrate the implementation of LADM VIM that contains the features and attributes regarding condominium rights for Turkey context. Gürsoy Sürmeneli et al. (2022b) proposed a CityGML ADE to be able to represent cadastral rights in Turkey in the 3rd and 4th dimensions. Gürsoy Sürmeneli et al. (2022a) created a Turkish country profile based on the LADM standard for 4D cadastral purposes. Recently, Celik Simsek and Uzun (2022) suggest using of BIMs in representing the condominium rights and calculating the land shares of condominium units. It is also proposed a framework that includes digital building permitting, 3D city model updating, and 3D registration of ownership rights for Turkey by means of the reuse of BIMs (Guler and Yomralioglu 2021a, 2022). Guler and Yomralioglu (2021b) demonstrate how condominium rights in the buildings in Turkey can be represented using the initial conceptual model containing IFC and LADM. The model in this study only contains a part of LADM classes without considering the building elements and linking these classes to suitable IFC entities.

2.3. Current state in Turkey

2.3.1. Legislative basis

Practicing cadastral registration and land administration activities is based on several laws and legislative documents in Turkey. Regarding this, real estate ownership is described in the Turkish Civil Code No.4721 (Official Gazette 2001). Article 704 of this law states that the subjects of real estate ownership are land, independent and permanent rights that are recorded on the land register, and condominiums that are recorded to the condominium register. The condominium rights are thus embodied officially with this law. Moreover, there exists a number of articles in the Civil Code that describe wide ranges of rights such as the right of way, timeshare, and preemption. Cadastre Law No.3402, Land Registry Law No.2644, and Zoning Law No.3194 are additional important legislative documents with respect to cadastral registration in Turkey.

The main legal reference that defines the RRRs pertaining to condominiums is Condominium Law No.634 (Official Gazette 1965). It is stated in Article 1 of this law that owner or joint owners can have the ownership rights on the different units of a constructed building that are eligible to be used independently and separately such as storey, apartment, office, store, cellar, and storage. The definitions of the main real estate, main building, condominium unit, annex, condominium right, and condominium owner are provided in Clause 1 of Article 2 of the Condominium Law as follows:

- **Main real estate**: The whole of the real estate that subjects to condominium rights,
- **Main building**: The main structural part of the real estate only,

- **Condominium unit**: The parts of the main real estate that are suitable for using separately and independently and as well as subject to ownership rights based on the provisions of the Condominium Law,
- **Annex**: The places that are outside of a condominium unit and as well as assigned to that condominium directly,
- **Condominium right**: The right that is established on the condominium units,
- **Condominium owner**: The person that has the condominium right.

As described in the Condominium Law, a condominium owner can have the right to use on condominium unit itself and as well as spaces that are located in the outside of the condominium unit. The cellar, water tank, garage, natural gas meter box, or toilet are examples of an annex. This law also implies that the shared facilities and spaces that are located in outside of the condominium units in real estate and as well as serve for protection and exploitation can be jointly used by condominium owners. In other words, these places and spaces have common ownership. The shared facilities and spaces can be main walls, beams, shafts, columns, entrance, boiler room, floors, ceilings, patios, stairs, and corridors. The Condominium Law also indicates that the land share of the condominium units is proportionally calculated based on their values that are estimated based on the location and size features.

Planned Areas Zoning Regulation (PAZR) (Official Gazette 2017) is another significant legal document regarding condominium rights as it defines how the areas of condominium units should be calculated. According to this document, there are four different area types with respect to the condominiums as follows:

- **Condominium gross area**: The area that the exterior contours of the condominium unit surround except shafts, skylights, air ducts, and gallery spaces,
- **Condominium total general gross area**: The area that contains the condominium gross area and as well as the areas that come from shared facilities and spaces assigned to the condominium,
- **Condominium net area**: The clean area that is inside of the walls except for the spaces that are located inside of the condominium with their internally connected parts,
- **Condominium total gross area**: The area that covers the condominium gross area and as well as the areas of the annex or annexes that are attached to the condominium unit.

It is also beneficial to mention the relationship between building permit issuing and registration of condominium rights. This is because Condominium Law states that registration of these rights should be realized by using condominium plans that are approved in the occupancy permit procedure. It is announced by the GDLRC in 2017 that the architectural projects that are needed for establishing the condominium rights are electronically sent to land registry directorates after scanning (GDLRC 2017). In 2021, a circular letter by the GDLRC informs that 3D digital building models should also be submitted to the land registry directorate (GDLRC 2021). This circular letter also contains that a condominium unit in the building can be registered as a shared/common facility by indicating the unit number of the condominiums that are assigned to exploit that condominium unit in the management plan. It is, in addition, stated in the same circular letter that social and infrastructure facilities in the building complexes can be registered as shared/common spaces such that they are assigned to all or a part of the condominium owners.

2.3.2. Developments and strategies

The current development plan in Turkey highlights completing the multidimensional cadastre. The plan also underlines that the digital, up-to-date, and trustworthy cadastral data will be published to form a basis for public and private sector organizations in their investments. In addition, transferring the ownership data into an electronic environment is included in the 11th Development. Publication of the '2020–2023 National Smart Cities Strategy and Action Plan' is one of the recent important developments since it is highlighted in this plan that BIMs will be utilized in the building permit issuing with the aim of digitalizing and automating the building permit processes (MoEUCC 2019). This creates a significant opportunity for benefiting the BIMs in the registration of condominium rights as 3D.

Before the 3D representation of cadastral rights, the earlier aim is to complete the national Spatial Data Infrastructure (SDI) for Turkey. This is because the spatial data exchange between a wide range of public or private organizations in an interoperable way is of utter importance. It is essential to note in this connection that establishing and maintaining the SDI are considerably benefitted from interoperable spatial data that is produced by different stakeholders. The Turkey National Geographic Information System (TNGIS) project is therefore conducted by the General Directorate of Geographic Information Systems (GDoGIS) (2020). The conceptual models and as well as their application schemas for data exchange are developed and shared for a large number of themes such as building, cadastre, and land use. These models and schemas are formed based on the Infrastructure for Spatial Information in the European Community (INSPIRE) data specifications. Since the TNGIS project is an ongoing activity, published conceptual models and application schemas are updated in specific periods. The previous version of the *Building* theme focused on only 2D representations. Considering the publishing of the new version of the CityGML (3.0) standard recently, the next version of this theme will encompass the 3D building models that are produced based on the provided CityGML Application Domain Extension (ADE) in the theme document (MoEUCC 2021). Furthermore, the '3D Urban Models and Cadastre' project is started to carry out by the General Directorate of Land Registry and Cadastre (GDoLRC) because of the increased interest in 3D cadastre globally. This project aims to create 3D models of cities as well as building models that contain the representation of apartment rights as 3D. First, 2D floor plans are digitized and then labeled in Computer-Aided Design (CAD) software based on the attributes with respect to the condominium rights, for example, apartment one or shared space. The CityGML 2.0 files are created afterward by using the produced CAD files.

2.4. Contributions of the present paper

The literature shares a common idea that there is a strong need for a better and more detailed representation of condominium rights in the buildings. The previous works, therefore, focused on the reuse of BIMs for the 3D depiction of legal rights because of the increasing adoption and support for both BIM and its open standard IFC. The review of the previous studies however reveals that the applicability of BIM and specifically IFC in representing the condominium rights in the buildings realistically and unambiguously by considering the current legal basis in Turkey was not investigated in depth even though there exist noteworthy investigations with regards to 3D cadastral registration. Further, the need for a complete model with respect to the integration of LADM and IFC standards can be fulfilled by improving the developed models in the earlier studies. It is also needed to examine the possibility of reusing the BIMs in 3D condominium registration in Turkey for keeping the newly created 3D database up-to-date. In addition, it is important to enrich the current spatial data schemas in TNGIS such that they enable to store and represent semantic and physical information as digital and 3D regarding condominium rights in the buildings. This study thus aims to contribute to the existing body of knowledge by:

- Proposing the thorough model integrating LADM and IFC for the 3D depiction of condominium rights in Turkey,
- Enabling the representation of ownership rights with their semantics regarding apartments and as well as building elements in a sufficient manner by means of the IFC model,
- Demonstrating the developed model using the BIM/IFC model of a building,
- Showing how the detailed building elements such as elevator and stair can be represented by which suitable IFC entities in the sense of complete delineation of condominiums rights,
- Providing examinations in terms of the different perspectives on advantages and disadvantages of the practicability of BIM/IFC-based approach for Turkey context.

The proposed model can be used by not only architects/designers to create the building models covering information that is requested by cadastre and land registry agencies in the sense of digitalization of construction and public services but also by these agencies to control modeling of condominium rights and also to register and disseminate these rights in 3D.

3. A conceptual model linking IFC and LADM for Turkish condominium

In this study, the model that links the features of LADM and entities of the IFC schema is developed for the complete delineation of condominium rights in the buildings. Figure 2 illustrates the conceptual model that consists of *Party* and *Administrative* packages of LADM. *TR_Party* is the feature that is used to model involved parties and stakeholders in the land administration activities. It has several attributes to store the semantics regarding condominium owners. *TRpID*, *nationality*, and *placeofBirth* are examples of these attributes. The model contains the *TR_GroupParty* feature for representing party groups. It has *groupID* attribute for identification. *TR_PartyMember* has a relationship between *TR_Party* and *TR_GroupParty* features and the *share* attribute for storing the share ratio. *TR_AdministrativeSource* feature is suitable for storing identifier information with respect to legal documents. This feature has therefore a number of attributes such as *journalNumber* and *pageNumber*. *TR_BAUnit* expresses the registration object and can have different types through *type* attribute. *TR_RRR* is suitable for storing RRRs regarding a registered *TR_BAUnit* instance. It has three subclasses namely *TR_Responsibility*, *TR_Restriction*, and *TR_Right*.

TR_Resctriction has also *TR_Mortgage* as a subclass that is used to depict the restrictions pertaining to the mortgage. *TR_Mortgage* has several attributes such as *amount* and *startingDate* to give information on a mortgage. The type of the right is indicated by *type* attribute in the *TR_Right* feature. Figure 3 shows the code lists that contain the selections for features within *Party* and *Administrative* packages.

For example, *TR_NationalityType* can be used to indicate if an involved party has Turkish citizenship, *TR_PartyType* states whether a party is a natural or legal person.

Figure 2. *Party* and *Administrative* packages of the integrated model.

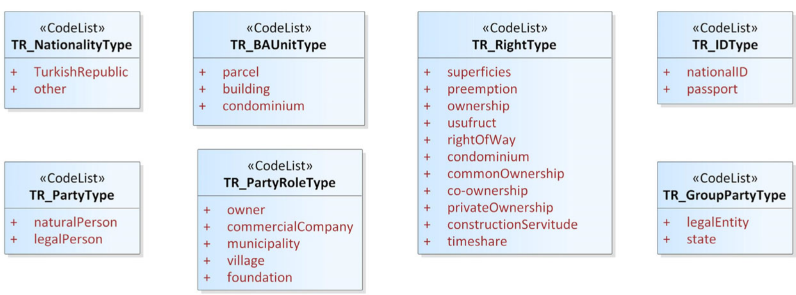

Figure 3. Code lists for *Party* and *Administrative* packages of the integrated model.

Furthermore, *TR_BAUnitType* has three options as a parcel, building, and condominium to express the type of registration object based on the legal basis. *TR_RightType* has a wide range of selections to state the various types of rights such as superficies, preemption, right of way, and timeshare. *TR_IDType* expresses if the national ID or passport is used by a party. Table A.1 lists the properties by providing the property set names, property names, property types, and data types that are suitable to store the attributes of the classes in the *Party* and *Administrative* packages of the integrated model. It can be noted that the IFC file would not be complete without these properties.

As can be seen from Figure 2, different entities in the IFC schema are associated with the features of the conceptual model in order for obtaining the physical representations of logical spaces and physical parts of the building with regards to condominium rights. For instance, whereas *IfcActor* can be used to depict the *TR_Party* feature, *TR_GroupParty* can be delineated with *IfcGroup* entity that can have multiple *IfcActor* instances thanks to *IfcRelAssignsToGroup* entity. *TR_AdministrativeSource* feature can be represented by using *IfcDocumentInformation* that is suitable to store external information within an IFC model. *IfcZone* entity that can have numerous *IfcSpace* instances can be utilized to store the *TR_BAUnit* feature in an IFC data. To provide a relationship between *TR_BAUnit* and *TR_AdministrativeSource* features within an IFC-based delineation, *IfcRealAssociatesDocument* that connects *IfcDocumentInformation* and *IfcZone* entities can be useful. In addition, *IfcBuildingSystem* that allows for grouping *IfcBuildingElement* instances is suitable for storing information of the building elements with respect to *TR_BAUnit* instance. Also, *IfcBuildingSystem* can be linked with *IfcDocumentInformation* by means of *IfcRealAssociatesDocument* to obtain information in *TR_AdministrativeSource* that is associated with *TR_BAUnit* instance.

Figure 4 represents the *Spatial* package and *Surveying and Representation* sub package of the integrated model. As can be seen from Figure 4 that *TR_SpatialUnit* as a subclass of *TR_BAUnit* enables the connection with *Party* and *Administrative* packages that are shown in Figure 2. *TR_SpatialUnit* has several attributes to represent the locational details of the feature, for example, *city*, *district*, and *neighborhood*. *TR_Parcel* as a subclass of the *TR_SpatialUnit* feature is used to express the land parcels in the conceptual model. It has several attributes such as *propertyID*, *area*, and *blockNumber*. *TR_Parcel* also includes two code lists namely *parcelType* and *landUseType*. The geometry of the *TR_Parcel* instance is provided by using *TR_BoundaryFaceString* within LADM. As illustrated in Figure 4, *TR_BoundaryFaceString* is realized by means of at least two *TR_Point* instances. Figure 4 also indicates that there is a relationship between *TR_Parcel* and *TR_Building* features. *TR_Building* has numerous attributes to detailedly represent the buildings. *numberOfFloor*, *totalFootprint*, *dateOfBuildingPermit*, and *zoningHeight* are examples of these attributes.

They can be beneficial for different domains such as spatial planning and urban redevelopment. *TR_Building* includes the *TR_BuildingStatusType* as a code list as well. Noteworthy to mention that there exists an inheritance relationship between *TR_SpatialUnit* and *TR_Building* classes since the condominium rights can be established on the whole building for specific use types of the buildings such as hotels, based on the Condominium Law. *TR_CondominiumUnit* is utilized to delineate spaces in the buildings regarding condominiums. It has numerous attributes to store semantics in detail. *marketValue*, *dateOfSale*, and *netVolume* are examples of these attributes. For example, whereas *totalGrossArea* is used to express the total gross area of registered condominium based on the definition in PAZR, *landShare* attribute stores the share on the land of a specific condominium. As can be seen from Figure 4, there is a composition relationship

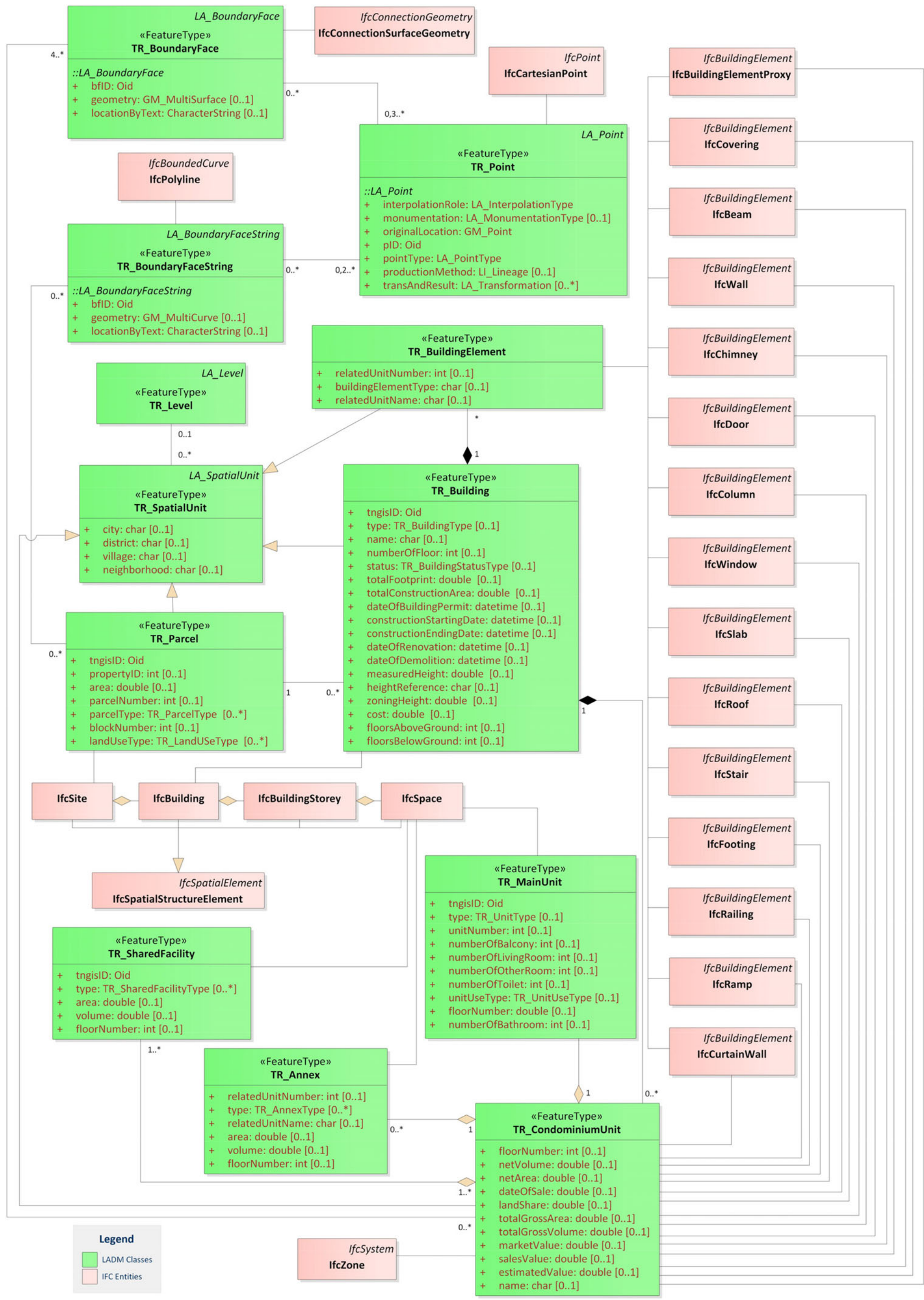

Figure 4. *Spatial* package and *Surveying and Representation* sub package of the integrated model.

between *TR_Building* and *TR_CondominiumUnit* features because it is not possible to establish the condominium rights if the building does not exist. It is also important to mention that *TR_BoundaryFace* is used to represent the faces of the *TR_CondominiumUnit* instances. There are aggregation relationships between the

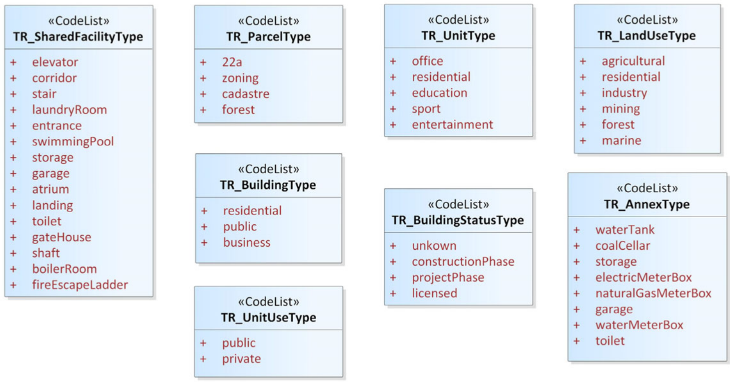

Figure 5. Code lists for *Spatial* package and *Surveying and Representation* sub package of the integrated model.

TR_CondominiumUnit and *TR_MainUnit*, *TR_Annex*, and *TR_SharedFacility* classes. These classes are used to model spaces that are defined in the Condominium Law. *TR_MainUnit* feature is suitable to depict the main parts of the apartments that can have various types of rooms such as living room, kitchen, and bedroom. This feature has a vast number of attributes such as *unitNumber*, *numberOfBalcony*, and *numberOfBathroom* and as well as two code lists namely *type* and *unitUseType*. These attributes and code lists allow for storing detailed semantics regarding the features of an apartment.

As reported in Sec. 2.2.1., the condominium owner has the right to use on the main unit and also different annexes that are attached to a specific condominium. *TR_Annex* is therefore used to delineate the ownership rights pertaining to annexes. It has two attributes as *relatedNumber* and *relatedUnitNumber*. These attributes are exploited to attach the annex instances to a specific condominium. *TR_Annex* has also a code list to store the information on different types of annexes. According to Condominium Law, the condominium owners have ownership rights on the shared/common spaces in the buildings. *TR_SharedFacility* feature is thus benefited to model these spaces. This feature has an attribute as *tngisID* and a code list namely *type* that stores the information of a shared/common space in terms of type. As also outlined in Sec. 2.2.1., a wide range of building elements can be subjected to the condominium right, for example, wall, column, beam, and stair. To be able to represent the ownership rights on the building elements, the conceptual model contains the *TR_BuildingElement* feature that has two attributes as *relatedUnitNumber* and *relatedUnitName*. These attributes are used to link the building elements to a specific condominium. It has also *buildingElementType* as a code list for storing the type information of the building element. Figure 5 shows the code lists that encompass the values for features in the *Spatial* package and *Surveying and Representation* sub package of the integrated model.

TR_ParcelType is used to express the type of the land parcels with different selections such as zoning and cadastre. *TR_LandUseType* is provided to store the use type of the land parcel. Whereas *TR_BuildingType* allows for selecting the type of the building, *TR_BuildingStatusType* is used to represent in which status the building is currently. *TR_UnitType* enables different values for the unit types of the *TR_MainUnit*, for example, office, residential, and education. It can be defined by *TR_UnitUseType* whether the use type of the *TR_MainUnit* is public or private. *TR_SharedFacilityType* provides a large number of values including *laundryRoom* and *gateHouse* for selecting the type of the shared/common spaces in the buildings. The different selections for annexes are also enabled by *TR_AnnexType* based on the annex examples in the Condominium Law.

Table A.2 details the property set names, property names, property types, and data types that are suitable to store the attributes of the classes in the *Spatial* package and *Surveying and Representation* sub package of the integrated model.

It can be seen from Figure 4, the integrated model contains various IFC entities to link the classes in the LADM. Whereas *IfcCartesianPoint* as a subtype of *IfcPoint* is suitable for depicting the *TR_Point* feature, *IfcPolyline* can be used to represent *TR_BoundaryFaceString*. Moreover, *IfcConnectionSurfaceGeometry* can be exploited to link the *TR_BoundaryFace* feature within the model. *IfcSite* is suitable to depict the *TR_Parcel* feature. *IfcBuilding*, which is a subclass of *IfcSpatialStructureElement* and is spatially contained in *IfcSite*, can be linked to *TR_Building*. *TR_MainUnit*, *TR_Annex*, and *TR_SharedFacility* features can be modeled *via IfcSpace* entity that enables to store logical spaces with their boundary specifications. The boundary information between the different *IfcSpace* instances that are mainly bounded and defined by different building elements such as doors, windows, walls, roofs, and slabs can be obtained through *IfcRelSpaceBoundary* which stores the geometric information by means of *IfcConnectionSurfaceGeometry* (Zhu et al. 2021). It can hence be brought ownership information into the walls that bound the spaces of a condominium. *IfcZone* entity is suitable to completely delineate the condominium rights of a condominium since it can have multiple *IfcSpace* instances. In this way, a condominium that has a *TR_MainUnit* instance and two different *TR_Annex* instances can be modeled for example. Figure 4 also indicates that ownership rights pertaining to wide ranges of building elements can be depicted by linking the various subtypes of *IfcBuildingElement* entity such as *IfcCovering*, *IfcDoor*, *IfcRoof*, and *IfcColumn*. These subtypes can be enriched with the property set of *TR_BuildingElement*. It is noteworthy to note that the conceptual model includes associations that come from the core model of LADM but the main purpose of this model is to provide an unambiguous representation of property rights in the apartments through entities of IFC.

4. Demonstration

This section presents the demonstration of the integrated model through a BIM/IFC model of a building. First, the CAD files of an apartment are obtained. After, all building elements are modeled in Autodesk Revit. Figures 6 and 7 show the front and rear views of the building, respectively. The entrance of the building can be seen in Figure 6. As can be seen from these figures, there is an elevation difference between the front and rear sides of the building. Figure 7 also illustrates the car parks and bicycle racks belonging to the building. After obtaining the BIM model of the building, a large number of parameters are used to store attributes of the classes in the integrated model that is presented in Sec. 3.

At this stage, the spaces in the building are created. As detailed in Sec. 3, a condominium unit can have ownership rights on the main unit, the annex, the shared/common building elements or spaces. Spaces are therefore populated to represent the legal rights that are subject to condominium rights according to the information in CAD drawings. In addition to the spaces, the building elements that are subject to condominium rights are also populated with the required information. Further, zones that contain the different spaces belonging to a specific condominium are formed.

When populating the instances is completed, the BIM model is exported as IFC in a way that it is enhanced with the property sets and properties that can be seen in Tables A.1 and A.2. BIMcollab[4] software, which has a free version, is used to visualize the

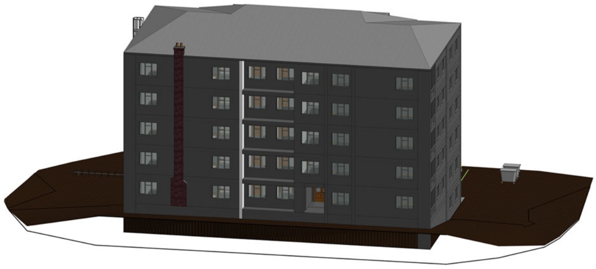

Figure 6. Front view of the building.

Figure 7. Rear view of the building.

exported IFC model with its properties. This software allows users to create visualizations based on the defined criteria on IFC entity instances. For example, Figure 8 illustrates all legal spaces that the condominium owners have the right to use commonly. The building has wide ranges of shared spaces such as shaft, elevator, boiler room, shelter, and corridor. *IfcSpace* instances that are defined as shared spaces have properties corresponding to the attributes of *TR_SharedFacility* class in Figure 4. The attributes are *area*, *floorNumber*, *tngisID*, *type*, and *volume*. The shelter that has these attributes is shown as an example in Figure 8. As mentioned in Sec. 2.2.1., the building elements can also be subjected to the condominium rights. Figure 9, therefore, presents the visualization of various building elements that the common ownership is established on. These elements for example are column, roof, ceiling, and chimney. Figure 9 also shows the properties of a column as an example.

As mentioned before, a condominium has a main unit that can be composed of a wide range of rooms that are assigned to a specific use such as kitchen and bathroom. Figure 10 is exemplified the legal spaces of four main units located at level zero of the building. As can be seen from Figure 10, it is shown the legal spaces without annexes.

Figure 11 illustrates the legal spaces belonging to *Condominium 4* and *Condominium 5* with their properties. It can be seen from Figure 11 that both condominiums have an annex that is assigned for car parking. Whereas *Condominium 4* has an annex as storage, an annex as coal cellar is attached to *Condominium 5*. Figure 11 also details the properties of the annexes. In addition, *TR_MainUnit* class that has various attributes is shown for both condominiums. As specified in Figure 4, the condominiums that have *TR_CondominiumUnit* class can be modeled by using the *IfcZone* entity. Figure 11 presents the attributes of this class for both condominiums. The values of attributes in Figure 11 are real except for *estimatedValue*, *landShare*, and *salesValue*.

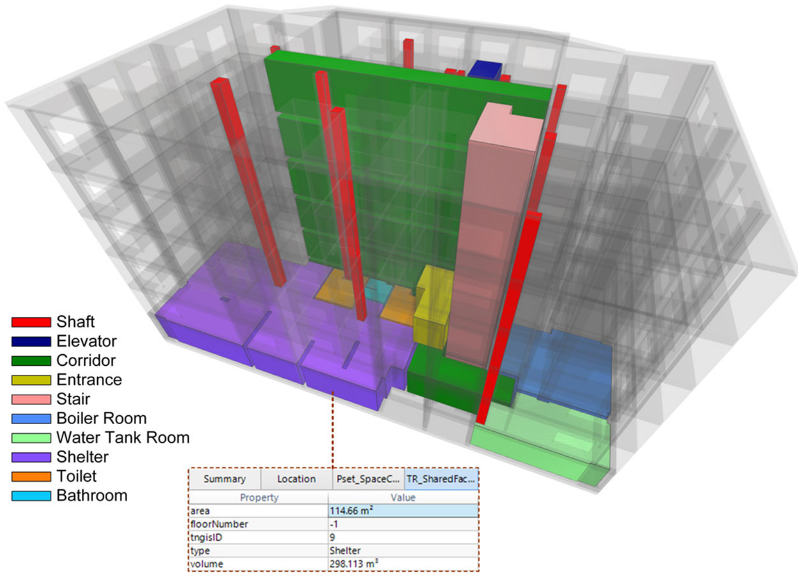

Figure 8. The shared/common spaces in the building.

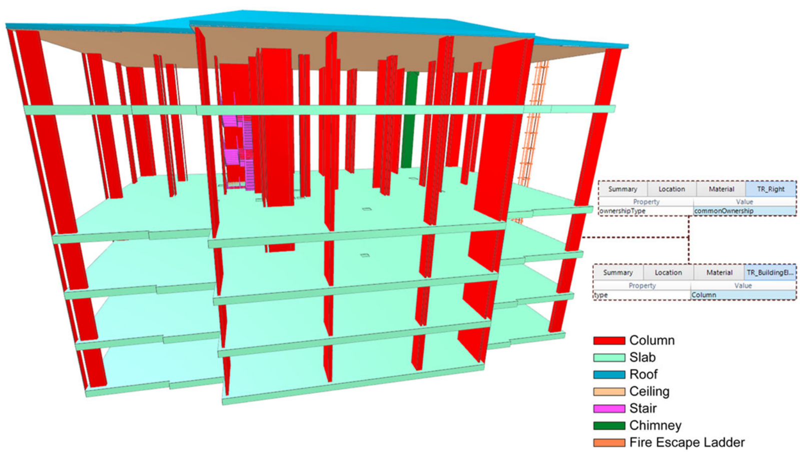

Figure 9. The shared/common building elements in the building.

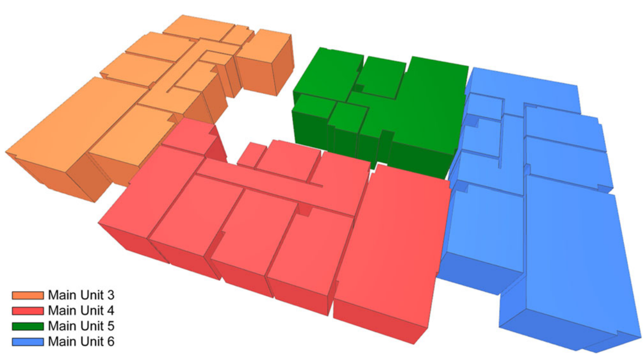

Figure 10. The legal spaces belonging to four example main units in the building.

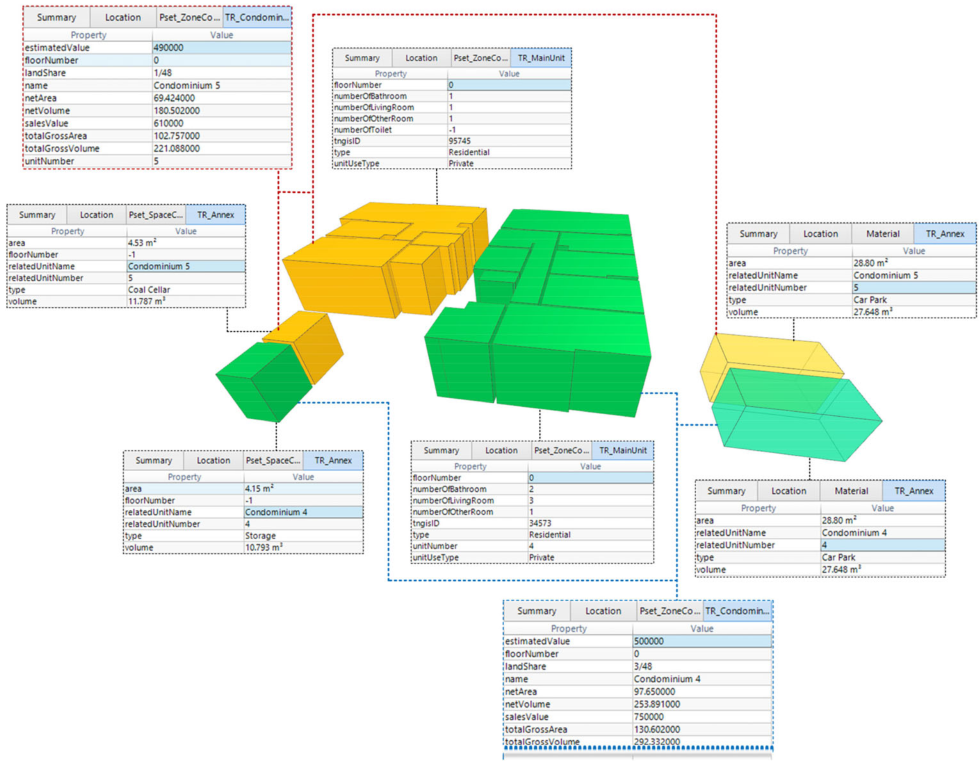

Figure 11. The condominium examples having a main unit and two different annexes as well.

Figure 12 illustrates the different building elements located at level zero of the building based on the ownership types. It can be seen from Figure 12 that whereas some windows in the building are used commonly, specific condominiums privately have ownership on some of them. The ownership information is provided by properties of related property sets. A wall that is privately used by *Condominium 4* can for example be seen in Figure 12. It is also shown the building elements such as natural gas meter boxes and water meter boxes that are attached to specific condominiums as annexes. In addition, the doors and walls that condominium owners have the right to use commonly can be seen in Figure 12. In addition to legal spaces located in hollows pertaining to the building elements such as elevator and stair, the common ownership that are established on these kinds of elements can be shown with the objects through *IfcBuildingElementProxy* instances.

5. Discussion

5.1. Legal perspective

This study provides a model that extends the IFC schema by referencing LADM to get the most out of the benefit of these standards in realistically representing condominium rights as 3D in the buildings. It is important to note that the integrated model contains specializations with respect to the current legal basis in Turkey. For example, the Condominium Law provides ownership rights regarding the annexes and common

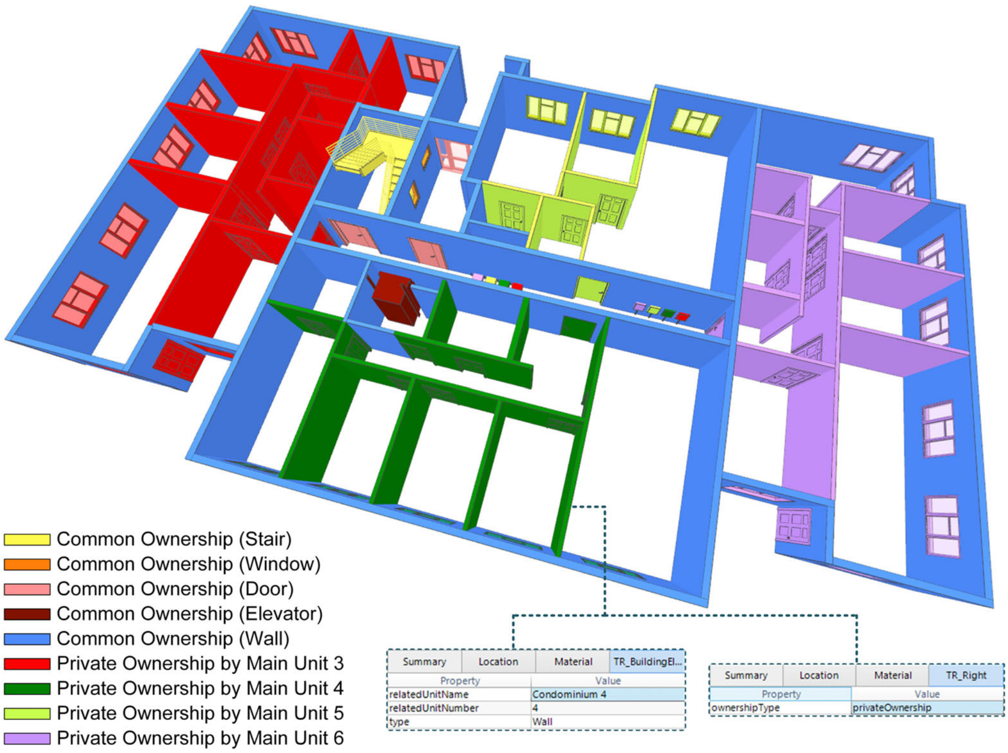

Figure 12. The building elements that are visualized based on the ownership type.

facilities/spaces in addition to the condominium rights. The features such as *TR_CondominiumUnit*, *TR_Annex*, and *TR_SharedFacility* and relationships between them are modeled based on the content of this law. Moreover, there is no definition of what amends the condominium owners can do on common building elements such as walls that separate the two main units. For example, it is not described that condominium owners have the right to use for which thickness of the faces of these walls. For this reason, such walls are modeled by using *IfcWall* instances in a way that the condominium owners have the right to use them commonly. However, different countries or jurisdictions such as Australia (Atazadeh et al. 2017b) can have detailed descriptions for ownership boundaries on the building elements in their legal documents and/or guidelines. For instance, the ownership boundaries in the walls are defined as interior, median, exterior, or other. This requires obtaining the boundaries of the walls such that they contain information on which condominium unit has the right to use on which parts of these walls.

Further, there exists another type of ownership namely exclusive ownership that can be subjected to the walls in the Saudi Arabia context (Alattas et al. 2021). If the wall separates the two main units, these main units have the right to use for a face of this wall that is a part of their legal spaces without causing any damage to the legal space of other main units. Exclusive ownership can also be established if one side of the wall belongs to the space of the main unit and the other side of it is a part of the space of a shaft within the building. As mentioned before, in Turkey, the shared/common facilities can be assigned to the specific condominiums for use through the management plan; however, there is no specific guideline or regulation on how the common ownership between two specific condominiums can be established on the building elements such as walls and slabs. Regarding this issue, updating the Condominium Law in Turkey such that it provides detailed and unambiguous definitions on who has the right to use for which parts of the different building elements such as walls can be considered.

At this point, it can also be mentioned the real estate valuation method that is utilized to estimate the land share of the condominium units in Turkey. The Condominium Law does not contain any detailed information on the valuation method. This might therefore result in subjective evaluations for the valuation of the condominium units. However, there is a bylaw in Turkey that describes different criteria such as the number of rooms and bathrooms, and construction and material type of the building in estimating the values of the condominiums and as well as shared facilities/spaces with the aim of taxation (Official Gazette 1972). Herein, it is important to note that if the BIM/IFC models of the buildings can be obtained in building/occupancy permit issuing, these models can be used to both 3D delineation of condominium rights and estimating the valuations of the condominium units. Furthermore, the land share of the condominium units can thus be calculated in an accurate manner since both the aforementioned and further criteria that affect the valuation can be derived from the BIM/IFC data, for example, material types, daylight and sunlight ratios, thermal and acoustic insulation levels, and energy efficiency (Isikdag et al. 2014; El Yamani et al. 2021; Celik Simsek and Uzun 2022). There is however a solid need for a legal basis that indicates and details how to estimate the valuation of the condominium units by using which criteria.

The Condominium Law in Turkey is updated several times for meeting the needs of the corresponding circumstances. Considering the both increased complexities of the buildings in the built environment and improved efficiency and accessibility of digital technologies such as BIM, updating the Condominium Law in a way that covers the 3D registration of condominium rights seems possible. In this regard, a bylaw that mandates a digital 3D building model as one of the required submission documents for the registration of condominium rights is published by GDLRC recently. This bylaw does not include detailed information about the data format of the digital building model. Therefore, the legal amendments that provide sufficient information on how to model which parts of the apartment units and which structural building elements in the sense of 3D registration of condominium rights can be realized. As a complementary change, the IFC schema can be modified such that it fulfills the requirements with respect to the delineation of ownership rights regarding the condominium units and related RRRs. In this connection, an additional legal document that provides modeling concept in detail by taking modified IFC schema into consideration can also be useful to support 3D digital BIMs-based registration of condominium units.

5.2. Technical perspective

The provided model that maps the IFC and LADM entities for the complete representation of condominium rights as 3D is fundamentally based on the current legal basis in Turkey. It is however significant to note that this model has similarities in the application and conceptual manners with the models that are proposed previously (e.g. Barzegar et al. 2021a; Alattas et al. 2021; Atazadeh et al. 2021; Ying et al. 2021). For example, whereas *IfcSpace* instances are utilized to represent legal spaces in a building or an apartment, *IfcZone* instances are utilized to represent all legal spaces including the main apartment unit and annexes belonging to an apartment. Furthermore, the building elements such as columns and beams are modeled such that the information on who has the right to use these kinds of elements is provided. The examples of the similarities are important because it is shown the increased usability of an integrated model that benefits from the BIM/IFC files as a data source in registering the ownership rights in different countries or jurisdictions as a considerable solution. In other words, the integrated model can be modified in terms of the classes and attributes in a way that corresponds to specific needs pertaining to the legal documents in the countries or administrations. It is also important to mention that the present paper does not contain any demonstration on the ownership information regarding the faces of the building elements such as walls because the current law in Turkey does not have a detailed definition in this issue. However, the current model does have a link between *TR_BoundaryFace* and *IfcConnectionSurfaceGeometry* and hence the ownership information can be brought in the faces of the various building elements. In addition, the attributes that express the ownership rights based on the faces in the different sides of the building elements can be added to the classes representing these elements as proposed by Alattas et al. (2021).

The differences in exported IFC models are also important from the technical perspective. For example, whereas the multi-storey stairs that are shared facilities and exported in the IFC2x3 version can be visualized in the IFC viewer software, these models could not be visualized by using the IFC model in the IFC4 version. The differences are significant for the complete representation of the condominium rights. For this reason, the uniformity with regards to the IFC schema version would be beneficial for the registration process in the land registry and cadastre agencies. In connection to this process, MVD enabling exchanging the necessary data between different stakeholders can be used to obtain the required information with respect to condominium rights in the buildings. If the necessary entities and their properties are defined for MVD, this will facilitate and improve the registration process of the ownership rights. At this point, it is vital to underline that the land registry agencies conduct the cadastral registration process based on the provided, approved architectural models. These models should therefore have the correct information on the condominium rights such as the use types, areas, and volumes of the units. It is important to note that the created BIM model is georeferenced in BIM authoring tool however further investigation regarding georeferencing of IFC data by using geoinformation-based software and surveyed control points should be conducted. It is also noteworthy to mention that some objects that are modeled by using specific family types in BIM authoring tool could be visualized differently in IFC viewer software. It can be noted that the first thing is to provide detailed examination regarding attributes that the BIM/IFC files should include. Moreover, the simplification of the CAD files can be enabled to facilitate automation. There is also a need to match the objects in the CAD files with suitable entities in the IFC schema. It is important to note that the final audit is required to check the correctness of the created BIM/IFC file with respect to modeling of legal spaces.

As stated earlier, *IfcZone* instances can be used to model all legal spaces located in the different parts of the building belonging to a condominium. It is however important to note that a variety of legal spaces such as car parks might be located in the immediate surrounding of the buildings (see Figure 7). In this case, the spaces pertaining to the car parks can be modeled using *mass* features in the BIM authoring tool rather than *space* or *room* features. This is because both *space* or *room* features can be defined only if the closed boundaries are existing. When it comes to modeling the logical spaces completely with different annexes such as car parks, it is not possible to use those features. It is noteworthy at this point that *IfcSpace* has an attribute namely *PredefinedType*, which points to *IfcSpaceTypeEnum* that can be *SPACE*, *PARKING*. Another important thing is that the BIM authoring tools only allow for grouping spaces to create the zones. The IFC model, therefore, needs to be amended after exporting such that an *IfcZone* instance of a condominium contains the legal spaces regarding both the main unit and other annexes such as car park that is modeled using the *mass* feature and exported as *IfcSpace* instance.

5.3. Societal perspective

Both the literature and the experiences from the field reveal that detailed information on the current state of the apartments in the buildings cannot be provided in an easy way (Shin et al. 2021). This information might be related to wide ranges of topics such as ownership rights and connected shares, land registry history, areas and volumes, features with respect to heating, isolation, and renewable energy features. The lack of such information on the apartments might cause problems in the buying/selling or leasing processes since the potential buyers or tenants want to have the correct information for the features of the apartment. Such problems can be prevented if the information on the aforementioned topics pertaining to the apartments is presented. The IFC model of the building can be beneficial in acquiring information on those topics. By doing so, prospective buyers or tenants can have detailed information through the visualization of the 3D models that include the representation of the condominium rights and other attributes regarding the apartment.

In addition, there might be some disagreements among condominium owners with respect to the ownership rights on the different parts and elements of the buildings. Accessing the 3D representation of condominium rights with their elaborate semantics by the owners would be useful as the misinterpretations and subjective decisions with regards to ownership rights that might due to the 2D delineation of the complex situations can be eliminated. In connection to this, it is important to underline that privacy issues should be considered for the dissemination of 3D condominium rights. This is because public availability of some information regarding condominiums might cause a violation of personal rights. For this reason, different parties involving the activities regarding real estate can have limited restrictions for various semantics.

5.4. Regarding relationship with the (digital)building permit issuing

As noted in Sec. 2.2.1., there is a connection between the building permit procedures and registration of the condominium rights in Turkey and in a large number of countries because of several reasons. One reason is because the subdivision plans should be submitted in the building/construction permit application. Another reason is because it is utilized the condominium plans including the boundaries, locations, and attributes of the condominiums in the building that the occupancy permit is approved. Even though the building permit issuing is carried out based on 2D data commonly, there is an increasing trend for the digitalization and automation of building permitting owing to the slow reviewing procedures and misinterpretations (Malsane et al. 2015; Noardo et al. 2020a, 2022). Therefore, a great number of countries are developing policies with respect to digitalization in order for facilitating and improving the public services in which building permitting is one of them. For example, in Turkey, the number of buildings that are given building permit and occupancy permit are 96,001 and 77,712 in 2020, respectively (TurkStat 2020). This numbers show that the building permit issuing is one of the frequently utilized and important public services in the country. The digitalization of building permitting encompasses the (semi)automatic compliance checking and exploiting 3D data. Considering the adoption of BIM allowing for modeling, storing, and visualizing the

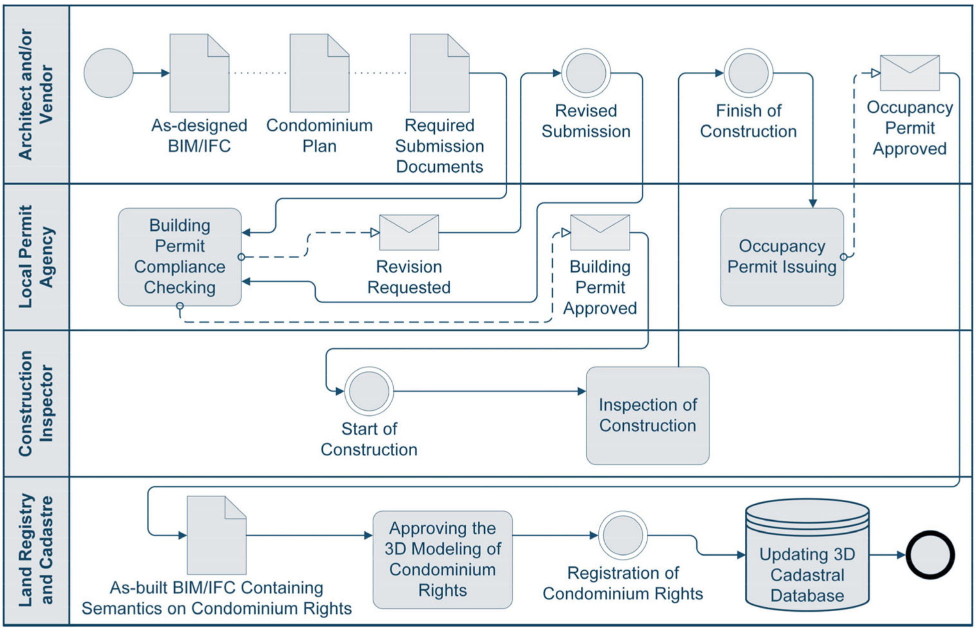

Figure 13. A BIM/IFC-based workflow containing both digital building permitting and 3D cadastral registration.

wide ranges of objects and semantics within the buildings is growing, using the BIM/IFC models in building permit procedures is considered as a highly solid solution.

At this point, it is pivotal to note that there exists a strong potential for 3D registration of condominium rights because of the reuse of BIM/IFC models within building permit procedures. It can, however, be noted that IFC models in building permitting submission are as-designed but there is a need for as-built versions of these IFC models in occupancy permit checking since a number of modifications might occur during the construction phase. Utilizing the as-built version of the IFC models is quite important in terms of the condominium rights because using the as-designed versions of these models might cause mistakes in registering a large number of attributes regarding the condominiums, for example, area, volume, and land share. In light of this information, Figure 13 illustrates a framework benefiting from BIM/IFC models in issuing the building permit and registering the condominium rights as 3D.

Building permit issuing is also a part of spatial planning relating to land development that is a counterpart of the land administration paradigm (Williamson et al. 2010; Indrajit et al. 2020). This means that there is a relationship between the AEC industry and the land administration sector. To make the most of this relationship, the architects/designers and other related stakeholders can be adequately informed about the legal spaces and boundaries pertaining to the ownership rights in the buildings. In doing so, more complete IFC models that encompass wide ranges of attributes regarding the condominium rights can be obtained for the cadastral registration process.

5.5. Regarding potential of updating 3D city models

There is a strong ambition to create and keep up-to-date the database of 3D city models in Turkey as similar to other countries worldwide so as to efficiently manage the built environment (Biljecki et al. 2015). In connection to this issue, it is expected to benefit from the approach in the present paper. Specifically, if the IFC models are obtained from the occupancy permit issuing for 3D representation of condominium rights, these models can also be utilized to update the current database of 3D urban models. Given that such a database is formed for the whole of Turkey by the GDoGIS, the significant thing is the up-to-dateness of this database. Noteworthy to mention that considerable changes are occurring in the cities, particularly metropolises namely Istanbul, Ankara, and Izmir of Turkey since there are a great number of ongoing construction activities for different reasons such as urban renewal.

Considering the growing adoption of BIM in the AEC industry, it can be exploited the opportunity of reusing the as-built IFC models through transforming them to geoinformation-based formats such as CityGML and CityJSON, so as to ensure the up-to-dateness of 3D city model database against these changes. It is however significant to underline that the conversion between GIS and BIM domains is not at the perfect level. There are important issues forming challenges regarding this conversion for example geo-referencing, level of detail (LoD), and volume geometries (Noardo et al. 2020b; Zhu and Wu 2022). It can also be mentioned that the BIM domain initially does not have an aim for creating models covering all the built environment. For this reason, geospatial data standards providing various modules that contain the specifications for geometric representation of the physical objects in the built environment from wide ranges of sub-fields such as building and land use are needed.

6. Conclusion

In this study, the model that extends the IFC schema by referencing LADM is provided with the aim of representing the condominium rights as 3D in Turkey. It is aimed to provide the extension in a way that encompasses all the necessary geometric representations and semantics of the physical objects and their corresponding legal spaces. Further, the integrated model enables to the 3D representation of condominium rights with related legal spaces in the apartment units as well as wide ranges of building elements that can be subjected to the right of use by the condominium owners. The applicability of this model is demonstrated in terms of different cases regarding the condominium rights in the buildings through a BIM/IFC model of a building. The provided model and demonstrations in this paper are expected to contribute to both efficient 3D LAS transition and increasing interrelation between the AEC industry and land administration sectors in Turkey for mutual benefit.

Last but not least, some suggestions regarding guidelines for adapting LADM-driven BIM models in Turkey can be provided. First, there is a need to enable efficient interrelations between different sectors in which the BIM models are utilized. For example, data interoperability between the applications related to the AEC and land administration sectors is highly significant to BIM-based registration of condominium rights in the country. In this regard, awareness in the AEC industry with respect to legal spaces and related RRRs can be increased since submitting the condominium plans in the building permitting is a requirement. In this way, BIM models that contain unambiguous and correct information in terms of the modeling of condominium rights can be obtained. What is more, there is a need for increasing the number of personnel in the land registry and cadastre offices who are able to understand and check the BIM models in the sense of delineation of property rights in the buildings. Second, the digital information flow with regards to BIM models should be enabled in the different applications with respect to buildings, that is digital building permitting and cadastral registration of condominium rights. By doing so, BIMs can be reused without a lack of information and up-to-dateness. Third, as an addition to the second point, both legal documents that provide detailed information on what the condominium rights covers in the buildings and technical documents containing requirements regarding objects and attributes that BIM models should have should be published by the central cadastral organization. Consequently, the abovementioned issues will contribute to the realization of a full 3D digital cadastre in the country through the lossless reuse of BIMs and their IFC data that results from efficient interrelations between the sectors related to the registration of condominium rights.

Notes

1. https://postgis.net/
2. https://oslandia.gitlab.io/SFCGAL/
3. https://www.postgresql.org/
4. https://www.bimcollab.com/

Acknowledgments

The first author is grateful to the International Federation of Surveyors (FIG) Foundation PhD Scholarship that enables the research visit to the Delft University of Technology (TU Delft).

Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, D.G., upon reasonable request.

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Appendix

Table A.1. Property set names, property names, property types, and data types for attributes of *Party* and *Administrative* packages of the integrated model.

Property set name	Property name	Property type	Data type
TR_Party	name	IfcPropertySingleValue	IfcLabel
	surname	IfcPropertySingleValue	IfcLabel
	fatherName	IfcPropertySingleValue	IfcLabel
	TRpID	IfcPropertySingleValue	IfcInteger
	nationality	IfcPropertyEnumeratedValue	IfcLabel
	partyType	IfcPropertyEnumeratedValue	IfcLabel
	IDType	IfcPropertyEnumeratedValue	IfcLabel
	gender	IfcPropertySingleValue	IfcLabel
	dateOfBirth	IfcPropertySingleValue	IfcDate
	placeOfBirth	IfcPropertySingleValue	IfcLabel
	phoneNumber	IfcPropertySingleValue	IfcInteger
	role	IfcPropertyEnumeratedValue	IfcLabel
TR_GroupParty	groupID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLabel
TR_AdministrativeSource	journalNumber	IfcPropertySingleValue	IfcInteger
	registrationDate	IfcPropertySingleValue	IfcDateTime
	volume	IfcPropertySingleValue	IfcInteger
	pageNumber	IfcPropertySingleValue	IfcInteger
TR_RRR	decription	IfcPropertySingleValue	IfcText
	rID	IfcPropertySingleValue	IfcIdentifier
	share	IfcPropertySingleValue	IfcReal
TR_Right	type	IfcPropertyEnumeratedValue	IfcLabel
TR_Mortgage	amount	IfcPropertySingleValue	IfcReal
	startingDate	IfcPropertySingleValue	IfcDateTime
	duration(numberOfMonths)	IfcPropertySingleValue	IfcInteger
TR_BAUnit	tngisID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLabel
	name	IfcPropertySingleValue	IfcLabel

Table A.2. Property set names, property names, property types, and data types for attributes of *Spatial* package and *Surveying and Representation* sub package of the integrated model.

Property set name	Property name	Property type	Data type
TR_Parcel	tngisID	IfcPropertySingleValue	IfcIdentifier
	propertyID	IfcPropertySingleValue	IfcInteger
	area	IfcPropertySingleValue	IfcAreaMeasure
	parcelNumber	IfcPropertySingleValue	IfcInteger
	parcelType	IfcPropertyEnumeratedValue	IfcLabel
	blockNumber	IfcPropertySingleValue	IfcInteger
	landUseType	IfcPropertyEnumeratedValue	IfcLabel
TR_SpatialUnit	city	IfcPropertySingleValue	IfcLabel
	district	IfcPropertySingleValue	IfcLabel
	village	IfcPropertySingleValue	IfcLabel
	neighborhood	IfcPropertySingleValue	IfcLabel
TR_Building	tngisID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLabel
	name	IfcPropertySingleValue	IfcLabel
	numberOfFloor	IfcPropertySingleValue	IfcInteger
	status	IfcPropertyEnumeratedValue	IfcLabel
	totalFootprint	IfcPropertySingleValue	IfcReal
	totalConstructionArea	IfcPropertySingleValue	IfcAreaMeasure
	dateOfBuildingPermit	IfcPropertySingleValue	IfcDateTime
	constructionStartingDate	IfcPropertySingleValue	IfcDate
	constructionEndingDate	IfcPropertySingleValue	IfcDate
	dateOfRenovation	IfcPropertySingleValue	IfcDate
	dateOfDemolition	IfcPropertySingleValue	IfcDate
	measuredHeight	IfcPropertySingleValue	IfcReal
	heightReference	IfcPropertySingleValue	IfcLabel
	zoningHeight	IfcPropertySingleValue	IfcReal
	cost	IfcPropertySingleValue	IfcReal
	floorsAboveGround	IfcPropertySingleValue	IfcInteger
	floorsBelowGround	IfcPropertySingleValue	IfcInteger
TR_BuildingElement	relatedUnitNumber	IfcPropertySingleValue	IfcInteger
	buildingElementType	IfcPropertySingleValue	IfcLabel
	relatedUnitName	IfcPropertySingleValue	IfcLabel
TR_CondominiumUnit	floorNumber	IfcPropertySingleValue	IfcInteger
	netVolume	IfcPropertySingleValue	IfcVolumeMeasure
	netArea	IfcPropertySingleValue	IfcAreaMeasure
	dateOfSale	IfcPropertySingleValue	IfcDate
	landShare	IfcPropertySingleValue	IfcReal
	totalGrossArea	IfcPropertySingleValue	IfcAreaMeasure
	totalGrossVolume	IfcPropertySingleValue	IfcVolumeMeasure
	marketValue	IfcPropertySingleValue	IfcLabel
	salesValue	IfcPropertySingleValue	IfcLabel
	estimatedValue	IfcPropertySingleValue	IfcLabel
	name	IfcPropertySingleValue	IfcLabel
TR_MainUnit	tngisID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLabel
	unitNumber	IfcPropertySingleValue	IfcInteger
	numberOfBalcony	IfcPropertySingleValue	IfcInteger
	numberOfLivingRoom	IfcPropertySingleValue	IfcInteger
	numberOfOtherRoom	IfcPropertySingleValue	IfcInteger
	numberOfToilet	IfcPropertySingleValue	IfcInteger
	unitUseType	IfcPropertySingleValue	IfcLabel
	floorNumber	IfcPropertySingleValue	IfcInteger
	numberOfBathroom	IfcPropertySingleValue	IfcInteger
TR_Annex	relatedUnitNumber	IfcPropertySingleValue	IfcInteger
	type	IfcPropertyEnumeratedValue	IfcLabel
	relatedUnitName	IfcPropertySingleValue	IfcLabel
	area	IfcPropertySingleValue	IfcAreaMeasure
	volume	IfcPropertySingleValue	IfcVolumeMeasure
	floorNumber	IfcPropertySingleValue	IfcInteger
TR_SharedFacility	tngisID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLabel
	area	IfcPropertySingleValue	IfcAreaMeasure
	volume	IfcPropertySingleValue	IfcVolumeMeasure
	floorNumber	IfcPropertySingleValue	IfcInteger