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Identifying Legal, BIM Data and Visualization Requirements to Form Legal Spaces and Developing a Web-Based 3D Cadastre Prototype: A Case Study of Condominium Building

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Abstract: Over the past decade, numerous countries and researchers have been investigating the potential of 3D cadastre based on the Building Information Model (BIM). In Türkiye, the General Directorate of Land Registry and Cadastre (GDLRC) has been engaged in the "Production of 3D City Models and Creation of 3D Cadastral Bases Project" since 2018. One of the objectives is to develop 3D (physical) digital building models (and databases) through the digitization of floor plans of architectural drawings. In order to ensure the long-term viability of this project, a new regulation was issued in 2021. This regulation mandates the submission of 3D digital building models to the land registry in order to register condominiums. The future goals of the GDLRC include utilizing the 3D digital building models produced to create legal spaces in condominium buildings for the 3D cadastre. However, no research has yet been carried out for this goal. The objective of this research is to identify the legal and BIM data requirements for deriving legal spaces in condominium buildings, in light of the legislative analysis, and to develop a web-based 3D cadastre visualization prototype (showing both legal spaces and physical objects) based on the requirements obtained from the scientific literature. The result of this research demonstrates that well-structured and annotated BIM data can be used to develop a 3D cadastre prototype that meets the legal requirements in the case of Türkiye. Moreover, it is evident that, although the GDLRC has initiated the construction of a robust foundation for a 3D cadastre based on BIM, further enhancements and resolutions must be implemented from a legal and technical standpoint. It is postulated that the identified requirements and the proposed methodology in this research may assist decision-makers in Türkiye and globally in formulating their strategic plans for a 3D cadastre.

Keywords: building information model; 3D cadastre; BIM; legal spaces; IFC; condominium building; condominium unit

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1. Introduction

Digitization has opened up many opportunities in a number of areas, including land administration as well as cadastre. According to [1], the move to build digital cadastral databases using the available digital technologies started in the 1990s, adding that the conversion of existing analogue registers to a digital format was relatively straightforward, whereas the conversion or creation of the digital cadastral map proved to be a much more complex process. Digitization in land administration is still an ongoing process and its importance is emphasized in global guidelines and frameworks. The New Urban Agenda, for example, indicates that digital platforms and tools, including geospatial information systems, should be used to improve long-term integrated land administration and management [2]. More recently, 'Digital Transformation and Land Administration', prepared by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Economic Commission for Europe (UNECE) and the International Federation of Surveyors (FIG), states that land administration systems should accelerate both strategic and operational digitization agendas [3].

Digitization has also affected the Architecture, Engineering and Construction (AEC) industry in various ways, and the explosive growth of digital information can also be linked to it [4]. The Building Information Model (BIM) can be considered one of the most advanced technologies to penetrate the AEC industry. BIM is defined by ISO 29481-1:2016 Building information models—Information delivery manual—Part 1: Methodology and format as "use of a shared digital representation of a built object (including buildings, bridges, roads, process plants, etc.) to facilitate design, construction and operation processes to form a reliable basis for decisions" [5]. BIM has begun to be adopted globally, with several countries making BIM mandatory in practice, and others in the process of doing so [6]. For example, countries in Scandinavia (e.g., Norway, Sweden, Finland and Denmark), Europe (e.g., France, Germany, The Netherlands), the United Kingdom, the United States of America, Australia, Singapore, Russia, China, India and South Korea have started to use BIM for public sector projects [6,7]. The Vision Report published by the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) notes efforts to combine AEC BIM with Geographic Information System (GIS) and other geospatial technologies [8]. The same report indicates that "significant research literature on the topic of data interoperability between AEC and GIS; specifically, between the open 3D data standards of Building Smart's International Industry Foundation Class (IFC) for the AEC industry, and Open Geospatial Consortium's CityGML for geospatial". The BIM data formats, BIM/IFC and OGC's CityGML, are considered by the UN-GGIM to be largely incompatible, and this assertion can also be found in the 3D cadastre and land administration literature [8].

One of the opportunities offered by digitization is the ability to store, retrieve and visualize three-dimensional (3D) data with unprecedented ease. It is perhaps no coincidence that the vertical dimension of the legal status of property has been explored more than ever since the 1990s. This increase has accelerated cadastral research and the first 'International Workshop on 3D Cadastres' was organized in 2001 to open international discussion on 3D cadastres and planned developments in the use of 3D cadastral registrations [9]. As one of the application areas in the geospatial domain, the 3D cadastre has started to investigate whether it is possible to use digital BIM data to provide some solutions to the problems in the two-dimensional (2D) cadastral systems. More specifically, 2D cadastral systems may not provide sufficient representation of legal spaces (i.e., private and common spaces) and efficient management of rights, restrictions and responsibilities (RRRs) in multi-level complex building structures [10,11]. Furthermore, the increasing structural complexity of high-rise buildings is a growing trend and tends to become mainstream in the built environment, it has a significant impact on the registration of RRRs [4,10]. The importance of 3D cadastre is also highlighted by the New America, a civic platform that connects a research institute, technology lab, solutions network, media hub, and public forum to incubate ideas, policies, and solutions for America [12]. This platform indicates that the 3D cadastre "has emerged to more adequately capture the 3-dimensional nature and dynamic characteristics of mixed land use and real property both above and below ground. [. . .] The need for 3D cadastres is growing in importance due to the increasing overlap of property rights in densifying urban environments" [12].

In fact, a number of studies have been carried out to establish 3D cadastral solutions for the creation of legal spaces in condominium buildings[1]. These studies use different data sources. For example, survey plans, i.e., as-built plans, are used in [14,15], while architectural drawings (plans) are used in [16–18]. Quite a number of studies have used OGC's CityGML to shape legal spaces [19–24]. On the other hand, the majority of studies in the literature have explored how BIM/IFC data can be exploited for sourcing legal spaces [10,25–39]. It should be noted that some of the studies mentioned here have directly used BIM/IFC data, while some of them have used digital architectural plans to derive legal spaces that are finally exported as BIM/IFC. In the literature, it can be observed that BIM/IFC is the most used data format for forming legal spaces in condominium buildings. Three-dimensional cadastral data should represent both legal spaces and physical objects together [40], thereby improving users' visual comprehension. On the other hand, Refs. [15,28,31,32,40] introduced web-based 3D geovisualization prototypes designed to represent the legal spaces within condominium buildings. However, none of these works developed a prototype that integrates the representation of both physical objects (e.g., walls, columns and beams, slabs, accessories, etc.) and legal spaces, while maintaining them as distinct entities.

It is expected that more and more countries will legislate for the use of BIM in the near future. One of the reasons for this expectation is that all physical building elements can be modelled, stored and managed hierarchically in BIM/IFC, which makes it easy to exchange building information for different purposes in different BIM platforms [30]. One of the countries trying to digitize land administration systems and move from a 2D cadastre to 3D is Türkiye. A recent digitization project of *the General Directorate of Land Registry and Cadastre* (in Turkish: *Tapu ve Kadastro Genel Müdürlüğü*—GDLRC) is *the Production of 3D City Models and Creation of 3D Cadastral Bases Project* (in Turkish: *3B Şehir Modelleri Üretimi ve 3B Kadastro Altlıklarının Oluşturulması Projesi—3DCMCB*), the main objective of which is to develop a nationwide web-based application that presents 3D buildings produced using photogrammetric methods with some attributes, and to digitize architectural drawings to produce CityGML-based 3D digital building models that will be used as a basis for 3D cadastre. The 3DCMCB is an ongoing project of the GDLRC, which started in 2018 [41–43], and some pilot studies have been completed in some provinces. To ensure the sustainability of the development of 3D digital building models as part of the project, the GDLRC has issued a circular requiring the submission of a *building survey project* (in Turkish: *yapı aplikasyon projesi*) together with the 3D digital building model created using the GDLRC's data schema for the registration of condominium units [44]. This obligation has started to be implemented in some provinces in 2023 and will be gradually extended to more provinces in the following months. On the other hand, the GDLRC has not taken any step to derive legal spaces in condominium buildings from 3D digital building models, although this is one of the future objectives of the GDLRC. As stated by [42], the transition from a 2D representation to a 3D digital cadastre requires not only the replacement of analogue drawings with 3D models, but also a re-examination of the workflow for defining property units, which can be considered as the need to describe the legal spaces in condominium buildings. Furthermore, the GDLRC has not allowed the delivery of 3D digital building models with BIM/IFC for condominium registration, the most commonly used data format for 3D cadastral studies.

This research aims at deriving legal spaces of condominium buildings from BIM/IFC data in a case study and publishing physical objects and legal spaces derived from BIM/IFC data through a web-based 3D geovisualization prototype. In order to achieve this goal, holistic requirements analyses in terms of legal (e.g., what is considered as private space and what is considered as common space, produced through relevant legislation analysis), BIM data (what BIM/IFC data are needed to derive legal spaces), and 3D visualization (what is needed to develop a 3D cadastre visualization prototype, derived from the scientific literature) are first carried out, and based on these findings, a 3D geovisualization prototype is developed to represent both legal spaces and physical objects within a condominium building, with the objective of enhancing user perception.

The remainder of the paper is organized as follows: Section 2 briefly introduces the legislation related to condominiums in Türkiye and the 3DCMCB. Section 3 lists the legal, BIM data and visualization requirements. Section 4 presents the case study which develops a prototype that visualizes both legal spaces and physical objects in a condominium building. A discussion of the current research is provided in Section 5. The final section presents the concluding remarks and future work.

2. 3D Cadastre Related Legislation and Project in Türkiye

Given the background presented in the previous section, Section 2.1 provides information on the legislation related to condominiums and 3D cadastre. Section 2.2 briefly presents the work performed and planned in the GDLRC's 3DCMCB.

2.1. Condominium Unit and 3D Cadastre-Related Legislation

The Turkish Civil Code (in Turkish: *Türk Medeni Kanunu*) states that a condominium unit is a type of immovable property [45]. The statistics published on the website of the GDLRC show that there are 59,100,360 parcels and 24,135,098 condominium units in Türkiye as of July 2024. The details of condominium ownership are regulated by the Condominium Law [46] and subsequent amendments to this law. It conforms to the principles of the "dualistic system", which integrates individual ownership of an apartment and co-ownership of the common property into a composite ownership [47,48].

In Condominium Law, the immovable property on which the condominium is established is referred to as the main property, while the structure itself is referred to as the main building (e.g., condominium building). The law classifies the legal spaces of the main property as the *condominium unit* (i.e., private parts of the main property), the *accessory part* (i.e., part(s) outside a condominium unit that are directly allocated to that unit) and the *common space* (i.e., spaces outside the condominium units of the main property that serve for protection and common use or benefit).

The condominium unit is the part of the main property intended for independent and exclusive use, such as an apartment, office, shop, store or warehouse. In addition, each condominium unit has a co-ownership share in the common spaces [46]. The location, floor area, internal partitioning, type of use, co-ownership shares and accessory parts of condominium units are specified in the architectural drawings and the *condominium deed* (in Turkish: *kat mülkiyeti sözleşmesi*) [46,48].

The accessory part is a legal space which is located outside the condominium units and directly assigned to the exclusive use of a particular condominium unit, such as parking spaces, cellars and storage rooms. An accessory part can only be allocated to one condominium unit and is considered an inseparable part of that unit. Therefore, the ownership of the condominium unit extends to the accessory part(s) allocated to that unit [46]. The boundaries of the accessory parts, their types of use and the condominium units allocated to them are indicated in the architectural drawings and the condominium deed [46,48].

The common space is another legal space in a condominium building that is jointly owned by the condominium owners in proportion to the co-ownership shares of their condominium units. The common spaces include the land, building facilities and installations located outside the condominium units and designed to protect and facilitate the common use of the main property. The law provides a list of building components and installations which are, in any case, deemed to be common spaces as follows: foundations and main walls; beams, columns and bearing walls forming the load-bearing system and other elements forming part of the load-bearing system; walls separating condominium units; ceilings and floors (slabs); courtyards; entrance doors; entrances; stairs; elevators; landings; corridors and common toilets and sinks therein; caretaker's rooms; laundry and laundry drying rooms; common coal cellars and common garages; slots and closed installations outside the condominium unit for the protection of electricity, water and gas meters; heating rooms; wells and cisterns; common water tanks; shelters; sewers, rubbish chutes, heating, water, gas and electricity installations, common networks and aerials for telephone, radio and television, hot and cold air installations outside the private spaces of each owner; roofs; chimneys; common roof terraces; rain gutters and fire escapes. In addition, those areas or components that are not listed in the law but are indispensable for common protection and use are considered common spaces [46]. Other places or facilities can also be designated as common spaces by the architectural drawing and condominium deed. In practice, it is assumed that spaces in the main building are all common spaces unless they are specified as condominium units or accessory parts in the architectural drawings [46,48].

A *provisional condominium* (also referred to as an *off-plan condominium* or *condominium easement*; in Turkish: *kat irtifakı*) is established on unbuilt land to be developed in the future and will become a *condominium* (in Turkish: *kat mülkiyeti*) when the development is completed, and the *building occupancy permit* (in Turkish: *yapı kullanma izin belgesi*) is issued. The documents required for the registration of a condominium in the land registry are the architectural drawings, the *condominium by-law* (in Turkish: *yönetim planı*) and the condominium deed [46].

According to the GDLRC's statistical information, 952,466 parcels have condominiums, while 835,639 parcels have provisional condominiums as of 8 July 2024 [49]. It should be noted that while provisional condominiums are legally considered unfinished structures, the majority of the provisional condominiums are occupied, and they have not proceeded to condominiums for various reasons that are not the subject of this paper.

Since the first version of the Condominium Law, architectural drawings are required for the registration of a condominium or a provisional condominium. According to a circular issued by the GDLRC in 2017, a scanned version of the architectural drawings must be sent to the land registry for the registration of a condominium unit (before this circular, analog architectural drawings were accepted) [50]. Following the amendment of the Condominium Law in 2001, a new circular was issued by the GDLRC, making it mandatory to send scanned architectural drawings together with the condominium by-law, *building survey project* (can also be called *building survey stakeout project*) and 3D digital building model to the land registration office for the registration of condominium unit [44]. Furthermore, According to the Planned Areas Zoning Regulation [51], the building survey project includes the setback distances of the buildings, the coordinates of the building corner points and the reference points [51]. The building survey project is designed on the basis of the *building layout plan* (in Turkish: *vaziyet planı*) and the *parcel survey sketch* (in Turkish: *parsel aplikasyon krokisi*).

The Turkish Chamber of Survey and Cadastre Engineers (CSCE) organized a workshop and prepared the report 'Workshop on Preparation, Implementation and Technical Liability of Building Survey Project—Final Report' [52], which includes example plans produced through the process of building survey project and a workflow diagram showing each step from the preparation of the parcel survey sketch to the registration of the property. Given the objectives of this research, the workflow diagram produced by the CSCE is simplified, summarized and some steps are even omitted to produce Figure 1. The first step for property owner(s) wishing to build a condominium building on their land parcel is to obtain a copy of the land title. The property owner(s) then apply to the certified surveying engineer for the parcel survey sketch, which includes the ownership and easement rights to the relevant parcel and adjoining road(s); and a large-scale topographical map showing the topography of the area where the parcel is located. The property owner(s) then apply to the responsible authority (e.g., the municipality) for the *development permit* (in Turkish: *imar durum belgesi*), which contains information on the planned type of use and construction conditions, a geological and geotechnical survey report, a report on the elevation of adjoining roads, and so on. The authority provides the property owner(s) with the aforementioned documents and the property owner(s) are required to consult an architect for the preparation of the architectural drawings, based on the development permit. After the pre-approval of the architectural drawings, the building inspection process is started. Various projects and reports (e.g., static project, soil investigation report, mechanical installation project, electrical installation project, and so on) are prepared in this step, which also includes the building survey project.

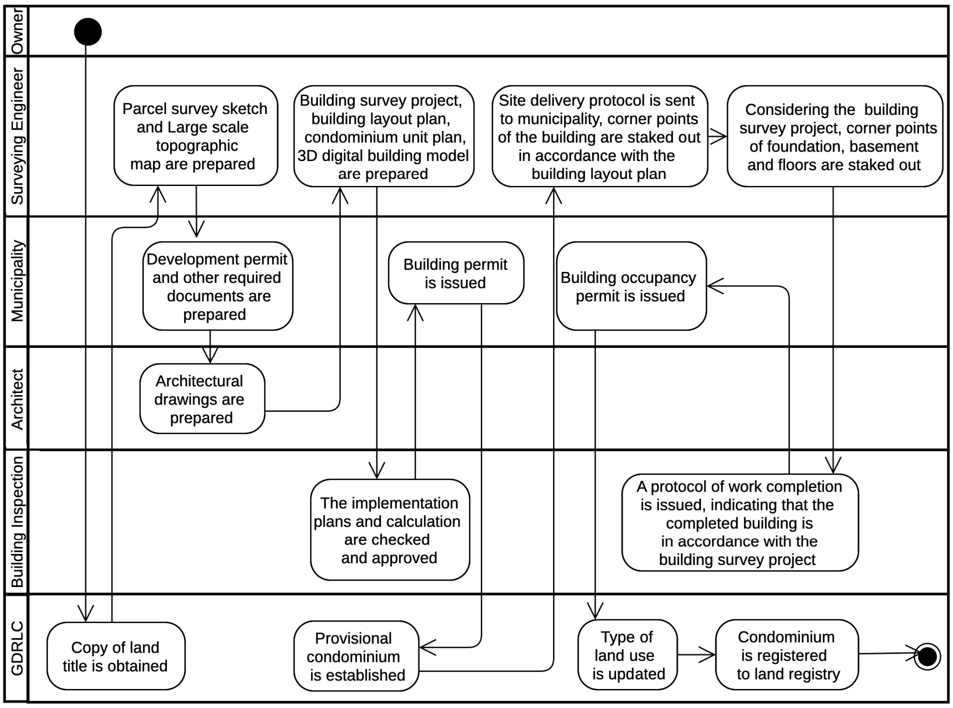


Figure 1. The workflow diagram for the registration of condominium, including the preparation of building survey project (modified from [52]).

Building survey project (in Turkish: *yapı aplikasyon projesi*) is prepared, which shows the location and height of the building as indicated in the development permit to ensure the application of the building corner points to the land parcel in accordance with the parcel survey sketch, large-scale topographic map and building layout plan. Figure 2 shows an example of a building survey project [52]. The parcel boundaries (red line), building boundaries with coordinates (blue line), setbacks (dashed green line), adjacent parcels and roads are shown in this plan. It also shows the elevation of points on the road and natural ground, on the corner of the parcel, the basement and the foundation.

The building layout plan, which forms the basis of the building survey project, shows the legal boundaries of the buildings. Figure 3a illustrates an example of a building layout plan. The *condominium unit plan* (in Turkish: *bağımsız bölüm planı*) shows the boundaries and locations of the condominium units and their accessory parts, which are prepared for each floor of a condominium building. Figure 3b presents an example of condominium unit plan [52]. It should be noted that, building layout plan and the condominium unit plan are required documents for cadastral registration of condominiums in Türkiye, since 2008, according to the *Regulation on Title Plans* (in Turkish: *Tapu Planları Tüzüğü*) [53].

Once all the necessary plans are prepared, they are checked and approved by the certified building inspection company. The relevant authority then checks the plans again and issues a *building permit* (in Turkish: *yapı ruhsatı*). This is followed by the establishment of a provisional condominium. The building permit, architectural drawings, the condominium by-law and the building survey project should be submitted to the land registration office for the establishment of the provisional condominium. After that, the *site delivery protocol* (in Turkish: *iş yeri teslim tutanağı*) is issued and sent to the relevant authority. The corner points of the building(s) are applied to the land parcel, in accordance with the building layout plan. After that, the foundation, basement and floors are applied to the parcel taking into consideration the building survey project. The *work completion protocol* (in Turkish: *iş bitirme tutanağı*) is then issued and sent to the relevant authority (e.g., municipality). This is followed by issuing the *building occupancy permit* (in Turkish: *yapı kullanma izin belgesi*). This permit is sent to the land registration office and the type of land use of the property is updated in the registry. Finally, after sending the required documents (i.e., architectural drawings, condominium by-law, building survey project and 3D digital building model) to the land registration office, the condominiums are registered in the land registry [52].

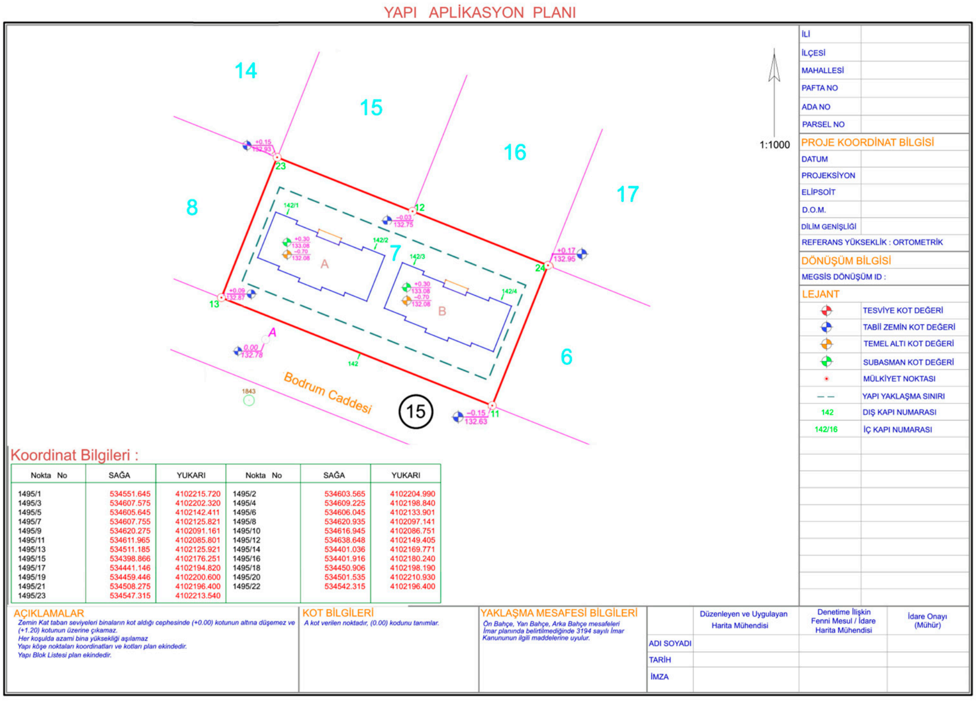
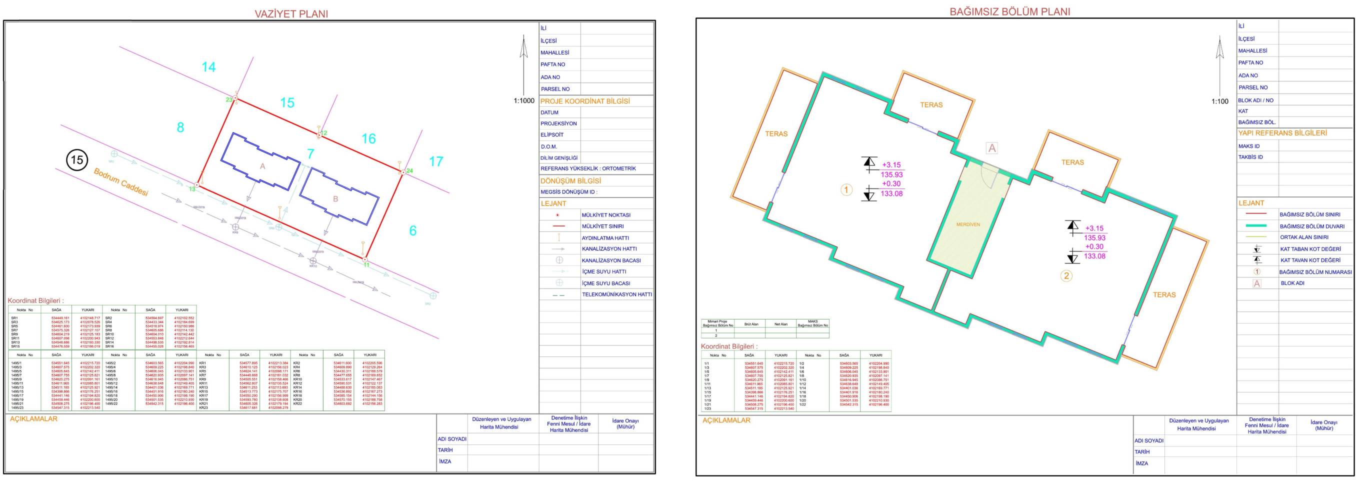


Figure 2. An example of a building survey project, with the red and pink lines showing the parcel boundaries, the blue line showing the building boundaries, the dashed green line showing the setbacks, the cyan text showing the parcel numbers, and the numbers in pink showing the elevations (Source: [52]).



(**a**) (**b**)

Figure 3. Examples of (**a**) a building layout plan with the red and pink lines showing the parcel boundaries, the blue line showing the boundaries of the buildings, and the cyan text showing the parcel numbers and (**b**) a condominium unit plan with the green lines showing condominium unit walls, red lines showing the condominium unit boundaries, and the pink text showing the elevations (Source: [52]).

It should be noted since the surveying engineers are now responsible for part of the building inspection process, the building survey project, building layout plan and condominium unit plan to be submitted for the establishment of the condominium may be considered as as-built plans rather than as-designed plans. Such plans can be used to support the 3D cadastre project that has been on the table in Türkiye for a number of years.

2.2. The Production of 3D City Models and Creation of 3D Cadastral Bases Project

The digitization process within the GDRLC began in the 1990s, similar to many other countries. *The Land Registry and Cadastre Information System* (in Turkish: *Tapu ve Kadastro Bilgi Sistemi*) project was launched in 2001 to digitize land registry records and cadastral plans. For the land registry records, the developed systems were put into use in 2005 (all records were digitized in 2012), while for the cadastral information, the desired result was achieved between 2009 and 2022 due to technical difficulties (e.g., the quality of cadastral maps) [54]. In addition, an open-source application has been developed in *the Spatial Property System* (in Turkish: *Mekânsal Gayrimenkul Sistemi*) project to harmonize land registry data with cadastral data in order to make it available to all stakeholders through a web map service, a web feature service and e-government services. According to the information provided in 2013, the success rate of web services in fulfilling requests, including system failures or technical problems, was calculated at 95% [55].

The digitization process was followed by the 3DCMCB, which mainly aims at (a) the production of 3D city models using photogrammetric methods for the identification of the entire building stock, (b) the production of 3D digital (vectoral) building models using architectural plans for the identification of legal spaces in condominium buildings and for the efficient management of RRR, (c) the development of the national digital building model standard based on the definitions of OGC's CityGML and the creation of a national 3D building database, (d) the integration of the 3D digital building model (database) with cadastral, address, development plan and valuation information, (e) the creation of a web-based service to disseminate 3D information produced to all stakeholders, and (f) the development of a framework for achieving sustainable and up-to-date 3D land administration systems [41,56,57]. As this is a long-term and ongoing project, not all objectives have been achieved throughout the country by the beginning of the second half of 2024. However, some pilot studies have been completed in some provinces. For example, Figure 4 shows the 3D city model of Amasya province with some data from the cadastre (e.g., building identifier, parcel identifier, parcel area, building height, registration information, etc.) [58]. In addition, the GDLRC has been successful in producing 3D building models in some provinces and has developed a CityGML-based building model standard that has been used to produce all 3D digital buildings. Figure 5 shows the photogrammetric model and architectural model of a 3D building that was produced by the GDLRC as part of the same project.

Figure 4. 3D City Model of Amasya province with cadastral data [56,58].

Figure 5. The photogrammetric (**left**) and architectural (**right**) model of a 3D building produced by GDLRC, adapted from [56].

As mentioned previously, the project has several objectives, some of which the GDLRC has started to realize. Specifically, aerial images were taken in various provinces to produce true orthophotos, point clouds, Digital Surface Models (DSM), Digital Terrain Models (DTM), and also to create vector data for 3D building using photogrammetric methods [43]. The 3D (photogrammetric) building data produced were then textured to create more realistic city models. Furthermore, the production of 3D digital building models has started by digitizing architectural drawings (each floor plan has been digitized) in various provinces. The external surfaces of the buildings were digitized first, then each floor, each condominium unit, each room in condominium units, each accessory part and common space were digitized using architectural drawings in a way that can be used to create 3D digital building models. Figure 6 presents the workflow followed in the project to create 3D city models and 3D digital building models, and integrate the two models with each other and other data sets [43,57]. Figure 7 shows an example of a 3D digital building model including (vectoral) floor plans (Figure 7a) and rooms of a condominium unit (Figure 7b), and the 3D digital building model (Figure 7c) [43].

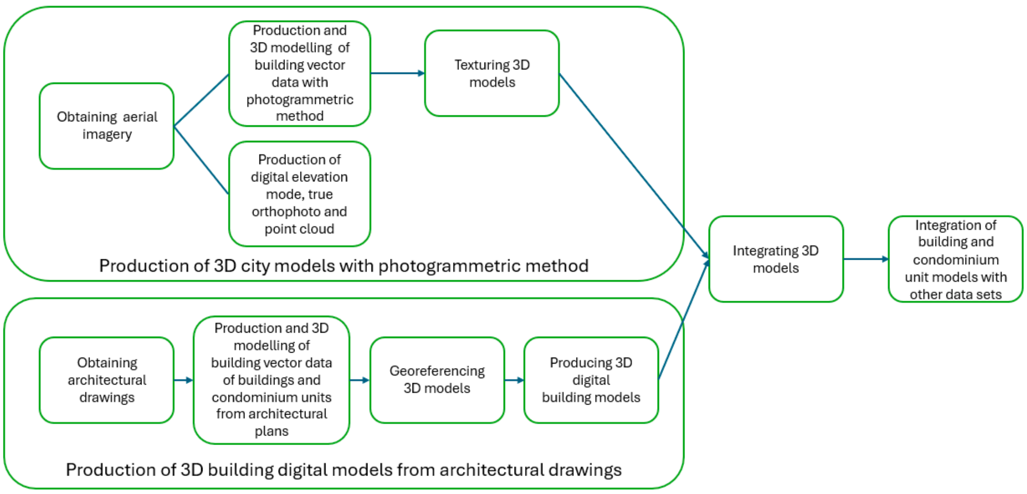


Figure 6. The workflow followed to create 3D city models and 3D digital building models (Source: [56,57]).

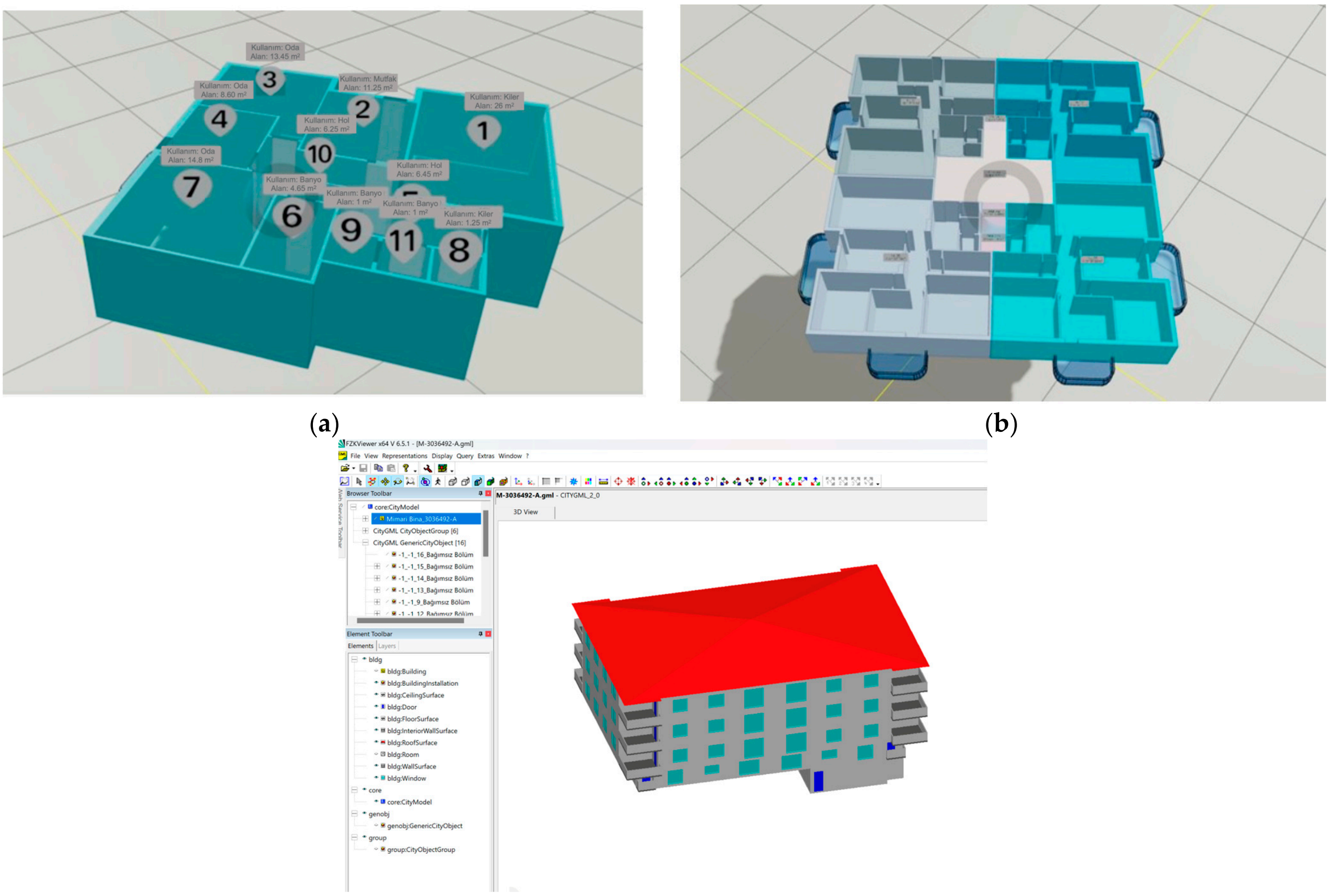


Figure 7. 3D digital building models including (**a**) floor plan and (**b**) the rooms of condominium units (**c**) 3D digital building models (Source: [43,59]).

One of the objectives of the project is to develop the national standard for 3D digital building models. The GDLRC has developed a data model (i.e., GDLRC-CityGML) based on the OGC CityGML structure. The 3D building models encoded in the geography markup language (GML) are first verified, and then the 3D digital building models are recorded in the GDLRC's 3D database, which incorporates the CityGML data model structure [57]. Both 3D city models and 3D digital building models are structured using the GDLRC-CityGML model and recorded into the database [59].

CityGML is designed as a universal information model, defining object types and attributes useful for many applications. On the other hand, some objects and attributes required for a specific application may not be included in the CityGML conceptual model, but CityGML provides three concepts for extending its model: (a) the generic extension of CityGML with either objects or attributes using the Generics module, (b) the Application Domain Extension (ADE) for specifying extensions to the CityGML conceptual model, and (c) the extension of CityGML with respect to the allowed values specified in code lists [60]. The difference between ADEs and generic objects and attributes is that an ADE has to be defined in an extra conceptual schema (provided in UML) with its own namespace, and the advantage of the ADE approach is that the extension is formally specified [60]. The generic objects and attributes approach is used when developing the GDLRC-CityGML data model. Table 1 presents the details of the GDLRC-CityGML data model and its relationship with CityGML, compiled from [59]. The first column presents the objects of GDLRC-CityGML model while the second and third show which CityGML schemas and classes are related to the objects of GDLRC-CityGML, respectively. The fourth column describes which class is used for including semantic information (e.g., attributes) of the objects of GDLRC-CityGML. The last column represents the definitions of the GDLRC-CityGML objects [59]. The definitions also include the principles used in the digitization of floor plans of architectural drawings. When digitizing the floor plans, each object is digitized in a different layer. It should be noted that each object of GDLRC-CityGML should be digitized in a separate layer [59]. The 3D digital building data produced in this project is structured using the GDLRC-CityGML model, exported as GML and recorded in the GDLRC database.

Table 1. The details of the GDLRC-CityGML data model and its relationship with CityGML (compiled from [59]).

GDLRC-CityGML Objects	CityGML Schema	CityGML Class	Semantics (Related Class)	Definitions of GDLRC-CityGML Types
Fotogrametrik Bina (Photogrammetric Building)	building	Building	genericAttributes (Building)	Buildings identified by the photogrammetry operator using orthophoto maps, land model, cadastral parcel/structure, address register, building services and, if available, architectural drawings associated with the parcel.
Mimari Bina (Architectural Building)	building	Building	genericAttributes (Building)	It represents digital buildings generated from architectural projects. In the architectural building, the block number, entrance number, floor number and condominium unit number are taken from the architectural project. Boundaries of the outer walls should be used in the digitization.
Bina (Building)	building	Building	genericAttributes	-
Kat (Floor)	core	CityObjectGroup	genericAttributes (cityObjectGroup)	It is the type that collects geometric and semantic information about floors of 3D building models created by digitizing the architectural project. Boundaries of the outer walls used in the digitization of the floor plan. When digitizing each floor from architectural drawings, the boundaries of the exterior walls are used. When drawing the outer boundary of the floor, details such as projections and recesses that do not affect the condominium units and remain below 50 cm are not shown.
Bağımsız Bölüm (Condominium Unit)	generics	GenericCityObject	genericAttributes (GenericCityObject)	It is the type that collects geometric and semantic information about condominium units of 3D building models created by digitizing the architectural project. When digitizing condominium units, the boundaries of the exterior walls are used.
Bağımsız Bölüm Kısım (Condominium Unit Part)	building	Building/ interiorRoom	genericAttributes (Room)	This type is used to collect the features of the condominium units of the 3D building models to be produced by the digitization of the architectural project, such as rooms, living rooms and bathrooms. The interior walls of the rooms are used when digitizing the floor plans. The floor area of each part is taken from floor plans of architectural drawings. If the floor area indicated in the floor plan of the architectural drawings and the measured floor area from the digitized floor plan differ by more than 10%, the measured area is used, stating the reason.

Table 1. *Cont.*

GDLRC-CityGML Objects	CityGML Schema	CityGML Class	Semantics (Related Class)	Definitions of GDLRC-CityGML Types
Ortak Alan İç Yapı (Common Space Inside Condominium Unit)	building	Building/ roomInstallation	genericAttributes (intBuildingInstallation)	It represents the types of structures that cannot be physically separated from the rooms within the condominium unit, such as columns and stairs.
Ortak Alanlar (Common Spaces)	building	Building/ interiorRoom	genericAttributes (Room)	It is the type that represents common spaces in buildings such as car parks, heating centers, electrical centers, cellars, water tanks and shelters. The interior walls of the common spaces are used when digitizing the floor plans. Non-qualified common areas (e.g., stairs, ventilation, main entrance, elevator) that are adjacent to each other are digitized as a single area.
Balkon (Balcony) and Teras (Terrace)	building	Building/ OutherBuilding Installation	genericAttributes (BuildingInstallation)	This is the type that shows the floor and the side walls of the balcony and the terraces. The external wall boundary and the wall thickness of the balcony should be taken into account in the digitization process.
Kapı (Door)	building	Opening/Door	-	It is the type that shows openings used by people to enter buildings or rooms.
Pencere (Window)	building	Opening/Window	-	It is the type used to represent openings that open outwards or between two parts.
Çatı (Roof)	building	Building/ RoofSurface	-	It represents the type created by drawing the outer boundaries of the roof plan in the architectural drawings. It is combined with roof types obtained by the photogrammetric method.
Bina Duvar (Building Wall)	building	Building/ WallSurface OuterFloorSurface InteriorWallSurface	-	It represents the wall type of the buildings.

The 3D digital building models were and are being created from architectural drawings for the existing building stock. For the new buildings, as stated in Section 2.1, a 3D digital building model and a building survey project are required for condominium registration [44], and from March 2023, this requirement has started to be implemented in some districts of Ankara, Türkiye. As of June 2024, it has become mandatory in about 25 provinces, and it is expected that the nationwide application will be activated in the following months.

The architectural drawings must be sent to the land registration office for the registration of a condominium or a provisional condominium (see Section 2.1) since the first version of the Condominium Law [46]. In the Administrative Activity Report 2023 of the GDLRC [61], it is indicated that the pilot project performed in Gölbaşı district of Ankara includes 13937 buildings. Of these, architectural drawings are available only for 4930 buildings, while architectural drawings for 9007 buildings are not available in the local land registration offices. Furthermore, [43,56] states that there are a total of 18,577 buildings in the other pilot project area, Amasya, but a total of 3854 3D digital building models could be created from architectural drawings. It should be noted that the integration of 3D digital building models with land registry, cadastre, public restriction data, address registry and implementation development plan data was carried out and completed in Amasya [43,56]. The approach used in the Amasya pilot project to integrate separate data sets (database) is expected to be applied to the ongoing and planned production of 3D city and digital building model studies in other provinces. Furthermore, a web-based visualization prototype has been published to represent a textured 3D city model of Amasya together with some integrated data (e.g., building identifier, parcel identifier, parcel area, public law restriction, registration information and so on), see Figure 4. The visualization prototype has been developed as open-source code based on HTML5, CSS3, JavaScript, WebGL and ReactJS technologies [56]. As part of this prototype, the 2D map applications were prepared using the Leaflet JS API, while the 3D globe application was developed using the Cesium JS API. The presentation of 3D tiles (b3dm) and 3D data in I3S format have also been prepared to work on Cesium JS [56]. The Amasya 3D city model is being shared with the above-mentioned structure (see Figure 4), while the 3D digital building models are not being shared online with all stakeholders. It is expected that the 3D digital building models will only be shared with relevant stakeholders and the owner(s) of the condominium unit, who may also share them with others.

The plans for the project are included in the 2024–2028 Strategic Plan of the GDLRC [62]. The two main objectives of the project stated in the report are (a) the acquisition of aerial imagery for the production of 3D city models and orthophoto maps, and (b) the production of 3D city and digital building models. The strategic plan also includes some specific targets for the project. For instance, the number of parcels for which 3D city models, cadastral data and other relevant data (e.g., address, implementation development plans, public law restriction, valuation) will be integrated is expected to be 5 million. One of the plans is to complete the production of 3D digital building models in 1000 districts by 2028. This is almost equivalent to the total number of districts in Türkiye, including the central districts. It should be noted that the identification of legal spaces in condominium buildings for the efficient management of RRR is not included in any of the above-mentioned future planning documents.

3. Legal, BIM Data and Visualization Requirements for 3D Cadastre in Türkiye

This section is divided into three subsections. The first subsection lists the legal requirements derived from the information given in Section 2.1. This is followed by Section 3.2, which specifies the information required from a BIM/IFC file in order to derive legal spaces from physical ones. The last subsection presents the requirements derived from the scientific literature for the development of a 3D cadastre visualization prototype that includes legal (e.g., private, common) and physical objects.

3.1. Legal Requirements

The Condominium Law [46] does not explicitly express the boundaries of condominium units, common spaces and accessory parts; however, the examples given in the law enable that the legal spaces (boundaries) in a condominium building can be derived. In other words, the Condominium Law implicitly states the boundaries of legal spaces in condominium buildings. Furthermore, architectural drawings and condominium deeds can provide information on whether a space is designated as a common space or an accessory part.

It should be noted that the Land Registry and Cadastre Technical Works Offering Circular [63] published in 1948 contains a statement on how the boundaries of condominium units should be determined: "*In the sketches of the ground floor and other floors, the boundaries of the condominium shall be measured from the inside of the walls, excluding the external and internal walls of the building and the walls around the land, and the thickness of these walls shall be indicated in these sketches*". However, this statement was unfortunately not taken into account in the drafting of the Condominium Act.

According to the information given in Section 2.1, the following requirements are derived from the legislation on the legal areas in condominium buildings:

- the inner face of walls should be used when drawing the legal boundaries (spaces) of a condominium unit or an accessory part of a condominium unit.

- if a space in a condominium building is not designated as a condominium unit or an accessory part, then it should be considered a common space.
- all the walls outside a condominium unit, all main walls and the walls separating the condominium units should be considered common spaces
- common spaces include, but are not limited to,
    - all the structural components (e.g., foundations, main walls, beams, columns, bearing walls forming the load-bearing system, other elements forming part of the load-bearing system, walls separating condominium units, ceilings, floors; roofs, chimneys, common roof terraces, rain gutters and fire escapes);
    - joint facilities (e.g., courtyards, entrance doors, entrances, stairs; elevators, landings, corridors, caretaker's rooms, laundry rooms, laundry drying rooms; coal cellars, common garages);
    - installations outside the condominium units (e.g., slots and closed installations for the protection of electricity, water and gas meters; heating rooms, wells, cisterns, common water tanks, shelters, sewers, rubbish chutes; heating, water, gas and electricity installations; common networks and aerials for telephone, radio and television; hot and cold air installations);
- accessory parts (e.g., parking space, cellar) that are indicated in the architectural drawings and/or the condominium deed should be considered as accessory parts.
- all of the above requirements should be supported by architectural drawings, building survey projects, building layout plans and condominium unit plans in order to support as-built BIM-based 3D cadastre.

3.2. BIM Data Requirements

In the case study presented in this paper (Section 4), the features and annotations in an architectural drawing obtained in the CAD environment are converted into the BIM/IFC data format that is used to derive legal spaces in condominium buildings (see Section 4). Ideally, the BIM/IFC data to be used as the source for the legal spaces are expected to meet all the requirements specified below. In this case, the legal spaces in condominium buildings can be derived automatically.

According to the authors, in order for BIM/IFC data to be utilized for the purpose of sourcing legal spaces in condominium buildings, it is essential that the following objects and annotations be included:

- All space-bounding physical objects, such as the structural components, including load-bearing walls, floors, and columns, as well as the architectural features, such as the roof, and non-load-bearing walls, should be represented with their true (scaled) dimensions as specified in the architectural drawing.
- The representation of all walls should include their functions, particularly whether or not they are main walls (e.g., exterior) and/or load-bearing.
- Space-bounding physical objects should not overlap.
- Spaces should be delineated by the interior boundary faces of the abovementioned space-bounding physical objects. If the spaces are not related to a physical object, then virtual boundaries should be specified.
- It may be beneficial to annotate rooms with the type of use indicated by the architectural drawing in order to provide users with further information regarding the 3D spaces.
- It is recommended that the spaces be grouped according to the condominium units to which they belong.
- All physical objects and spaces, including those extending from the lowest to the highest points of the building, should be separated and associated with the relevant storeys (levels).
- The elevations of the storeys should be stated.

3.3. Visualization Requirements

Several studies have investigated the expectations of an effective visualization prototype for a 3D cadastral system [15,28,40,64–66]. The requirements are selected within the scope of this research considering the life cycle in land administration [67]. Since the main purpose of this visualization prototype is to serve the legal spaces of condominium buildings, which are derived from physical structures, and physical objects along with their attributes, the requirements were determined mainly considering the legal background (Section 2.1) in Türkiye. The main requirements for the visualization and dissemination of 3D legal and physical objects derived from the literature analysis and the legal situation in Türkiye are listed below:

- the parcel on which the condominium building is built should be identified. Annotations and attributes (e.g., identifier, area and so on) on the parcel should be included;
- the georeferenced condominium building should be identified. Annotations and attributes (e.g., identifier, area and so on) on the condominium buildings should be included;
- the private (main part) space of the condominium unit should be identified. This can be carried out by grouping each part (e.g., rooms) of the private space into one space. It should be noted that the rooms have no legal significance [68]. On the other hand, by grouping all rooms into one space, the legal space of the condominium unit can be created;
- the common spaces should be identified. Annotations and attributes (e.g., identifier, area and so on) on the common spaces should be included. Grouping all common spaces into one may help users to better understand these spaces;
- the accessory parts should be identified. Annotations and attributes (e.g., identifier, area and so on) on the accessory parts should be included;
- the condominium unit and the accessory part(s) should be associated (grouped) for a better understanding of the private ownership spaces together;
- spaces above and below ground should be identified;
- all spaces in condominium buildings should be topologically consistent;
- the legal spaces should be visually distinguished from the physical objects in 3D;
- having the option to visualize both the legal space of condominium buildings and physical building objects in the same prototype system can further support effective visualization and dissemination.

Since one of the purposes of this research is to develop a web-based 3D visualization prototype, a platform should be selected to serve the data. In this paper, the open-source JavaScript library Cesium is chosen, which is preferred in 3D city models and 3D digital building model studies carried out at GDRLC (see Section 2.2) and is the most used platform for presenting 3D data in the land administration literature. In the case study, legal spaces and physical objects produced in BIM/IFC format are converted to 3D tiles format and presented on the web using Cesium.

4. Case Study to Form Legal Spaces and Develop a Web-Based 3D Cadastre Prototype

A five-story condominium building in Ankara, Türkiye, was selected as the case study for the creation of legal spaces and the visualization of these spaces together with the physical objects of the building. In this context, the architectural drawing is employed as a foundation for examination, along with the layout plan and the condominium unit plan.

Firstly, the physical elements and annotations from the CAD-format architectural drawing are represented within the BIM environment using the Revit 2025 software tool, resulting in the provision of BIM data in IFC format. Subsequently, Safe FME software (version 2024.1.0) is employed to create legal spaces and convert the data into 3D tiles format for visualization purposes. Lastly, Cesium JS (version 1.74) is used for geovisualization. The geovisualization prototype is available online https://3dlandadministration.github.io/BIMLegalSpace/ (accessed on 25 August 2024). The methodology is described in the following subsections.

4.1. Preparation of the Data—Depicting Physical Objects and Basis of Legal Spaces

The building layout plan, which was obtained in CAD format, contains the coordinates of the corner points of the land parcel and the border within which construction is permitted. Therefore, the building layout plan is employed for the purpose of georeferencing the project site in accordance with the official reference system of Türkiye. Subsequently, the five floors, from the basement to the attic level, were created based on their relative height information. For each floor, the physical elements of the building, including walls, floors (slabs), columns and beams, and roof, along with non-structural elements such as doors, non-bearing walls, and stairs, were digitally transferred to the BIM environment using Revit. In this process, the objects, their horizontal and vertical locations, and their dimensions, as specified in the floor plans in the architectural drawings, were accurately reflected in the BIM. The physical elements are spatially joined with one another in order to prevent overlap and ensure accurate determination of the areas and volumes of the legal spaces.

In order to indicate whether a wall is external and/or load-bearing, the IsExternal and LoadBearing attributes of the wall type are used, respectively. The properties of walls are represented by the property set called Pset_WallCommon, which defines the properties common to the definition of all occurrences of IfcWall. Figure 8 demonstrates an extract of the IFC data file, relevant for representation of IsExternal and LoadBearing properties of the IFCWALL instance with id #17585. The relationship between the wall and its properties is represented by IfcRelDefinedByProperties, with an id of #17629.

```
#17629=IFCRELDEFINESBYPROPERTIES('157Ky6nQwIj7NM3a9TVza$',#18,$,$,(#17585),#17607);
#17585=IFCWALL('2105yTlWHExwVkp7XR96r9',#18,'Basic Wall:Generic - 250mm Ext:230057',$,'Basic Wall:Ger
#17607=IFCPROPERTYSET('3$F2MSIP1G9nWTTGZb$V9I',#18,'Pset_WallCommon',$,(#13707,#13711,#13712
#13711=IFCPROPERTYSINGLEVALUE('IsExternal',$,IFCBOOLEAN(.T.),$);
#13712=IFCPROPERTYSINGLEVALUE('LoadBearing',$,IFCBOOLEAN(.F.),$);
```

Figure 8. IFC data file extract showing the representation of properties of an IfcWall object (green) by Pset_WallCommon property set (blue) and its values (yellow).

All physical entities, including walls, floors/ceilings, structural columns, and roofs are specified as space-bounding (or room-bounding in Revit) elements. Once the space-bounding physical building elements are placed, spaces are defined in each storey as illustrated in the architectural drawing, including the balconies and terraces. The height of spaces is defined in accordance with the height of the floors to which the spaces in question belong. This height is measured from the top surface of the floor to the bottom surface of the floor above. For instance, in the case of the first and second floors, this measurement is 2.9 m minus 0.15 m (the thickness of the slab above), as illustrated in Figure 9. An exception to this measurement occurs with terraces on the attic level, where the height is considered equivalent to the floor height of the preceding story. The areas and volumes of spaces are stored in IFC by the quantity set named "Qto_SpaceBaseQuantities" which defines the base quantities for space elements.

In order to reconstruct the condominium legal space, it is necessary to delineate the boundaries of each condominium unit in the condominium building. These boundaries are formed by the inner boundaries of the enclosing walls. As previously stated in Section 2, the exterior walls, the walls separating the condominium units, the columns, the slabs, the floors, and the areas designated for common use by the condominium unit owners and the walls separating these areas, collectively constitute the common spaces. In essence, a condominium legal space is comprised of the (non-load bearing) interior walls and enclosed spaces, or rooms, within a given unit. Accordingly, in order to ascertain which spaces are allocated to which condominium units, it is necessary to group together the individual spaces and walls that are associated with a specific unit. Consequently, zones (HVAC Zones in Revit), which are collections or groups of spaces, are created for each condominium unit by assigning relevant space units (i.e., rooms) to each zone in accordance with the condominium unit plan and architectural drawing. The names of the zones are given the designation "CU_Number", with the number indicating the condominium unit id in the condominium unit plan/architectural drawing (Figure 10).

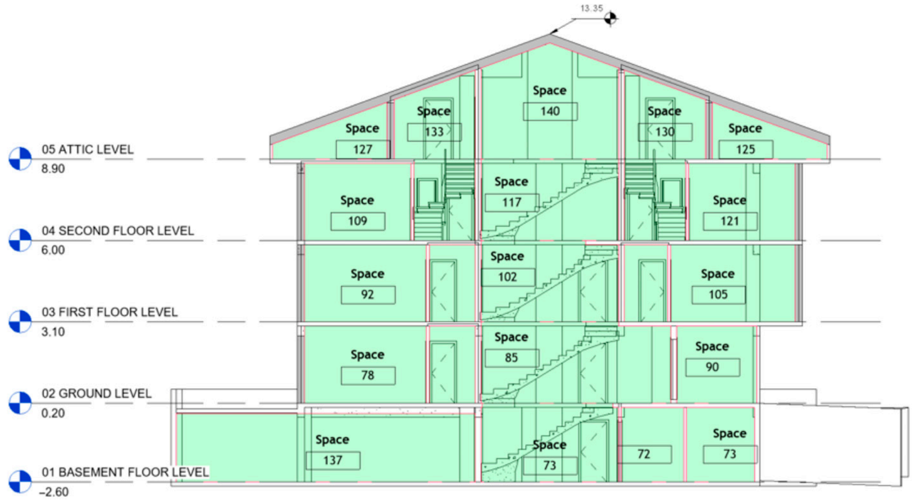


Figure 9. Section view of the building, illustrating the elevations of levels and spaces.

The BIM in Revit is exported to IFC 4.0 reference view model view definition. The export setup included 1st level space boundaries, splitting walls and columns by level, and exporting property sets and base quantities (quantity sets). The spaces defined in Revit are translated to IFC as "IfcSpace", walls as "IfcWall", columns as "IfcColumn", floors as "IfcSlab", beams as "IfcBeam", and zones as "IfcZone".

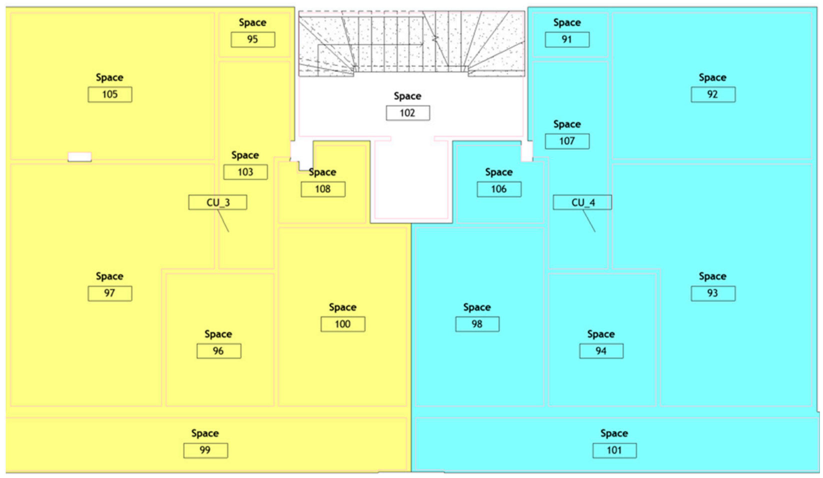


Figure 10. Zones representing condominium units and spaces shown in the floor plan view of the first floor level. Yellow and blue represent condominium unit numbers 3 (CU_3) and 4 (CU_4), respectively.

4.2. Producing Legal Spaces and Geovisualization

Once the BIM in IFC-format has been provided and has addressed the requirements described in Section 3.2, the subsequent step is the definition of legal spaces, followed by providing a geovisualization prototype along with the physical objects. In order to achieve this objective, it is necessary to process the data in IFC format and perform certain edits to the geometry and attributes. Appropriately, a workspace is generated and employed using Safe FME software, which is available online: https://github.com/azerilgar/legalbim (accessed on 25 August 2024). The primary geometric operations employed include filtering or extracting 3D geometries ('Body') and merging or combining pertinent features. Attribute editing is primarily utilized for joining or merging property and quantity sets with the entities of IFC and recalculating the dimensions of constructed legal spaces.

The classification of all spaces and walls according to their legal space type (condominium unit space or common space) is a crucial step in defining legal spaces. In order to categorize the spaces according to whether they are located within a condominium unit or common area, the aforementioned grouping mechanism, namely the zones (IfcZone), which are the spaces grouped by condominium units is employed. In other words, the space elements belonging to a zone are considered to be situated in a condominium unit legal space, whose ID is the relevant zone object's "Name" attribute value. The process of categorizing spaces and walls according to the legal space of which they are a part is illustrated in Figure 11.

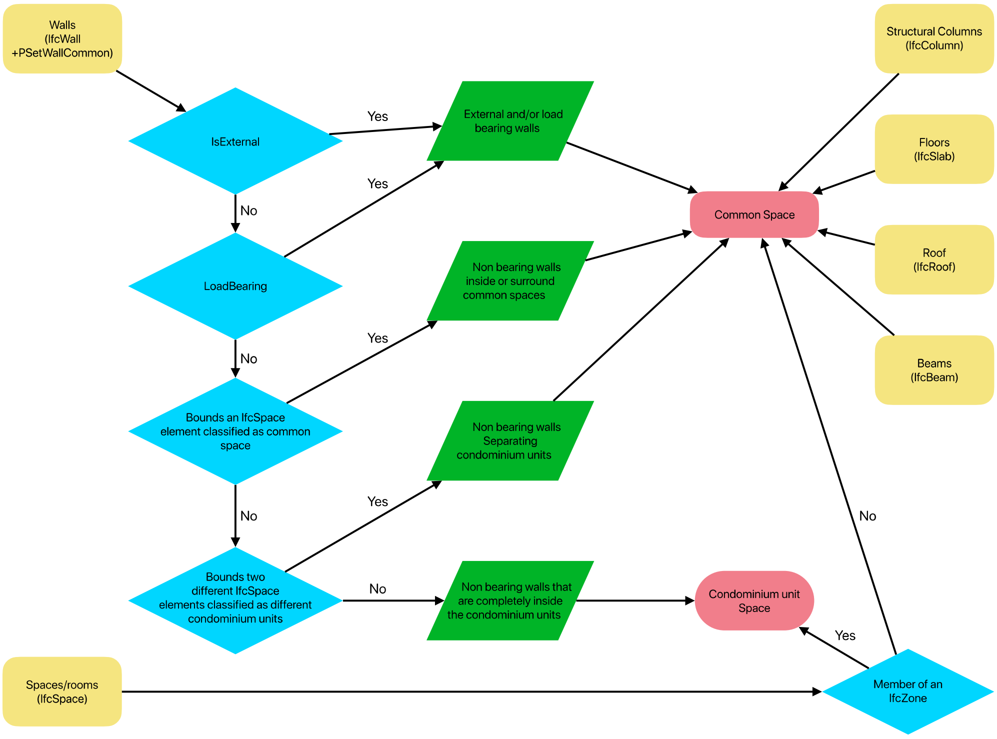


Figure 11. The process of categorizing rooms and walls according to the legal type to which they belong (yellow represents the physical objects and their IFC correspondences, blue represents properties of physical elements, green represents walls according to the legal space types to which they belong, and pink represents the legal spaces).

Once the IFCSpace elements pertaining to condominium units and common spaces have been defined, it is possible to ascertain the type of legal space to which walls belong. In condominium buildings, the exterior or load-bearing walls are to be considered common spaces. Accordingly, the "IsExternal" and "LoadBearing" attributes of the "IfcWall" type (provided by the "PSetWallCommon" property set) are checked. Consequently, walls with an attribute value of "Yes" for these attributes are regarded as common areas. The remaining walls are non-bearing walls within the building. These comprise walls that: (i) are in or surround common spaces, (ii) are within condominium units, or (iii) separate condominium units from each other. In order to identify the walls that fall into the first category, it is necessary to first determine which walls enclose a common space or form the boundary of a common space. As the common spaces (rooms) have already been identified, the walls that are associated with these common spaces can then be identified using the IfcRelSpaceBoundary relation, which provides a one-to-one relationship between an element or a virtual boundary and the space it bounds. The remaining walls can either be within condominium units or separate condominium units from each other. Again, using the space–element pairs defined by the IfcRelSpaceBoundary, walls separating the condominium units and walls within condominium units are identified, by grouping the walls that form a boundary for a space belonging to two different condominium units as common spaces. After this grouping, the remaining walls that are inside the condominium units are considered to belong to the condominium unit (legal) spaces.

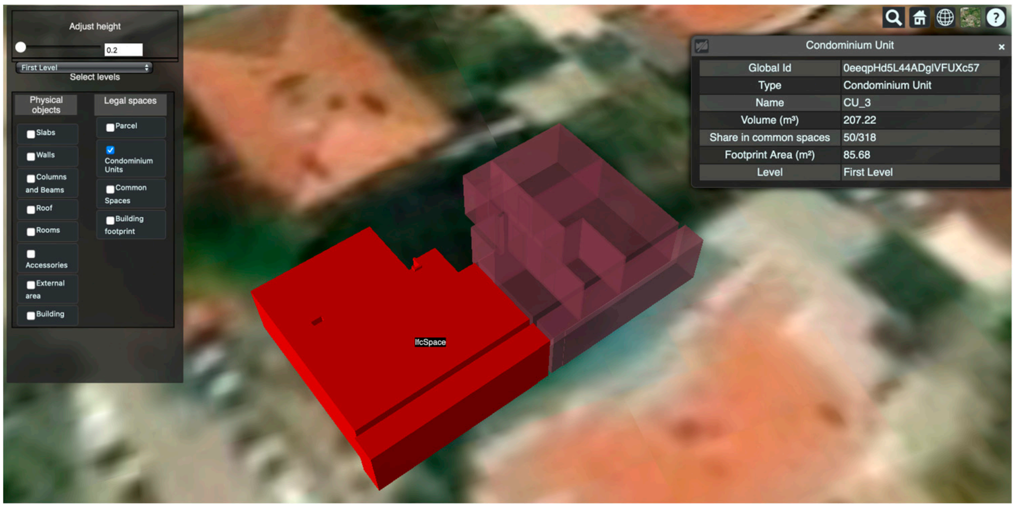
Consequently, the walls and spaces (or rooms) located in condominium units are merged to represent the legal space of the condominium unit. In a similar manner, other walls, structural columns, common spaces (rooms), and floors collectively constitute the common spaces. The areas and volumes of these legal spaces are then calculated. Finally, the physical building objects and the legal spaces are then transformed into 3D tiles format. Subsequently, the geovisualization prototype is created using Cesium JS.

4.3. Web-Based 3D Cadastre Prototype for Geovisualization

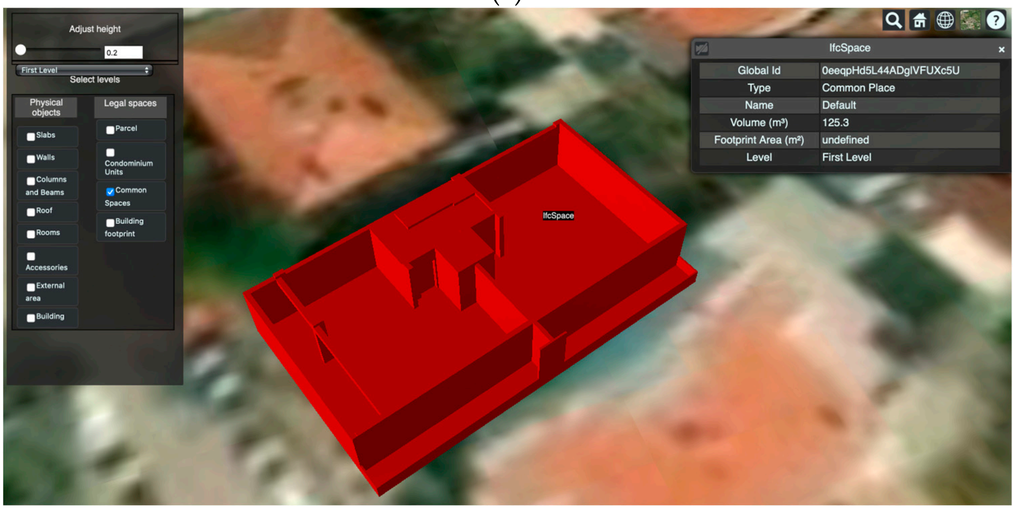
The prototype enables the visualization and identification of legal spaces and physical objects, thereby supporting the requirements set in Section 3.2. The prototype incorporates a panel comprising two sections, one for physical objects and the other for legal spaces. Each section contains checkboxes that enable the user to control the visibility of entities. As the objects are defined in reference to the levels (or floors) within the BIM, the visibility of entities can be set at the requisite level through the use of a drop-down menu. Furthermore, the elevation of the entities can be adjusted to enhance their visibility, particularly for those situated underground.

In the panel section dedicated to legal spaces, the visibility of the legal spaces can be controlled. This encompasses condominium unit spaces, common places, the footprint of the building, and the land parcel. The land parcel and building footprint are represented in the prototype with their locations and identity information, as obtained from the building layout plan. The legal spaces of condominium units are comprised of rooms within the condominium units, and the interior (non-load bearing walls) walls that delineate these spaces. Consequently, the area or volume of a condominium unit is determined by the sum of all rooms' and interior walls' area or volume. Accordingly, the physical elements defined as common space by the legislation should be excluded from the net area or volume of the condominium unit. The attributes of condominium unit entities include footprint area (or net floor area), type of legal space (e.g., condominium unit or common space), name, volume, share in common space, and name of the level that the condominium unit resides on. Figure 12a depicts condominium unit number 3 on the first floor, whereas Figure 12b illustrates the physical building elements on the same floor. It is notable that the balconies are included within the condominium space, while all walls surrounding them are classified as common spaces.

The panel section for physical objects comprises slabs, walls, columns, beams, roofs, rooms, and external areas, as well as doors, windows, stairs, and railings, which are grouped under the label of "accessories." Additionally, the building itself, which is treated as a single object, is included. The attributes of the physical objects include the object's unique identifier, its type, the area and volume of the object, as well as information regarding the legal space type to which the object belongs. To illustrate, the prototype includes rooms as physical objects with no legal significance, yet the legal space in which they are situated can be identified (see Figure 13a). An additional illustration is shown in Figure 13b,c, where the walls, as physical objects, comprise data regarding their classification, which were previously utilized to determine the legal space to which they belong. This information implies that the objects are situated in a common space or a condominium unit.



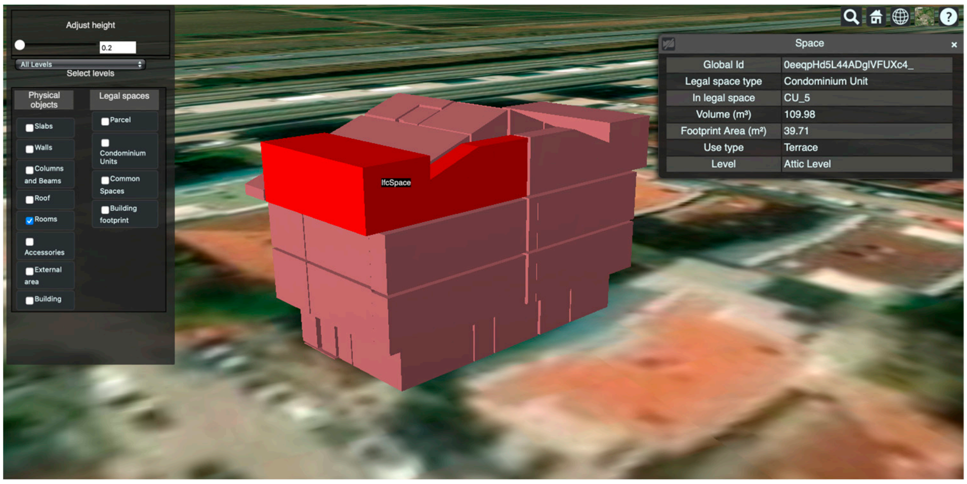
(**a**)



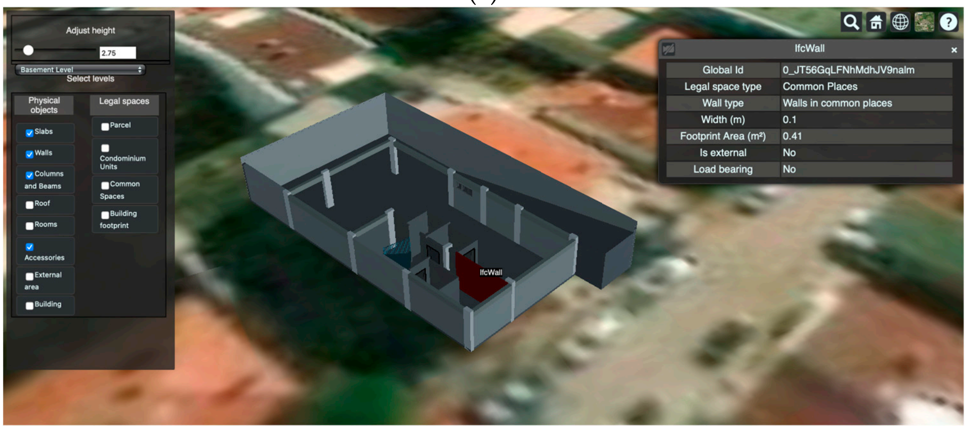
(**b**)

Figure 12. Legal spaces in geovisualization prototype (**a**) condominium unit space, (**b**) common spaces.

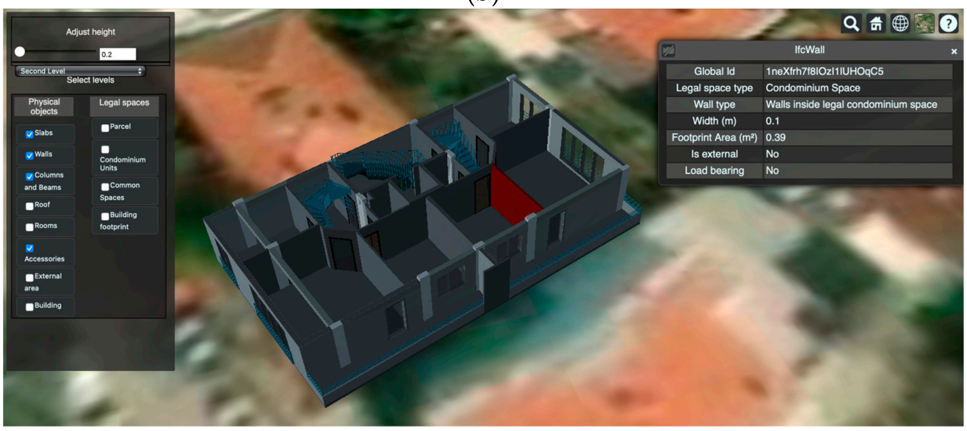
It can be concluded that the methodology described herein demonstrates the viability of utilizing BIMs as a source for derivation of legal spaces, in accordance with the requirements specified in Section 3. Furthermore, the 3D visualization prototype presents a concurrent representation of legal spaces and physical objects, facilitating an enhanced understanding of their interrelationships.



(**a**)



(**b**)



(**c**)

Figure 13. Physical building elements with their legal space types. (**a**) terrace which belongs to condominium number 3 (**b**) a wall in common space (**c**) a wall in condominium space.

5. Discussion

The connection between 3D models of the physical world and 3D models of legal entities has become much more apparent with advanced 3D capture techniques and the availability of detailed BIMs [69]. BIM data, together with legal information, can be a solid source for deriving legal spaces in condominium buildings. In order to form legal spaces in condominium buildings, physical objects can be used as a source, as the legal spaces and physical objects coincide with each other in the case of condominium buildings in Türkiye. To derive legal spaces from BIM the following steps can be simply taken: (a) obtain BIM data (they should include physical building elements with their true dimensions and annotations for all floors of the building, see Section 3.2) (b) RRRs information is incorporated with the BIM data, using the building layout plan or building survey project (c) boundary surfaces of the legal spaces (e.g., condominium unit space, common space, accessory) are specified and the legal spaces are formed, and (d) condominium units are grouped (zoned) with their accessory parts (if any) and also the common spaces may be grouped (zoned). However, this flow may not be ideal for complex situations.

In recent years industry has started to use BIM in large contraction projects in Türkiye. Moreover, a number of public institutions put BIM into their strategic plans. For instance, "Energy Efficiency 2030 Strategy and II. National Energy Efficiency Action Plan (2024–2030)" published by the Ministry of Energy and Natural Resources indicates that the BIM (BIM/IFC) approach will be taken into consideration in the construction processes of newly designed public buildings [70]. On the other hand, it is not easy to find properly structured and annotated BIM data from today's construction companies. This is one of the problems faced in this research. Since it was not possible for the authors of this paper to find proper BIM data (and also to be able to create an application that is compatible with the approach that is being used by the GDLRC), the floor plans of architectural drawings are first 3D modelled and annotated considering the requirements identified in Section 3.2.

From the legal point of view, a number of decisions are made in the case study. Since the legal boundaries are not explicitly indicated in the relevant legislation, some inferences need to be made for forming legal spaces. For example, in the Condominium Law, the wall separating the condominium units is determined as common space. Therefore, the inner face of walls is used when specifying the legal boundaries of condominium units. One other issue about the legal boundaries is about balconies and terraces. As it is not possible to make an inference from the legislation for the legal boundaries of balconies and terraces, the following approach is used: (a) the inner face of most exterior wall is used when specifying the legal boundaries of balconies and terrace, and considering the walls of the balconies and terraces as common places (b) The vertical extent of the legal boundaries for balconies and terraces is regarded as equivalent to the height of the legal space of the condominium unit. It can be argued that to avoid this confusion, a regulation should be enacted to clearly define legal space.

In order to define the condominium boundaries, it was necessary to manually group together the space units, rather than overlaying the condominium unit plan with the floor plans. This latter approach would be a more automatic way of grouping, but it was not feasible in this instance. The reason for this lies in the fact that the condominium unit plan depicts each individual condominium unit on each floor, yet it provides only the coordinates of the building footprint in addition to the relative elevation of each floor. Furthermore, the condominium unit plan does not include the balconies. It is also important to note that the footprint of a floor may differ from that of the ground floor. Consequently, superimposing the condominium boundaries with the floor plans of the architectural drawing with the objective of delineating the boundaries of each condominium unit in the condominium building may be an inadequate approach. The availability of an official document that accurately depicts the legal condominium boundaries would facilitate the automation of the formation of legal condominium unit spaces.

The geovisualization prototype illustrates legal spaces grouped by each floor. Therefore, the roof, which is situated on the top of the last floor, is included in the last floor's common space. Consequently, the visibility of features located beneath the roof is challenging. To enhance this aspect, the appearance of the features is made transparent; however, this results in difficulties in distinguishing between the objects. As a potential solution, the roof itself may be regarded as a legal space that is independent of the levels.

One of the limitations of this research is that the case study is only conducted for one condominium building due to the difficulty in accessing BIM data and architectural drawings. Therefore, the authors could not find a way to implement all the requirements within the case study. For example, the requirement "group main part and accessory part(s) of condominium unit" could not be implemented in the developed prototype because there are no accessory parts identified in the condominium building used in the case study. In addition, the BIM data requirements (see Section 3.2) are identified with regard to the case study. This may also be considered as one of the limitations, as there may be many different cases of condominium buildings that should be considered before moving forward to a, for example, nationwide application.

The 3DCMCB of GDLRC can be evaluated as a big step forward in many respects, but the project should be strengthened and improved in some ways. First, creating 3D city models and publishing them on the Web for the entire country is one of the project's key objectives, as it allows identifying the entire building stock. The 3D city models make it easy to identify unregistered buildings, as there are a number of unregistered buildings in the land registry of Türkiye. One other big step is the developed national standard for 3D digital building models, namely the GDLRC-CityGML data model. The floor plans of architectural drawings are digitized using the rules defined by GDRLC (see Table 1) in order to produce 3D digital building data compatible with the GDLRC-CityGML model. The generic objects and attributes extension approach of CityGML is used when developing the model. This approach has some drawbacks over the ADE approach. The extension is formally specified in ADE while it is not possible in the generic objects and attributes approach [60]. The namespaces and inheritance are supported by the ADE approach which makes it flexible, easier to understand and direct support for using existing software [71]. While extending an open-source standard to develop a national data model is considered a good approach, there are some issues in the implementation. The fact that surveying engineers who are expected to produce 3D digital building models usually have little knowledge of architectural drawing interpretation, 3D modeling, and the GML format leads them to purchase commercial software that runs scripts developed by commercial companies for this process. Since the GDRLC does not provide software support, this can create an ecosystem that is dependent on commercial software, even though it has created an open-source data model and requires result products in GML format. Another issue is that only one type of data encoding is supported for the 3D digital building model required for condominium registration. Although the data model and encoding of GDRLC are open source, the BIM/IFC model has started to be used throughout the world and there are also some plans to use BIM/IFC in Türkiye, it would be reasonable to enable the submission of BIM/IFC data for 3D digital building model. Moreover, similar to the workflow presented in the case study, BIM/IFC data can be used to derive legal spaces in condominium buildings. Note that it was evaluated that the 3D digital building models produced by the GDLRC largely meet the requirements specified in Section 3.2. This means that 3D digital building models created in the GDRLC project can be consumed to form legal spaces in condominium buildings.

Requiring a 3D digital building model and building survey project for condominium registration is considered a reasonable step toward digitization and effective 3D land administration. However, the lack of architectural drawings for existing buildings causes some problems. The plot projects carried out in Amasya and Gölbaşı have shown that architectural drawings are not available for all buildings and the main reason for this is the unregistered condominiums. Therefore, it can be stated that it is not possible to create 3D digital building models for all existing buildings and this means that a nationwide application is not possible in the current situation. On the other hand, there have been some efforts by GDLRC to obtain or reproduce (e.g., by indoor mapping) the missing architectural drawings. As of July 2024, a 3D digital building model and a building survey project are required for condominium registration in about 25 provinces. It can be stated that it would be beneficial to implement it throughout the country. Another issue is that digitization may cause a decrease in the accuracy of the plans. Lastly, it should be noted that in the strategic plans of GDRLC for 2024–2028 [62] there is no statement about the determination of legal boundaries or the creation of legal spaces in condominiums. In the near future, it would be reasonable to start pilot studies on the implementation of 3D cadastre in the case of condominium buildings on the basis of the information collected in the 3DCMCB.

6. Conclusions

The digitalization of land administration started more than three decades ago, and this process is still going on at an increasing pace. This also increased the amount of research in 3D cadastral studies as some situations that cannot be represented in 2D can be represented in 3D such as RRRs in complex structures. Looking at the development of land administration from a broad perspective, it can be affirmed that digitization will continue until the last cadastral map and the last source data important for the cadastre (e.g., floor plans of architectural drawings) are digitized. The evolution and development of land administration systems vary widely around the world, depending on national legislation and technical and organizational capacity. Regardless of national capacity, however, decision-makers need access to efficient, geospatially accurate, legally binding 3D property information linked to a detailed 3D physical model. For effective and efficient property management, nations are seeking to develop or improve their 3D land administration systems.

In this paper, BIM/IFC data are used as a source to form legal spaces in condominium buildings in Türkiye. The floor plans of architectural drawings are first represented within the BIM environment considering the identified legal and BIM requirements to derive legal spaces (e.g., condominium unit, common space, accessory part) in buildings. Furthermore, a web-based prototype was developed based on the specified visualization requirements, with the goal of concurrently representing physical objects and legal spaces as distinct entities. This approach aims to enhance users' visual perception and improve the quality of communication. In addition, the current status of the 3D cadastre project carried out by the GDLRC, which has initiated the construction of a robust foundation for a 3D cadastre, is given and some proposals for further enhancements and resolutions of the project are made. The identified needs and the proposed methodology can assist policymakers in Türkiye and globally in formulating their strategic plans for 3D land administration. More specifically, the holistic analyses conducted in this research to determine the legal, BIM data and 3D geovisualization requirements can be used by countries that are evaluating their current data and future plans to pave the way for a 3D cadastre.

There are a number of issues which have not been the subject of in-depth investigation in this paper, and which may be the subject of future research. The organizational capacity for 3D cadastral developments in Türkiye should be studied to determine how to take further steps. The studies on national standards for digital building models should continue to be improved and it should be explored how to benefit from the international standards. Specifically, an ADE can be developed for the 3D digital building models and a BIM/IFC-based national standard can be developed. Finally, the prototype developed in this paper should be tested through usability tests to further improve the visualization of legal spaces in condominium buildings.

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Note

[1] According to the OGC's LandInfra/InfraGML (OGC, 2016), the term 'condominium building' is defined as "a Building containing CondominiumUnits and therefore subject to a single CondominiumScheme which may comprise more buildings" and the term 'condominium unit' defined as "a concurrent ownership of real property that has been divided into private and common portions" [13].

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