

# Developing a Prototype for 3D Cadastre in Iran Using OpenBIM

Farid Cheraghi\*, Erfan Hosseini

Department of Geomatics Engineering, Faculty of Civil and Transportation Engineering, University of Isfahan, Iran -  
(f.cheraghi@cet.ui.ac.ir, e.hosseini@trn.ui.ac.ir)

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## ABSTRACT:

Rapid urbanization and the growing complexity of multi-level buildings have exposed the limitations of Iran's current two-dimensional cadastral system in accurately representing property boundaries and legal rights. To address these challenges, this research develops a prototype framework for implementing a three-dimensional (3D) cadastre based on the OpenBIM<sup>1</sup> approach and the IFC<sup>2</sup> standard. The proposed methodology transforms existing 2D cadastral data into 3D representations by integrating geometric, semantic, and legal information within a unified BIM environment. Unlike previous studies that relied on proprietary software or partial data integration, this research exclusively employs free and open-source tools to ensure interoperability, transparency, and vendor independence. The prototype was tested on a real apartment building in Tehran, demonstrating the feasibility of modeling both physical and legal spaces—such as ownership units, shared zones, and easements—through standardized IFC object classes and property sets. The resulting 3D model complies with international standards and aligns with the current land administration workflows in Iran. The findings confirm that OpenBIM-based modeling provides a practical foundation for establishing 3D cadastre in Iran, improving property registration accuracy, supporting advanced spatial analysis, and enhancing urban management. The study also emphasizes the importance of incorporating elevation data in cadastral surveys and developing a legal and institutional framework for the adoption of 3D cadastral systems nationwide.

## 1. INTRODUCTION

In recent years, the demand for property registration within Iran's cadastral system has significantly increased. According to Publication No. 108 of the Iranian Deeds and Properties Registration Organization, approximately 99% of national and natural lands and about 67% of agricultural lands have already been surveyed and registered (Property Registration Organization of the Iran, 2024). Consequently, the need to record ownership information in Iran's cadastral system remains a national priority, and with the continuous advancement of urban management technologies, this necessity is expected to grow even further.

Currently, registering a property in Iran requires the preparation of a cadastral map by a licensed surveyor recognized by the Registry Office. These maps are produced exclusively in two dimensions. Therefore, all cadastral maps currently held by the Registration Organization are in 2D format. Representing multi-story buildings in 2D introduces various challenges, such as the need to draw each floor separately, which limits the system's capability in several ways. For example, it is not possible to accurately model underground utilities such as electricity, water, and gas networks. Modeling complex properties with RRRs<sup>3</sup> that vary at different heights is extremely difficult, if not impossible, in 2D (Figure 1) (Stoter et al., 2013). Topological queries relevant to building elements must inherently be conducted in 3D (Einali et al., 2022; Jazayeri et al., 2014).

Hence, with the increasing complexity of construction and property ownership structures, the traditional two-dimensional cadastral system is no longer sufficient for meeting the needs of the Deeds and Properties Registration Organization. In recent years, many studies have been conducted to propose 3D cadastral models. For example, Emamgholian utilized 3D

cadastre to model RRRs, aiming to perform spatial neighborhood analyses in three dimensions to identify surrounding rights (Emamgholian et al., 2021). In another study, Einali et al. (2022) introduced an approach for implementing 3D cadastre in Iran using BIM and IFC, in which two different software packages were used—one for creating the 3D model and another for attaching legal information. Similarly, Khoshboresh and Sadeghian (2018) proposed a method for collecting 3D cadastral data using photogrammetric imagery. Sadidi et al. (2021) developed a virtual environment for 3D cadastre using BIM and CityGML for modeling, and WebGL for visualization in the browser. Shokri and Sadeghian (2021) presented a UAV-based photogrammetric approach without ground control points for 3D cadastre implementation. They generated a 2D map of the area through aerial imagery and used point cloud processing to derive building heights and create the 3D model. In another study, Atazadeh et al. (2021) converted 2D cadastral and surveying data into a BIM model using IFC classes to represent both geometry and legal spaces.

Previous research on 3D cadastre has not been specifically focused on Iran; instead, various implementation approaches have been proposed in different countries. In one study, Ying et al (2011) utilized the Land Administration Domain Model (LADM<sup>4</sup>) to develop a model for 3D cadastre. They successfully created a prototype system based on 3D topology that integrated LADM to support cadastral registration. Aien et al. (2012) proposed a 3D Cadastral Data Model (3DCDM) which was conceptually designed and tested for the first time on a building in Melbourne, Australia. Ding et al. (2018) developed and implemented a multi-dimensional cadastral data model known as MDCTDM<sup>5</sup>. In addition to incorporating the third dimension, this model also included a temporal (fourth) dimension. All data were stored in a relational database while preserving topological characteristics,

\* Corresponding Author

<sup>1</sup> Building Information Model

<sup>2</sup> Industry Foundation Classes

<sup>3</sup> Rights, Restrictions and Responsibilities

<sup>4</sup> Land Administration Domain Model

<sup>5</sup> Multidimensional Cadastral Topological Data Model

allowing for various spatial and temporal queries to be executed.

Stoter et al (2017) proposed a method for the 3D registration of complex ownership structures in the Netherlands. Using Building Information Modeling (BIM), they modeled two locations with multi-level property rights. However, they did not leverage OpenBIM (IFC) and its related entities in 3D cadastral. Sun et al. (2019) also proposed a method for 3D cadastral visualization by integrating BIM and GIS. In their approach, BIM and CityGML were used to model the physical structure, while LADM was applied to link legal information to the model. El-Mekawy et al. (2014) attempted to integrate ownership information into BIM-based 3D models. They proposed a method for combining these two domains to facilitate 3D land registration. Oldfield et al. (2017) proposed a process for 3D registration in the Netherlands. Their methodology used BIM and IFC to define workflows for generating both geometric data and associated legal spaces.

Across previous studies, various models and techniques have been developed to support the three-dimensional representation of cadastral systems. All these approaches have aimed to combine geometric data with legal and ownership information. This information is typically extracted from various sources and adapted for integration into 3D models. However, a major challenge in these efforts has been the lack

of data and software integration. In many cases, legal ownership and RRRs are not explicitly recorded in a structured or machine-readable manner.

The present study aims to propose a method for converting Iran's existing two-dimensional cadastral data into a three-dimensional format using the BIM approach and the IFC standard and to create a prototype model based on digital cadastral maps and using free and open-source software (FOSS) tools applicable to the Iranian cadastre. The FOSS approach ensures vendor independence, offers a high degree of customizability, and reduces long-term development and maintenance costs. It is also compatible with international standards and benefits from an open, robust community of developers and users, which makes learning and adoption easier. It is emphasized that no proprietary software was used in the development of this model to avoid a vendor lock-in (Cheraghi, 2018).

The remainder of this paper is organized as follows. Section 2 introduces the fundamental concepts related to this study. Section 3 describes the methodology, including the required data, selected software tools, the 3D modeling process, and the integration of legal information into the model. Section 4 presents the results of the modeling process. Finally, the study concludes with a summary and future recommendations.

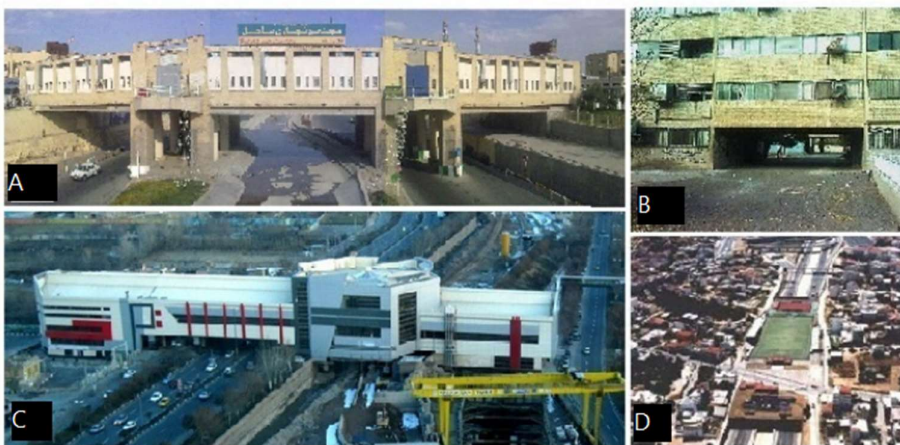


Figure 1. Difficulty of representing complex properties with multiple ownership rights along Z-axis in 2D (Gholizadeh Einallo and Sadeghian, 2015).

## 2. THEORETICAL BACKGROUND

Since the objective of this research is to develop a comprehensive prototype based on a standardized 3D model suitable for Iran's cadastral system, it is essential to first provide an overview of the existing 3D modeling approaches. This background information serves as a basis for evaluating the feasibility of the proposed method. Where necessary, selected models will be examined in greater detail, including relevant diagrams and conceptual illustrations.

### 2.1 Three-Dimensional Models

Currently, various 3D modeling frameworks exist for representing buildings and spatial features. Some of these are particularly suitable for use in cadastral systems, as they can store both geometric and legal data. Several of these models also function as conceptual frameworks for representing different building components. This section focuses on two complementary 3D models that are especially relevant for cadastral applications

### 2.2 BIM and IFC Entities

One of the most widely used 3D models in the construction sector is Building Information Modeling (BIM). BIM is a digital, 3D representation of a building throughout its lifecycle—from design and construction to operation and maintenance. It has emerged as a promising development in the Architecture, Engineering, and Construction (AEC) industry (Eastman, 2011). BIM enables comprehensive modeling of all building components from initial design through final completion. Key characteristics of BIM include (Isikdag, 2015):

- **Object-Oriented Structure:** BIM stores data using object-oriented data models.
- **Rich Information Content:** BIM models serve as repositories of detailed spatial and semantic information describing various elements of a building.
- **Multi-dimensionality:** BIM supports not only 3D data but also additional dimensions such as time (4D) and cost (5D).

- **Geospatial Connectivity:** BIM enables complex spatial relationships between building components, such as connections, containment, and hierarchical groupings.
- **Extensibility:** Through open standards like IFC and proprietary BIM authoring tools (e.g., Revit), the model can be extended to include domain-specific data not originally covered in BIM.

These features make BIM a suitable 3D model for building representation. Alongside BIM, the Industry Foundation Classes (IFC) standard serves as a robust open data format for exchanging 3D information. IFC is an international standard developed by buildingSMART to support interoperability across AEC software platforms (Laakso and Kiviniemi, 2012). It is a BIM-based data model that facilitates the sharing of construction and facilities management information and is widely adopted in 3D cadastre research (Atazadeh et al., 2017). IFC provides the capability to create and model all the building components and concepts required. The hierarchical structures and inheritance relationships among different entities ensure the coherence and integrity of the resulting model.

Originally based on the STEP<sup>6</sup> format developed by ISO, IFC uses the EXPRESS modeling language to define entities and relationships. These definitions are human-readable and machine-processable, and the relationships among IFC entities can be visualized using EXPRESS-G diagrams.

### 2.3 IFC Entities and Their Structure

The IFC standard consists of multiple levels and layers. A *level* refers to the hierarchical position of an entity within the model, while a *layer* indicates a logical grouping of entities based on their function or domain of application. The structure of IFC includes four fundamental layers: the Resource layer, the Core layer, the Interoperability layer, and the Domain layer (ISO, 2024). The Resource layer contains basic components that are reused across all other layers, such as time and date, length and area, as well as fundamental topological elements like vertices, edges, and faces. The Core layer is built around the "IfcKernel", which provides the foundational definitions of objects, relationships, and property sets. The Interoperability layer is intended for defining shared data structures between various domains within the architecture, engineering, and construction industry. Finally, the Domain layer defines domain-specific sub-schemas tailored to the different areas of the AEC field.

At the top of the IFC hierarchy is the entity *IfcRoot*, from which all other entities are derived. At the next level, three key entities exist: *IfcObjectDefinition*, *IfcPropertyDefinition*, and *IfcRelationship*. Under *IfcObjectDefinition*, which serves to define general objects, there are four major subclasses: *IfcObject*, *IfcProduct*, *IfcSpatialElement*, and *IfcSpatialStructureElement*, each of which plays a specific role in describing objects, products, spatial elements, and spatial hierarchies, respectively.

The *IfcObject* entity is one of the most fundamental classes in IFC and represents any type of object within the model. This includes all physical components such as walls, roofs, and windows. Each *IfcObject* can have unique properties that add spatial or semantic information to it. *IfcProduct*, as a subclass of *IfcObject*, specifically refers to physical entities that exist in real-world space. *IfcSpatialElement* refers to the spatial components of a building, which may include floors, public and private areas, and other spatial units. These entities help

define the spatial organization of the building and describe relationships among different components. This class is further divided into two categories: *IfcSpatialStructureElement* and *IfcSpatialZone*. The spatial structure itself consists of four elements: *IfcSite*, *IfcBuilding*, *IfcBuildingStorey*, and *IfcSpace*. These four entities are considered part of a larger project model, represented collectively by the *IfcProject* entity. *IfcSpatialZone* is a non-hierarchical and potentially overlapping decomposition of the project which includes HVAC<sup>7</sup> zones, security areas, or access zones.

Beyond the level of *IfcObject*, and excluding *IfcSpatialElement*, we encounter the entity *IfcElement*, followed by *IfcBuiltElement*. These classes represent all building components, including walls, windows, doors, and similar elements. An example of these components is illustrated in the schema shown in Figure 2.

*IfcSpace* is considered a key entity in this study. It represents both internal and external spaces within a building project, including rooms, corridors, and other usable areas. This entity plays a central role in defining the specific characteristics of each space, such as dimensions, usage type, and spatial relationships. Each designated space within a building project may be subject to legal or regulatory constraints, which can be described using the entity *IfcLegalPropertyObject*. This class stores legal documentation and attributes associated with a property or space, including ownership details, limitations, and compliance requirements. In this study, *IfcSpace* was used to define legal spaces within the building model, as illustrated in Figure 2. As previously mentioned, IFC includes a wide range of complex entities and relationships. However, this paper has focused only on those parts of the schema relevant to the implementation process. These entities and their relationships not only contribute to a better understanding of building structures and workflows but also facilitate more effective use of available information in the IFC standard for a variety of research purposes.

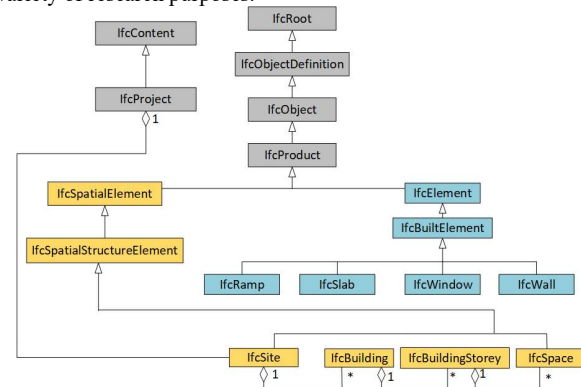


Figure 2. UML schema of selected IFC entities

In this research, we utilize a selected group of these entities and relationships to construct a three-dimensional model. In fact, in any 3D building model, each contributing factor can be represented by an IFC entity—ranging from people and spaces to the physical components of the structure. The following section outlines the process undertaken in this study.

<sup>6</sup> Standard for the Exchange of Product Data

<sup>7</sup> Heating, Ventilation, and Air Conditioning

### 3. METHODOLOGY

By utilizing the BIM model and IFC entities, it is possible to generate a comprehensive 3D model that includes all necessary information—legal, cadastral, and geometric. In this research, a prototype 3D model of a building was developed using this approach. This model is capable of representing all required components for registering legal property data within Iran’s cadastral system. The methodology begins by introducing the input data used to build the model.

#### 3.1 Input Data

The prototype was developed based on real cadastral information from the current Iranian registration system. The primary dataset consisted of a 2D apartment subdivision map prepared by a certified cadastral surveyor. The case study was a building located on Rouyintan Street in the Tehranpars district of Tehran. The property includes a basement, a ground floor, five upper floors, and a rooftop. The 2D maps, which were acquired for this research, are shown in Figure 4. The subdivision plan illustrates details such as ramps, parking spaces, storage rooms, elevator shafts, and structural columns.

The ground floor includes similar elements. Since floors 1 through 5 have the same layout, only the first-floor plan is shown. The rooftop plan includes its openings and structures. These maps contain precise dimensions and designated ownership rights for each spatial unit (Figure 5).

In addition to the 2D plans, floor-to-ceiling heights for each level were required. However, since the original surveys were not intended for 3D modeling, this data was not available. three alternative methods are proposed for obtaining vertical measurements:

1. Manual height measurements by the cadastral surveyor using simple tools such as a laser distance meter.
2. Aerial remote-sensing methods such as photogrammetry and UAVs equipped with imaging or LiDAR sensors to capture the total building height. One may estimate the average storey height by dividing the height by the number of storeys. However, if storey heights are not uniform, this method may be prone to error.
3. Use of architectural design drawings available from the municipality

In this project, the first method—manual measurement—was used. However, for large-scale implementation, the second or third method would be more efficient.



Figure 3. Case study building used in this research: **right**) exterior photo; **left**) floor plans

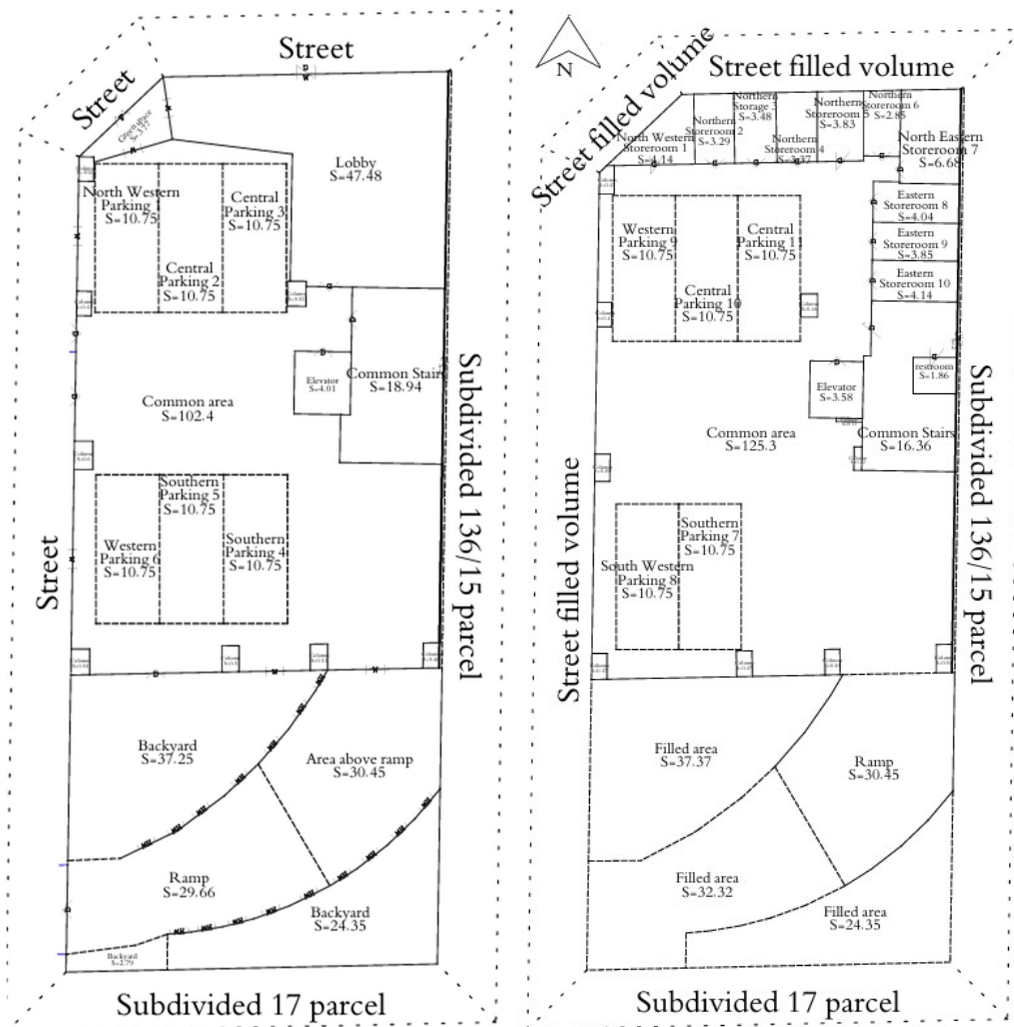


Figure 4. From right to left: single-line plans of the basement and ground floor of the case study building

### 3.2 Implementation

The first step in developing the prototype was creating a 3D model of the property. The model needed to precisely replicate the 2D geometry and convert it accurately into a 3D format. Furthermore, all spatial units within the model had to be clearly defined and categorized. For this purpose, the Blender software was selected (Blender Foundation, 2025). Blender is a powerful open-source 3D graphics tool commonly used for animation, rendering, and modeling. It allows for the integration of plugins, which significantly extend its capabilities.

To work with IFC models, the IfcOpenShell library was used. IfcOpenShell is an open source software library for working with IFC format. This open-source toolkit provides extensive support for reading, writing, and analyzing IFC files. It is comparable to commercial BIM software in functionality, supporting quantity take-offs, scheduling, and geometric processing (IfcOpenShell Contributors, 2024). Bonsai, a Blender plugin derived from IfcOpenShell, was used to enable BIM functionalities within. Blender and Bonsai allows users to view, edit, and create IFC-compliant models while preserving their semantic structure. It also supports metadata management, classification, scheduling, and cost analysis. Using these tools, the 3D models for the basement and ground floor were generated (Figure 5). To this end, the property's

DXF file was first imported into the software, and the required IFC elements (IfcWall, IfcWindow, etc.) were drafted from the 2D plan. We also manually generated the legal spaces from surrounding IFC elements. The model adhered to the hierarchical IFC structure discussed earlier. All structural elements were placed precisely according to the original map. Doors and windows were positioned approximately, as their exact coordinates are not recorded in Iran's cadastral system. Parking spaces were represented with transparent geometric placeholder.

In the next stage, spatial units needed to be defined. As previously discussed, the IfcSpace entity was employed to represent each legal or physical space. These spaces included parking areas, shared zones, storage rooms, elevator shafts, staircases, and courtyards. To categorize these spaces, a "Predefined Type" was assigned to each one. For exterior spaces, the type EXTERNAL was used, while interior spaces were labeled as INTERNAL.

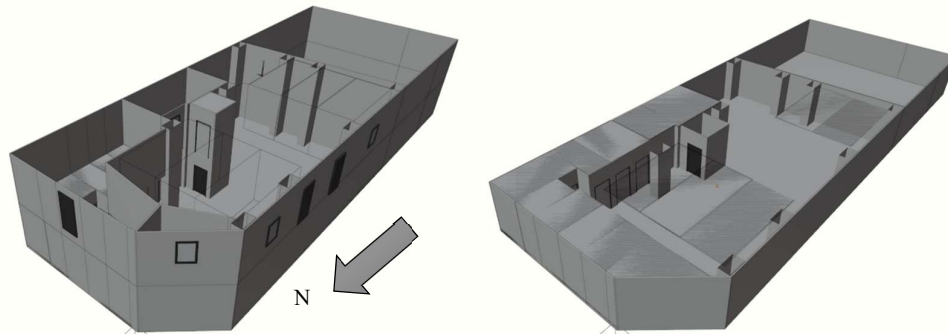


Figure 5. 3D representation of the case study building. Right) first basement floor and, left) ground floor

The general building footprint was designated as GFA<sup>8</sup>, and parking spaces were marked as PARKING. All other types of spaces that did not fall into the predefined categories were assigned the type USERDEFINED, with customized descriptors such as "elevator", "shared courtyard", or "private storage", depending on their specific use within the building. In addition, a IfcPropertySet (p-set) was assigned to each space. P-sets are attribute collections used in IFC to describe object properties. They may include legal and spatial information. For example, the elevator shaft had a p-set containing:

Field	Value
IFC Entity	IfcSpace
Space Volume	8 m <sup>3</sup>
Predefined Type	USERDEFINED (Elevator)

Table 1. Definition of elevator space using IfcSpace

Further attributes such as ownership type, right of way, and elevation rights were also included in the p-set:

Field	Value
Easement	Right of Way
Space Type	Shared

Table 2. Property sets assigned to the elevator space

At this point, the 3D model was completed. It contains both geometric accuracy and semantic richness, making it suitable for implementation within Iran's cadastral infrastructure. It also serves as a strong example of how IFC entities can be used to model legal ownership, access rights, and shared spaces in a unified, analyzable format.

#### 4. CONCLUSION AND RECOMMENDATIONS

In this study, a prototype was developed for 3D modeling based on cadastral data currently used in Iran. The prototype leverages the OpenBIM approach and converts existing 2D cadastral parcels into three-dimensional representations. Unlike previous research, this work uses open-source software for modeling and aims to create an integrated geometric and legal model based on the IFC standard. In this method, both physical and legal spaces are accurately modeled in a 3D environment, and legal attributes such as space type, ownership status, and easement rights are attached to the model using property sets (p-sets) and relevant IFC classes. Another advantage of this approach is its adaptability and compatibility with official registration systems and spatial analysis platforms, since the IFC structure, as an international standard, supports data exchange with systems like GIS. Furthermore, the use of tools such as Blender and IfcOpenShell demonstrates that it is possible to achieve high

levels of accuracy and analytical capability without relying on commercial software. Since the 3D model was derived from the property's precise 2D plan, its accuracy is reliable and it is suitable for use in the Iranian cadastre system.

Research on the implementation of 3D cadastre has been conducted in the past. In these studies, a combination of GIS-based approaches, such as the use of CityGML models or the integration of LADM and BIM, has mostly been employed for implementing 3D cadastre systems. Only a limited number of studies, such as those by Liu and Yang (2025), Oldfield et al. (2017), and Atazadeh et al. (2021), have utilized the BIM/IFC approach alone for cadastral applications. All of these studies were conducted in contexts different from Iran. The only research carried out in Iran using the BIM/IFC approach is the study by Einali et al. (2022), which employed commercial software tools for 3D modeling. Earlier, we discussed the individual, organizational, and institutional aspects of such tools. Our new case study complements Einali et al. (2022) and confirms the capability of OpenBIM for 3D cadastral modelling to register apartment rights in Iran.

Given that one of the authors is a veteran licensed cadastral surveyor authorized to prepare official cadastral maps, the developed model has been automatically validated to ensure full compliance with the current regulations and technical standards of the Iranian cadastre system. Although, it would be preferable to test the proposed method for mapping legal spaces and boundaries in the Iranian cadastre to IFC classes on at least 100 apartment buildings to fully ensure its consistency and reliability. One of the major challenges faced in this research was the lack of available 3D data. The absence of building height information significantly limited the accuracy of the reconstructed model. Since current cadastral subdivision plans do not include three-dimensional measurements, we had to rely on alternative methods such as manual measurement or photogrammetric estimation of floor heights. This issue highlights the need to enhance data collection processes during property surveying by incorporating height and elevation data in formats compatible with BIM and GIS standards. Moreover, the absence of a formal structure for storing and linking legal data in digital formats presents another barrier to the development of functional 3D cadastral systems.

The Organization for Registration of Deeds and Properties can, by defining new protocols for future apartment subdivisions, require surveyors to capture height data. For scalability and integration with existing systems, the best approach is an interoperability with the municipality, to obtain all architectural design drawings of buildings and extract inter-storey heights from them. In other words, by automatically processing all 2D CAD files with elevation codes, 3D modelling can be made more scalable.

<sup>8</sup> Gross Floor Area

Based on the outcomes of this research, future development of 3D cadastre based on OpenBIM in Iran may follow several key directions. First, the creation of a legal and technical framework to accept 3D models within official registration platforms is essential. This may involve adjusting existing regulations and drafting local standards based on IFC and LADM. Second, the development of automated tools to convert 2D cadastral maps into 3D models—using algorithms and artificial intelligence—could significantly speed up implementation. Additionally, the integration of these models into GIS platforms and legal databases would enable advanced spatial and legal analysis for land administration and urban planning. Finally, future research may explore more detailed modeling of legal spaces, including easements, ownership restrictions, and overlapping rights, thus contributing to the realization of intelligent and integrated.

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