

Article

Development and Integration of LADM and BIM for 3D Cadastre in Iran

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Abstract

The rapid urbanization and development of vertical construction and subsurface spaces in Iran, along with national policy emphasis on transparency in land administration, have highlighted the need to transition from a two-dimensional (2D) to a three-dimensional (3D) cadastre. Iran's current cadastral system, based on 2D parcel maps, fails to adequately capture complex ownership relationships in multi-story buildings and underground spaces. This study proposes an integrated model combining the Land Administration Domain Model (LADM) country profile with the Industry Foundation Classes (IFC) standard for 3D cadastre implementation. The LADM country profile of Iran was extended to support 3D spatial units. A 3D building model was developed in Autodesk Revit by integrating as-built cadastral maps with architectural drawings and exported in IFC format. Legal attributes were added to Building Information Modeling (BIM) elements in Simplebim via custom Property Sets, allowing physical and legal information to be stored in one IFC file. Functional and interoperability testing in IFC-compatible software showed that the file could be read and used for legal-spatial queries, although the results may depend on each software's IFC support. For national use, database-level implementation may provide a more reliable option. These results demonstrate that integrating LADM and BIM for a 3D cadastre is technically feasible in Iran at the building scale, as shown by the successful mapping between LADM classes and IFC entities, implementation of custom Property Sets, and interoperability testing across IFC-compatible software platforms.

Keywords: 3D cadastre; Land Administration Domain Model (LADM); country profile; Building Information Modeling (BIM); Industry Foundation Classes (IFC); Iran



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1. Introduction

Urban development in Iran has increasingly moved toward dense, vertical, and multi-layered forms of land use. In major cities, especially Tehran, multi-story buildings, complex apartment ownership structures, underground parking areas, tunnels, subway infrastructure, and other subsurface facilities have created situations in which land and property interests are no longer limited to the surface parcel. These developments have increased the need for cadastral systems that can represent not only parcel boundaries in two dimensions but also the vertical and volumetric relationships between legal and physical spaces [1–3].

At the same time, national policies in Iran have emphasized digital transformation, system integration, electronic registration, and transparency in land and housing manage-

ment [4,5]. BIM and related digital technologies have also been promoted in national and academic discussions, including through BIM-related policy documents [6,7]. However, BIM models are not yet formally integrated into Iran's land administration and cadastral processes. Existing BIM models, where available, are mainly produced for design and construction purposes and are not submitted to public authorities as legally valid cadastral documents. Therefore, they cannot currently be used directly for official property registration or title deed issuance [8].

In the field of cadastre and property registration, three key laws have been established as the legal and executive basis in Iran [9]:

1. Law on Determining the Registration Status of Lands and Buildings without Official Title Deeds (2011)
2. Comprehensive Cadastre Law of Iran (2015)
3. The Law on Mandatory Official Registration of Real Property Transactions (2024)

These laws are presented to clarify the legal and institutional context within which cadastral registration currently operates in Iran. They provide a systematic framework for the cadastre sector and indicate that Iran's cadastral system is expected to move toward greater integration, transparency, and digital registration. However, they have not yet established an operational framework for the registration, representation, and management of volumetric property rights in three dimensions (3D). To address this gap, a 3D cadastre is proposed as a necessary development in land administration.

Fundamentally, a cadastre consists of two interrelated components: spatial data, which describe the location, geometry, and extent of cadastral units, and legal data, which define rights, restrictions, responsibilities, and ownership interests. Their integration is essential for representing complex property situations in multi-story buildings, underground spaces, and other volumetric cadastral contexts [10].

In Iran, the cadastre system is still implemented in a two-dimensional (2D) framework, with legal spaces predominantly defined by descriptive texts. These records primarily represent surface parcel boundaries and do not explicitly model underground, above-ground, or volumetric legal spaces as 3D cadastral units. This approach fails to meet the complex and multi-layered needs of contemporary land and property management. Figure 1 shows the MIKA Knots Building in Tehran through several 2D floor plans, each corresponding to a specific floor of the building. Although these plans provide useful floor-level information, they cannot adequately capture the overall 3D structure, vertical relationships between floors, and spatial complexity of the building. Currently, Iran lacks an operational 3D cadastre system, with only limited studies conducted in this area [11]. Therefore, adopting international standards in the design and implementation of a 3D cadastre system may be the best path for developing this field [12].

The Land Administration Domain Model (LADM) is widely recognized as one of the key conceptual models for land administration and cadastre. Research on the development and implementation of LADM in cadastral systems has been carried out at various levels in more than 40 countries across five continents. This broad body of work highlights the significant potential of LADM for national deployment and for supporting integrated land and property management frameworks [13,14].

LADM is an abstract conceptual model for representing the legal and spatial components of land administration. It supports the representation of spatial units in both 2D and 3D; however, it does not prescribe implementation-level geometric modeling or detailed building-scale encoding. Instead, its primary role is to provide a standardized conceptual framework for structuring legal and spatial relationships. Accordingly, complementary standards such as BIM and Industry Foundation Classes (IFC) are required to represent detailed physical geometry and to operationalize 3D cadastral concepts in practice. Such

integration bridges legal semantics and detailed 3D geometry. This connection enhances the representation and analysis of spatial relationships in 3D cadastral environments [15,16].

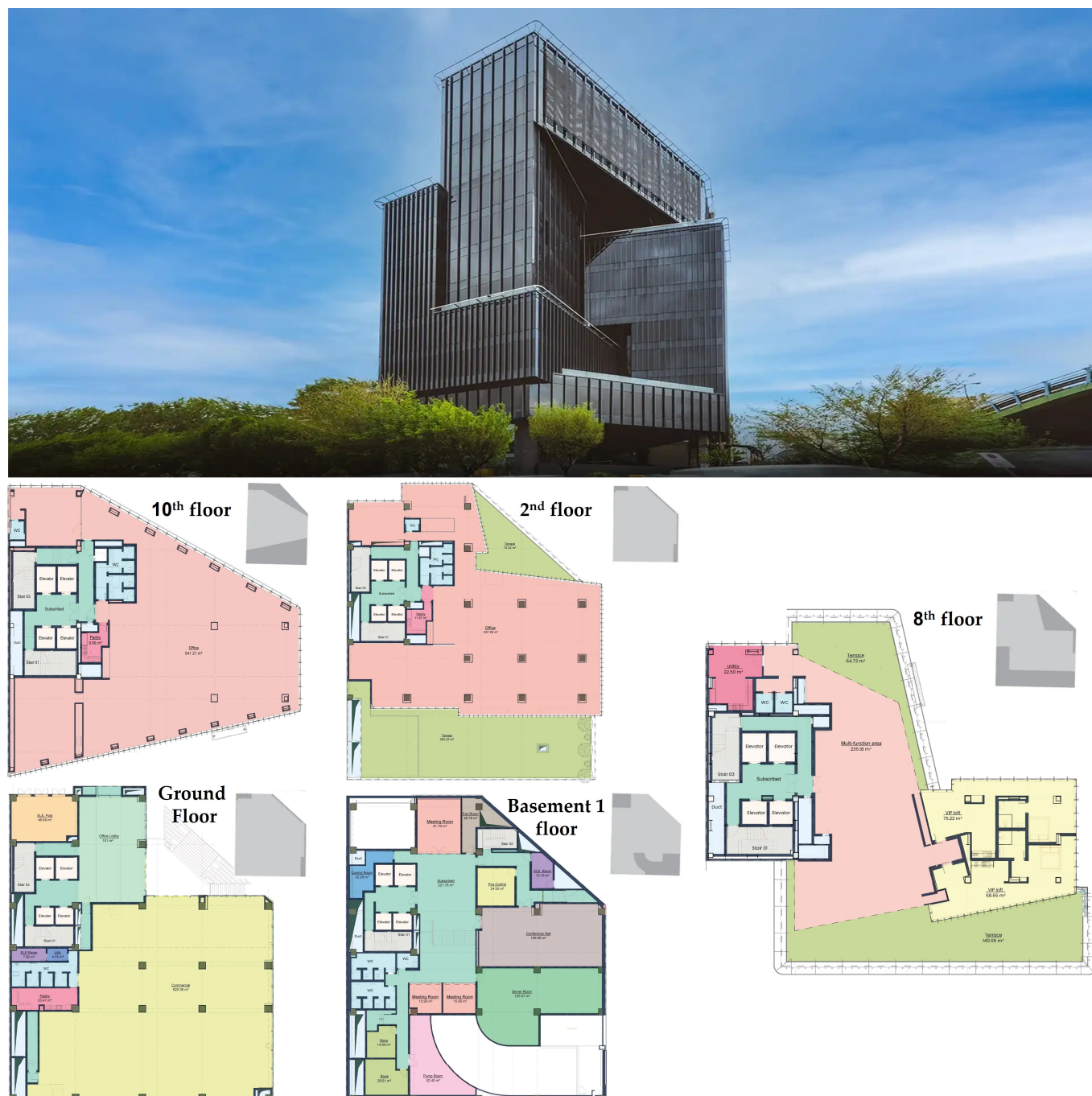


Figure 1. Example of a complex building represented through 2D maps and a corresponding building photograph: MIKA Knots Building, Tehran. Each 2D map represents one floor of the building. Source: MIKA Corporation [17].

In this study, IFC is used as a building-scale implementation and exchange layer, not as a replacement for LADM or for a cadastral database. This choice is consistent with the scope of the prototype, which focuses on detailed building units, spaces, walls, and physical-spatial relationships. Although other 3D standards such as IndoorGML and CityGML support indoor or urban-scale representations [10,18], IFC is more suitable for the building-scale implementation adopted here because it provides a standardized BIM structure for representing detailed geometry and building elements [19,20]. It also allows LADM-based

legal and cadastral attributes to be attached to BIM elements through custom Property Sets, enabling the proposed workflow to link legal semantics with detailed 3D building geometry in an interoperable IFC-based model [16]. Figure 2 presents this integrated framework as a conceptual and idealized model; given that Iran currently lacks an official operational 3D cadastre, the present study focuses on the building-scale component as a first practical step toward its development.

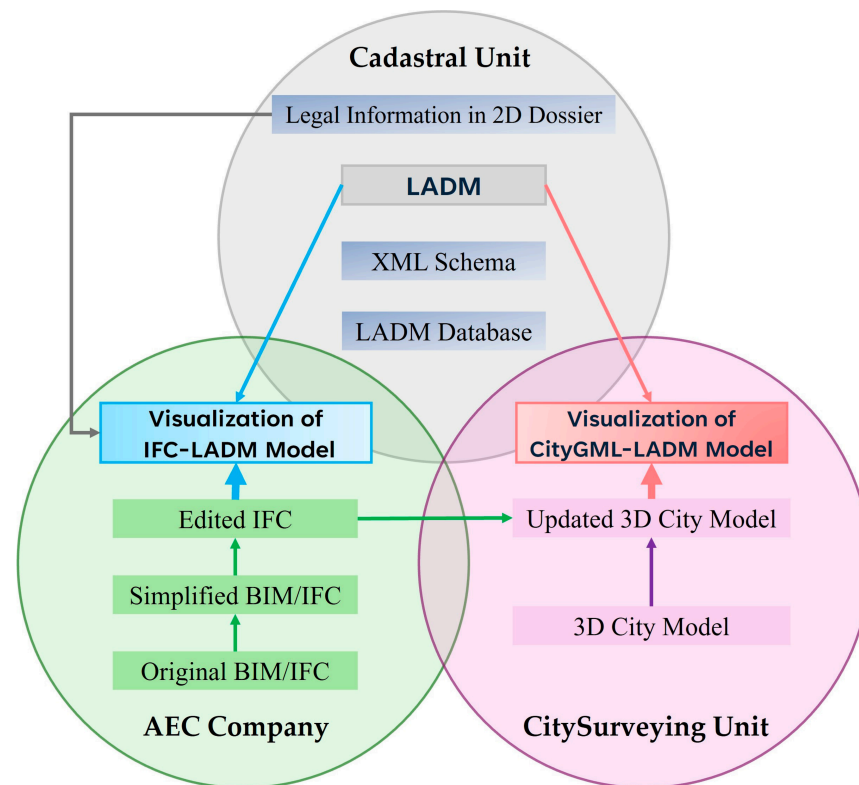


Figure 2. General framework for integrating a cadastre with Building Information Model (BIM) and Geographic Information System (GIS) [21].

One widely used integration approach in recent studies, primarily at the building scale, is the combination of the LADM and IFC standards. Given the wide range of entities defined in the IFC standard for geometric and architectural modeling, this standard can complement LADM effectively, enabling the simultaneous coverage of legal data and 3D spatial data [22].

Based on the LADM country profile developed for Iran, this study proposes and tests an IFC-based workflow for integrating legal cadastral information with a 3D building model. The workflow maps LADM classes to IFC entities, incorporates legal attributes as custom Property Sets, and uses real cadastral, architectural, and legal data to evaluate the feasibility of a building-scale 3D cadastre prototype.

Previous LADM–IFC studies have provided important foundations for conceptual and technical mappings between LADM classes and IFC entities, including the use of IFC extension mechanisms such as Property Sets for legal and cadastral information [16,23]. However, less attention has been given to implementing a national LADM country profile at the class and attribute levels within a complete IFC-based workflow. This creates a gap between conceptual integration and practical implementation in country-specific cadastral contexts. In response, this research operationalizes the LADM country profile of Iran within a complete IFC-based workflow aligned with national legal and institutional requirements.

To address this gap, the primary objective of this study is to examine the feasibility of implementing a 3D cadastre in Iran and to demonstrate the potential of an integrated

model based on international standards that combines legal and spatial data within the country's land and property management system. In this regard, the present research examines the feasibility of the developed prototype at the building scale and discusses its potential extension to larger-scale applications as a future direction. The findings are intended to inform future efforts toward a national 3D cadastre system in Iran.

To clarify the specific contributions of this study beyond previous LADM country profile studies and generic LADM–IFC integration research, the main contributions of the present work are as follows:

1. Revising the LADM country profile of Iran to support building-scale 3D cadastral applications;
2. Operationalizing the revised profile within an IFC-based BIM workflow grounded in Iranian legal and cadastral conditions;
3. Integrating as-built cadastral maps with as-designed architectural drawings to generate legally informed 3D building units;
4. Implementing legal semantics in IFC through custom Property Sets and testing interoperability across multiple IFC-compatible software platforms.

2. Literature Review

This section reviews the literature to identify the conceptual, methodological, and implementation gaps that motivate the present study. Research on 3D cadastre, international data modeling standards, and BIM-based technologies has become a central focus of many research efforts and national initiatives. Therefore, this section positions the present study within this body of literature through a structured review of relevant concepts and prior studies. The section begins by reviewing the evolution of 3D cadastre and the associated technical, data-related, and institutional challenges. It then discusses the roles of land administration systems (LAS) and data modeling within the LADM framework and its country profiles. The physical aspects of the topic are explored from the perspective of BIM and the IFC standard. The section then introduces approaches for integrating LADM and BIM using IFC and concludes with a discussion of studies and experiences in Iran related to 3D cadastre and the use of the aforementioned standards.

2.1. 3D Cadastre

Initial studies conducted in the 1990s demonstrated that 2D systems were incapable of representing ownership relationships across multiple layers. In this context, the International Federation of Surveyors (FIG) workshop officially introduced 3D cadastre as one of the key research and application domains in 2001 [24]. Today, the applications of 3D cadastre have significantly expanded, addressing the complex issues of urban ownership. Rapid population growth has increased the demand for vertical land use, and the expansion of high-rise buildings and transportation infrastructure has made new approaches to land management necessary [25]. One important application of 3D cadastre is the management of underground spaces. The effective development of these spaces can optimize land use in urban environments and enable the creation of vital infrastructure networks to respond to population pressures and sustainability goals [26]. Modern applications of 3D cadastre are increasingly integrating with smart cities and digital twins. The integration of BIM and geographic information system (GIS) technologies is rapidly becoming a standard in the construction sector, improving building management, maintenance, and planning for conservation [27].

Despite significant progress in recent years, the full implementation of 3D cadastre still faces several technical, data-related, legal, and institutional challenges that must be addressed to achieve a sustainable and operational cadastral system. A fundamental weak-

ness of 3D cadastre lies in the limitations of database management systems for processing 3D spatial data. Most databases that support various types of 3D data have limited support for 3D topology and typically require the decomposition of 3D objects and the use of new approaches for data collection [28]. Furthermore, the transition from 2D to 3D systems presents specific challenges, as the registered rights in 2D are not aligned with the 3D data obtained from new technologies. This misalignment creates significant obstacles to updating and transforming traditional systems into 3D, requiring extensive changes to data structures and workflows [29]. Additionally, challenges such as simultaneously georeferencing 3D data and spatial information, as well as the lack of compatible tools and file formats that can address these areas, remain among the main issues in the current state of 3D cadastre [30–32]. Overall, the reviewed studies clearly establish the need for 3D cadastre and its technical challenges; however, fewer studies demonstrate how these concepts can be implemented within national legal and cadastral contexts using operational workflows.

2.2. Data Modeling and LAS

To understand how 3D cadastre can be implemented within national contexts, it is first necessary to consider the broader role of land administration systems and data modeling. The concept of LAS is rooted in traditional surveying and cadastre activities, which established the basic registration of land boundaries and associated rights [33]. Land management has always been a vital pillar of governance. Historically, societies have created mechanisms to ensure property security, control land use, and assess land value. In this regard, property rights and registration systems were developed as the most fundamental tools. Initially, LAS focused on cadastre and property rights registration. Over time, land administration systems have evolved into multipurpose infrastructures that integrate land tenure, land value, land use, and land development functions to support sustainable development across economic, social, and environmental dimensions. Since the early 21st century, this integrated perspective has been widely adopted, in which land administration systems are conceptualized around four core functions: land tenure, land value, land use, and land development [34,35].

Today, LAS is not limited to property registration. It supports land governance by organizing information related to property security, economic efficiency, environmental protection, and social justice. These functions are important for sustainable development and good governance [36]. As property structures have become more complex and urban development challenges have increased, LAS has required new tools to depict legal and spatial relationships more accurately. This need led to the introduction of data modeling as one of LAS's scientific and technical foundations. In fact, data modeling provides a way to represent ownership, restrictions, and responsibilities not only in two dimensions but also in three dimensions, addressing some of the limitations of traditional systems. In cadastre, 3D data models have been developed to represent complex ownership relationships that are difficult to depict in conventional 2D systems. Data modeling in this context refers to a systematic approach for structuring, organizing, and displaying cadastral information to accurately record the geometric, topological, and legal aspects of 3D property units [37]. A key milestone in the history of data modeling for 3D cadastre was the introduction of the LADM, which enables the representation of cadastral data in both 2D and 3D [38].

2.3. LADM

The LADM was introduced in 2012 under ISO 19152 [39] with support from international organizations such as UN-Habitat, the Food and Agriculture Organization (FAO), the European Union Joint Research Centre (JRC), and the FIG, and the participation of over fifty experts from around twenty countries [40,41]. Since the official publication of

the LADM standard (ISO 19152), LADM has received increasing attention in 3D cadastre and land administration research. Recent literature surveys on 3D cadastre have classified the reviewed publications into four main categories: legal, technical, registration, and organizational. Using this classification framework, studies involving LADM were found to be mainly associated with registration and technical issues [42].

In LADM, land administration information is described through three main packages. The Party package identifies the people and organizations involved in land administration. The Administrative package stores information on rights, restrictions, responsibilities, and other legal interests. The Spatial Unit package represents parcels, spatial units, and their geometric characteristics. These packages together define the basic structure of the model (Figure 3) [43].

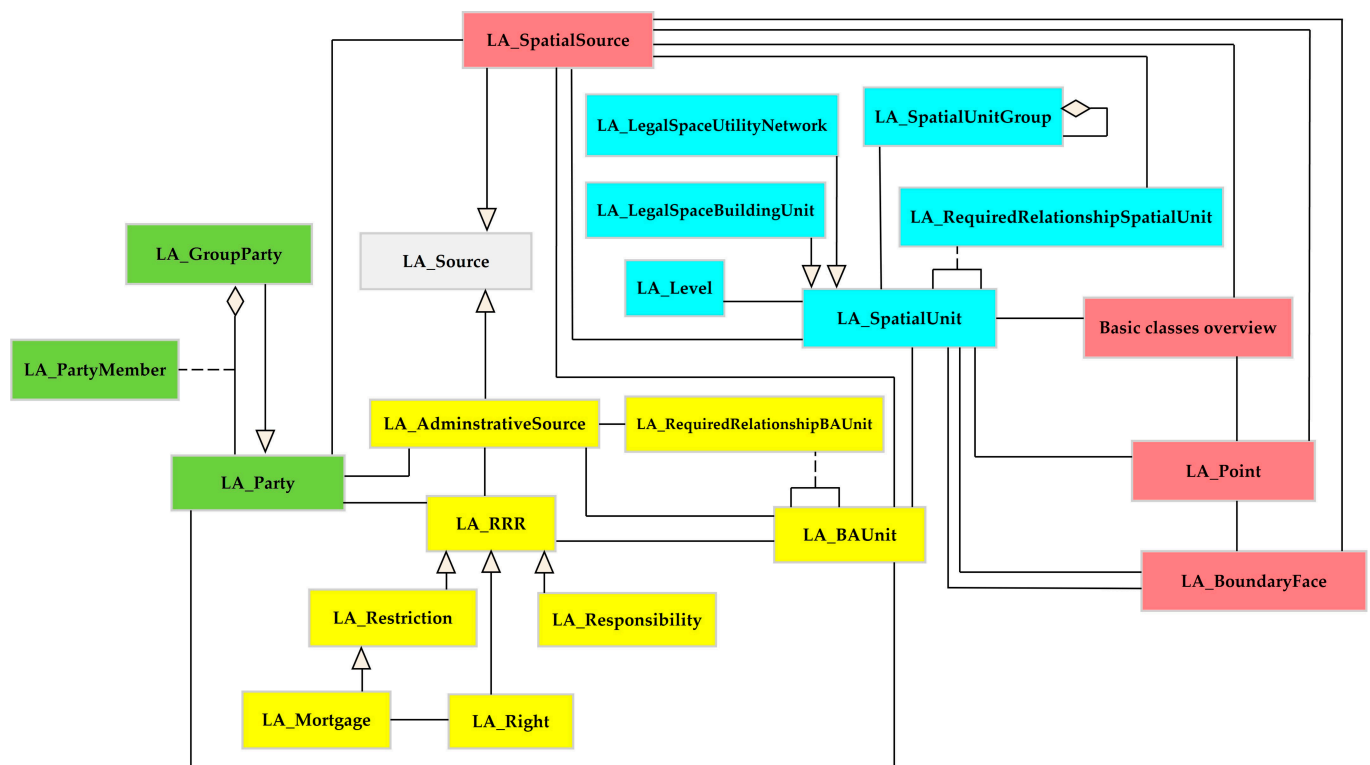


Figure 3. The Land Administration Domain Model (LADM)—Edition I [43]. Party, administrative, spatial unit, surveying and representation classes, and the source class are shown in green, yellow, blue, pink, and gray, respectively.

LADM is fundamentally based on the concept of “Rights, Restrictions, and Responsibilities” (RRRs) and provides guidelines to ensure the interoperability and integrity of their representation. This model can standardize multidimensional representations, including the temporal capability to document and visualize legal aspects of land use [43]. This comprehensive approach makes LADM a specialized tool for managing complex ownership situations that traditional 2D systems cannot effectively represent [19]. One of the critical applications of LADM is the development of a 3D cadastre. Many countries have adopted ISO 19152 to enhance their cadastral systems in the context of developing a 3D cadastre [12]. The integration of LADM with BIM technologies enables the physical and legal dimensions of buildings to be represented within a common framework [22]. This is especially important for high-rise buildings and complex urban developments where 2D representation is insufficient [44]. More recently, LADM Edition II (ISO 19152-1:2024) was developed to restructure and extend the original LADM framework in order to better support 3D land administration and domain-specific information modeling [45]. Its revised

modular, multipart architecture improves conceptual clarity and interoperability, particularly in relation to 3D spatial representations and land registration processes [46]. These developments are especially relevant to the present study because the proposed workflow links legal and spatial information through a 3D BIM/IFC environment. Although this research is based on the existing LADM country profile of Iran, originally developed in the context of LADM Edition I, the integration logic adopted here is consistent with the broader direction and objectives introduced in Edition II.

LADM Country Profile

The flexible structure of LADM enables the development of country profiles tailored to each country's legal and administrative context [47]. These profiles preserve the core conceptual structure of LADM while incorporating country-specific legal frameworks, cadastral concepts, and administrative procedures, thereby supporting interoperability and alignment with international standards [48,49]. LADM country profiles have been developed and applied in a wide range of contexts. For example, studies in Serbia, Croatia, and Turkey have explored their role in supporting 3D rights registration, condominium modeling, and utility or easement management [48,50–53]. In Poland, China, Pakistan, Kenya, and Brazil, country profiles have been used to improve land information infrastructure, integrate legal and cadastral information, support implementation, and modernize cadastral systems in both 2D and 3D contexts [49,54–59]. These studies demonstrate the broad applicability of LADM country profiles across different cadastral contexts while also suggesting that their systematic integration with BIM/IFC-based workflows has received limited attention.

2.4. BIM

Since the present study addresses this integration gap at the building scale, BIM and IFC are reviewed as the physical and geometric components of the proposed framework. BIM constitutes an integrated framework and a comprehensive digital representation of a facility's physical and functional characteristics. This framework provides a set of policies, processes, and technologies for managing critical design information and project data in digital format. This approach encompasses all phases of a facility's lifecycle, from initial conceptualization through operation and maintenance, enabling integrated information management across all these stages [60,61]. In the context of data exchange and interoperability, IFC is the main open standard used to represent and transfer BIM information.

IFC

From the 1950s through the 1970s, data exchange was primarily conducted through proprietary and closed solutions. In the late 1970s, open standards for geometric data exchange emerged, with the Initial Graphics Exchange Specification (IGES) serving as a prominent example. However, IGES failed to keep pace with the industry's transition to 3D modeling. In 1994, twelve American companies convened to develop an open standard in the BIM domain, and this collaboration led to the formation of the Industry Alliance for Interoperability (IAI) in 1995. This organization was subsequently renamed buildingSMART and continues to serve as the custodian of IFC to the present day. The first version of the IFC standard, designated IFC 1.0, was released in 1997. In subsequent years, the standard underwent numerous updates and a gradual expansion of its application scope, leading to newer versions. This evolutionary process has continued to the present day, with the number of IFC classes and entities now exceeding 880 entities. The latest official version, IFC 4.3, was published and ratified as an ISO standard in 2024 under the designation ISO 16739:2024 [62]. Concurrently, development of the subsequent version, designated IFC 5, has commenced; however, this version remains in the design and development phase and

This object-oriented model follows a layered architecture comprising four primary levels, as outlined below [69]:

- Domain Layer: Domain-specific entities for architecture, structure engineering, and facility management.
- Shared/Interoperability Layer: General entities shared across different domains, such as IfcWall or IfcSlab.
- Core Layer: Fundamental classes including IfcRoot, IfcObjectDefinition, and IfcRelationship.
- Resource Layer: Definitions of basic objects such as materials, profiles, geometry, and scheduling.

One of the most critical mechanisms of IFC is the use of Property Sets, which allow designers and software tools to attach collections of properties to IFC entities to transfer semantic and domain-specific information without modifying the entities' core definitions. In the context of 3D cadastre applications, previous studies have shown that IFC Property Sets can be extended to support cadastral information requirements [16,23]. Despite its widespread adoption, IFC faces several challenges that hinder its full interoperability. In particular, the standard lacks sufficient semantic clarity, and different models often use varying definitions to represent the same type of data [70].

The most significant application of IFC in the cadastral domain lies in the development of 3D systems, where its capability to represent complex 3D building information aligns well with the spatial requirements of modern land administration. Petronijević et al. [19] conducted pioneering research in this area and, by proposing extensions to the IFC schema to support 3D cadastral geometry based on the LADM, demonstrated how BIM data can be extracted and adapted for 3D cadastre applications [19].

2.5. Integration of BIM and LADM Using the IFC Standard

One of the key application areas of 3D cadastre is the integration of legal and physical dimensions, which enables the combination of legal and physical information within a single data source. This integration can provide maximum efficiency and flexibility in urban management and land development processes [10]. In such an approach, LADM is primarily used to represent the legal dimension, while IFC is employed to model the spatial dimension. Oldfield et al. [23] investigated the potential of open BIM standards, particularly IFC, in supporting 3D cadastre. In the context of this integration, they proposed a method for mapping LADM concepts to IFC. They recommended using Property Sets to store and manage legal data within the BIM environment [23]. In general, three main approaches have been proposed for integrating these two models [16]:

- Extending LADM: In this approach, physical building information is incorporated into an LADM-based representation to provide additional spatial and modeling detail. However, this method is highly complex and not well aligned with the conceptual and intentionally abstract nature of the LADM standard.
- Extending the corresponding 3D physical model: This approach involves adding LADM packages to the IFC structure through Property Sets, allowing various legal concepts to be incorporated as Property Sets without significant changes to the core IFC structure.
- Providing a mapping between LADM and 3D physical models: This approach establishes conceptual and semantic relationships between LADM classes and IFC entities without modifying their core structures. While this approach does not require changes or extensions to the standards themselves, the resulting model is largely conceptual, more limited in scope, and involves greater complexity in practical implementation.

Atazadeh et al. [71] first examined different pathways for the development of a 3D cadastre and proposed a conceptual framework for integrating legal and physical information within a digital 3D environment. Subsequently, by extending the IFC model with LADM legal elements using Property Sets and user-defined values, they created a shared

environment for physical and legal data and demonstrated it through a multi-story building case study [16]. Güler et al. [68] combined the LADM and IFC standards to enable unambiguous 3D registration of ownership rights in multi-story buildings. Their study, based on a real-world case in Turkey, demonstrated that the use of BIM/IFC allows for accurate representation of individual units, common spaces, and building elements, providing a practical foundation for the transition to 3D cadastre [68]. Korkmaz et al. [22] proposed an integrated model for combining LADM legal data with the physical BIM/IFC model and managing the four main land administration functions, namely tenure, land use, land development, and land value, in a 3D context throughout the building lifecycle. By designing a national LADM profile for Turkey and conceptually mapping it to IFC via Property Sets, their study demonstrated how RRRs can be directly embedded in the IFC model and applied during planning, construction, renovation, and taxation processes [22]. Liu and Yang [72] proposed a BIM-based 3D cadastral framework that extends the IFC standard to integrate legal concepts like ownership boundaries and RRRs. Using a multi-level semantic model, the framework addresses ambiguities in 2D legal documents and provides clear 3D representations of ownership spaces. A case study in China demonstrates its effectiveness in clarifying property rights and resolving disputes [72]. These studies confirm the potential of LADM–IFC integration for 3D cadastre, but they also show that most implementations remain generic or case-specific and do not fully address country-profile-based workflows.

2.6. LADM Integration with CityGML, LandInfra, and INTERLIS for 3D Cadastre

Although this study focuses on the LADM–IFC pathway, other standards have also been integrated with LADM to support 3D cadastre at different scales and application domains. The integration of LADM with various standards such as CityGML, LandInfra, and INTERLIS plays a vital role in enhancing the effectiveness of 3D cadastre systems. By combining legal and spatial data, these integrations enable more efficient land management, particularly in urban and subsurface environments, overcoming the limitations of previous systems [73]. Previous research has shown that integrating LADM and CityGML can effectively support urban-scale 3D cadastre by separating legal information from physical city models. In the Turkish case study, this integration was realized through a CityGML ADE aligned with LADM, enabling the association of legal spatial units with 3D city objects while preserving interoperability between legal and physical domains.

In the context of surveying and infrastructure data, Kalogianni et al. [74] focus on revising the Survey Model of the LADM to align it with the OGC (Open Geospatial Consortium) LandInfra standard. Their work addresses the limitations of the first edition of LADM in representing modern surveying processes, particularly those related to infrastructure projects and subsurface environments. LandInfra is presented as an appropriate standard for modeling survey activities and infrastructure-related spatial information, which are essential for the registration and updating of 3D cadastral boundaries, especially in underground contexts. By distinguishing between the state-based nature of LADM and the event or project-based character of LandInfra, the study demonstrates how LandInfra can function as a complementary implementation model for LADM while maintaining LADM's role as the authoritative legal and administrative reference framework [74].

The integration of LADM with INTERLIS is crucial for enhancing the management of land rights and 3D spatial data. While INTERLIS serves as a data modeling and exchange standard, it facilitates interoperability between legal and spatial data, bridging the gap between land administration and infrastructure data. Kalogianni et al. [75] emphasize the complementary roles of LADM and INTERLIS, with INTERLIS supporting the encoding of LADM concepts and enabling the exchange of 3D cadastral data. They demonstrate

how INTERLIS effectively models infrastructure and spatial data, particularly in urban environments, where managing subsurface and infrastructure data is crucial. This integration allows for a seamless representation of legal rights alongside 3D cadastral boundaries, advancing land management in complex urban settings [75].

2.7. Studies on 3D Cadastre in Iran

After reviewing international approaches and standards, it is necessary to examine how the 3D cadastre has been studied in the Iranian context. Despite the significant growth of research on 3D cadastre at the global level, studies conducted in Iran in this field remain limited [76]. Most domestic research has primarily adopted a legal and registration-oriented perspective, in which the use of emerging technologies is generally proposed as a main solution to address challenges in Iran's cadastral system. However, studies that have focused on the technical aspects of this field, excluding research on data acquisition methods, are reviewed below. In studies conducted by Emamgholian et al. [11,77] in Iran, a novel approach for 3D neighborhood analysis in buildings was proposed and implemented. In this research, 2D cadastral map data were transformed into 3D models within a GIS environment, enabling the automatic identification of lateral, upper, and lower neighbors of each building unit, as well as existing easement rights [11,77].

Einali et al. [8] developed a BIM-based approach for 3D cadastre in Iran to address the shortcomings of the 2D cadastral system and tested it on a multi-story building in Tehran. The results demonstrated that, by integrating geometric and legal data, the proposed method effectively modeled ownership units and common spaces [8]. Hajiheidari et al. [78] investigated the challenges of integrating cadastral and urban maps in Tehran and identified differences in scale, data format, and standards as the main barriers. They suggested that the use of international standards such as ISO and OGC, along with GIS formats, could enable the production of integrated and enriched maps for urban management and digital cadastre applications [78]. Zamiri et al. [76] localized the first version of the LADM standard (ISO 19152) for Iran and proposed a national country profile (Figure 5). This profile was developed based on the legal framework and organizational structure of the State Organization for Registration of Deeds and Properties, which is responsible for the country's cadastre. Model evaluation using the Abstract Test Suite demonstrated that the LADM country profile of Iran fully complies with Level 2 (medium level) of the standard. Moreover, survey results from officially affiliated cadastral and land registration experts indicated a high level of acceptance and validation of the effectiveness of the proposed model. Although this study developed and evaluated the Iranian LADM country profile, it remained at the conceptual modeling level and was not technically implemented in an operational system. In addition, the proposed profile was developed based on the current conditions of Iran's cadastral system, which is still primarily based on a 2D cadastre [76]. A recent study by Jafari et al. [3] proposed an integrated conceptual framework for 3D cadastre in Iran that addresses the technical, legal, and institutional dimensions of implementation and identifies the corresponding challenges and limitations affecting 3D cadastre development in Iran. This work provides an important national-level reference for the transition from 2D to 3D cadastre in Iran; however, it remains primarily conceptual and has not yet been formally adopted or mandated by the primary responsible authorities, such as the State Organization for Registration of Deeds and Properties [3].

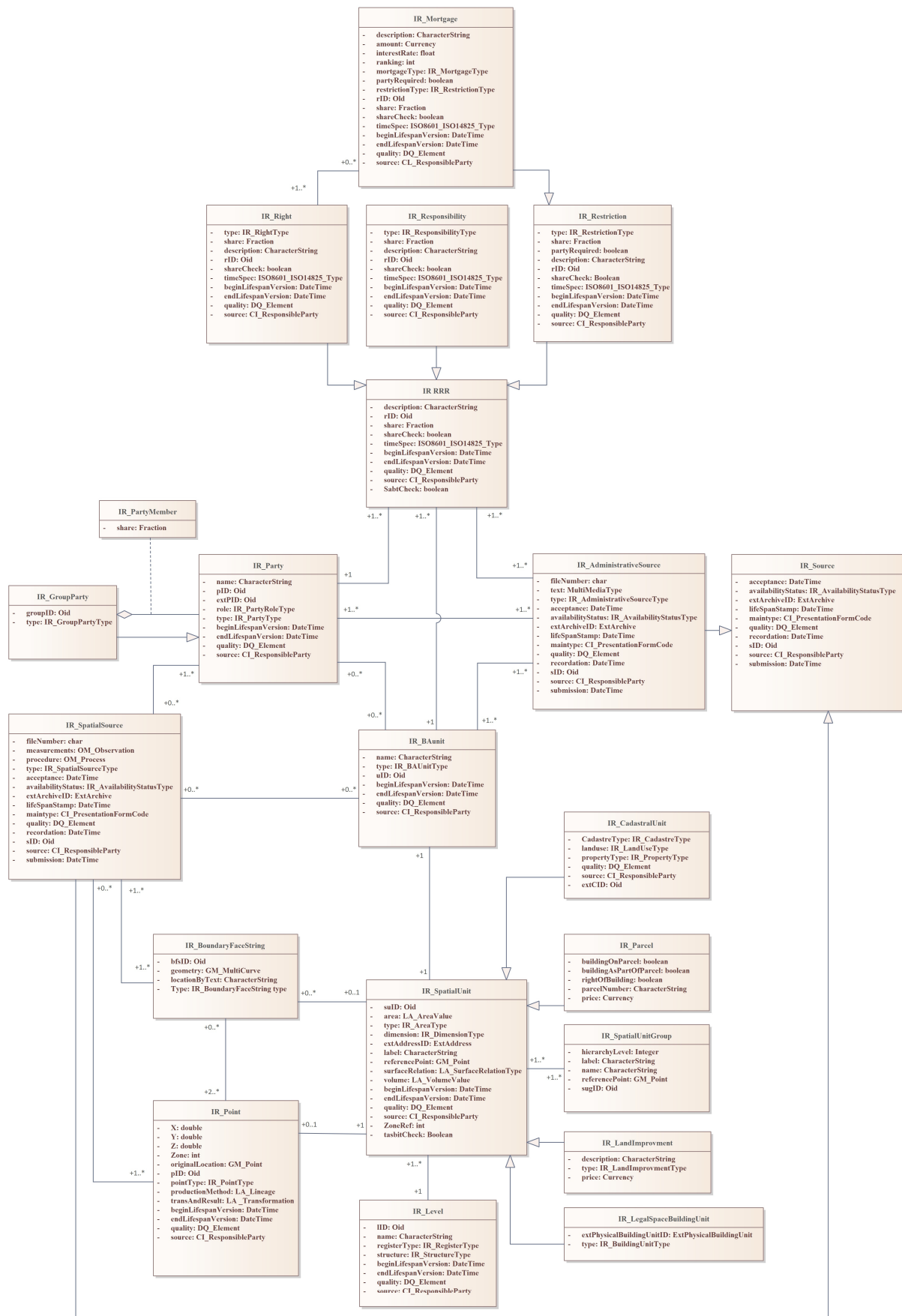


Figure 5. The LADM country profile of Iran [76]. The multiplicity labels follow the Standard Unified Modeling Language (UML) notation defined in ISO 19152 (LADM).

2.8. Research Gaps

Based on the literature reviewed in the preceding sections, the research gaps related to the implementation of 3D cadastre and the integration of the LADM and IFC standards can be classified into two main categories: gaps related to the national context of Iran and gaps associated with the practical implementation of the integration process at the country profile level.

First, in the context of Iran, the review of domestic studies indicates that despite the strong emphasis of policy documents and academic research on the necessity of transitioning to a 3D cadastre, the use of BIM as an official data source within the national cadastral system has not yet been realized. Moreover, although an LADM country profile for Iran has been developed, this profile, in its initial form, has been primarily oriented toward the requirements of a 2D cadastre and faces limitations in supporting the implementation of a practical 3D cadastre prototype. These gaps have resulted in the absence of an operational BIM-based cadastral implementation in Iran that is aligned with existing legal frameworks, institutional procedures, and international standards.

The second category of research gaps relates to the integration of LADM and IFC in the international literature. A review of previous studies shows that the integration of these two standards has often been pursued through conceptual mappings or limited prototype implementations, mainly focusing on the core entities and classes of LADM and IFC. While the development of LADM country profiles has been widely promoted as a means of localizing legal and administrative concepts across countries, the systematic use of country profiles in the LADM–IFC integration process has received limited attention in prior research. As a result, many of the proposed integration approaches show limited practical applicability, particularly in terms of alignment with national legal and institutional frameworks.

Table 1 summarizes the closest prior studies on LADM–IFC integration and BIM-based 3D cadastre, highlighting their main focus, limitations, and the contribution of the present study.

Table 1. Comparison with selected prior studies.

Focus Area	Previous Approaches	Main Limitation	Present Study Contribution
Implementation	Conceptual and pilot-level workflows for linking legal spaces and BIM/IFC, including IDM/MVD-based extraction and LADM–IFC mapping approaches [23,71]	Generic or conceptual; not based on a country profile	Implements an Iran-specific LADM–IFC workflow for a building-scale 3D cadastre case, integrating legal and geometric layers for private and common spaces in a multi-story building.
Property Sets	Extended IFC with Property Sets to link legal and physical data [16,19]	Focused on generic LADM-based integration or geometry-oriented IFC extension, without operationalizing a country profile	Mapping the LADM country profile of Iran to IFC using custom Property Sets, covering private and common spaces
3D Cadastral Modeling	BIM-based 3D cadastre prototypes and integrated legal–physical modeling approaches at the building or city level [8,21,22]	Prototype-level; often focused on geometry or visualization; limited interoperability	Generates 3D building models from as-built cadastral maps + as-designed drawings; integrates legal boundaries and ownership; tests cross-software interoperability

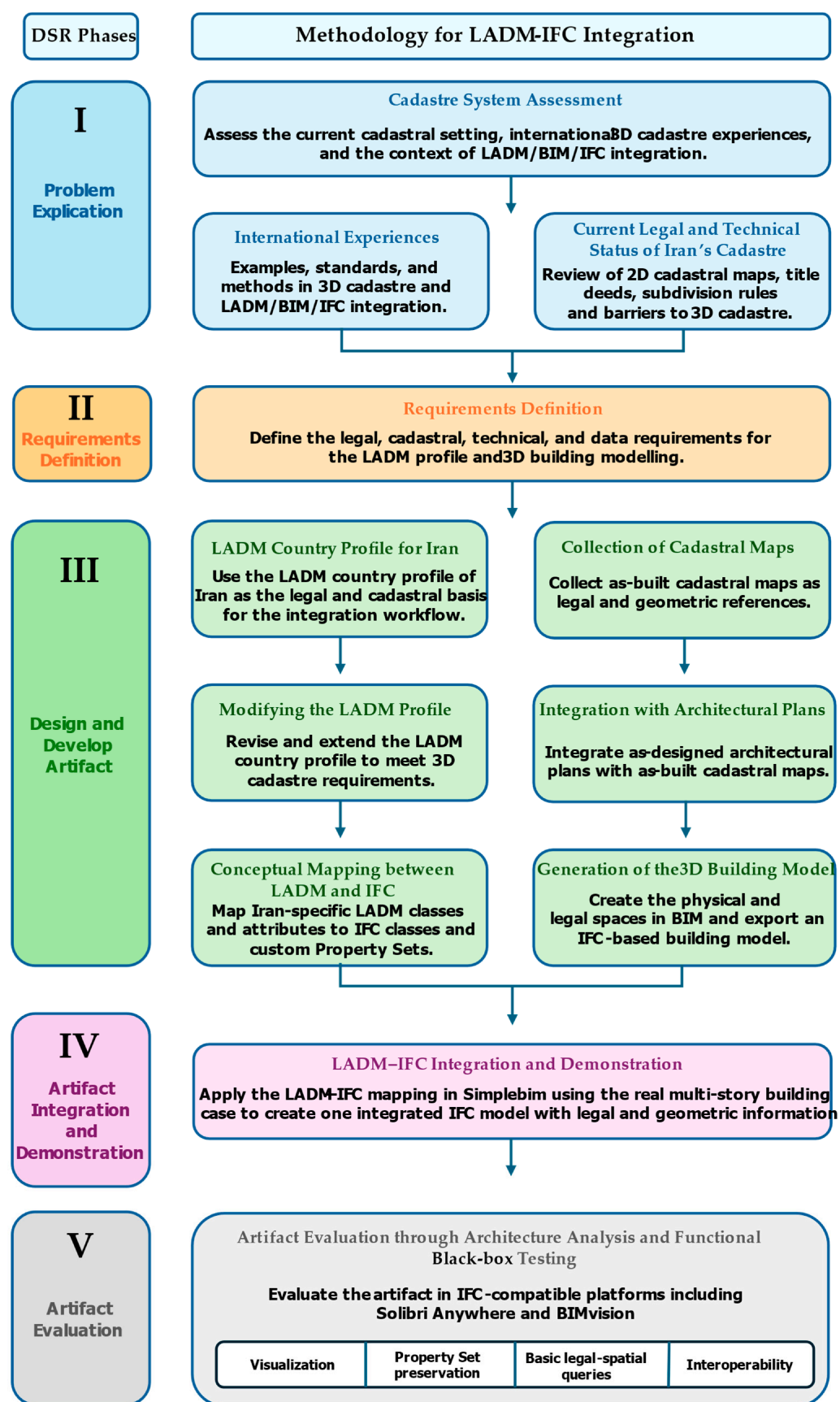
Across both categories, another common limitation observed in the existing literature is that a considerable portion of studies remains confined to conceptual mappings or abstract models, with relatively few implementations based on real-world data. This limits the assessment of the operational feasibility of the proposed approaches and their applicability in actual cadastral workflows.

In response to these gaps, the present study contributes to both the country profile and methodological levels through several specific extensions. At the country profile level, it operationalizes the LADM country profile of Iran for 3D cadastre, thereby addressing the lack of an implementation aligned with Iranian legal and institutional conditions. At the methodological level, the study goes beyond conceptual mapping by implementing the integration through custom IFC Property Sets, combining as-built cadastral maps with as-designed architectural drawings and official documents to generate a building-scale 3D cadastral model and explicitly representing private and common spaces within the integrated BIM/IFC environment. In addition, by testing the resulting model across multiple IFC-compatible software platforms, the study demonstrates that the proposed approach is not dependent on a single tool and supports practical interoperability and data exchange.

3. Methodology

This section describes the research workflow adopted to develop and assess the proposed LADM–IFC artifact. This study is positioned within the Design Science Research (DSR) paradigm [79,80], in which the developed LADM–IFC integrated prototype serves as the primary design artifact. The research is grounded in the absence of an operational 3D cadastral system in Iran, which defines the relevance cycle of DSR. The rigor cycle is addressed through alignment with established international standards, particularly ISO 19152 (LADM) and ISO 16739 (IFC), as well as prior LADM–IFC integration studies. Following the DSR activity structure discussed by Johannesson and Perjons [81], particularly their treatment of designing, developing, and evaluating artifacts, the methodology distinguishes between artifact design and development, implementation and integration of the LADM–IFC mapping in the case environment, artifact demonstration, and artifact evaluation. This distinction is reflected in Figure 6 and further specified in Table 2 using Hevner et al. [79]’s design evaluation methods [79]. Within this DSR framework, a proof-of-concept prototype-based approach is adopted to examine the feasibility of integrating the LADM country profile of Iran with IFC using available cadastral, architectural, legal, and software resources. This methodological choice is considered appropriate and well justified given the standards-driven nature of the research problem and the current absence of an operational 3D cadastral system in Iran. The primary focus of this methodology is to demonstrate the practical feasibility of integrating legal and spatial data in accordance with international standards while leveraging available data, tools, and institutional conditions.

To support the practical implementation of the proposed framework, the study employs a building-scale case study, which enables the examination of the real-world application of the integrated model within an actual scenario. While the study does not aim for statistical generalization, the integration logic and the proposed framework are designed to be transferable to similar building types and suitable for future pilot studies. The methodology is organized into five DSR-aligned phases: problem explication, requirements definition, design and development of the artifact, artifact integration and demonstration, and artifact evaluation (Figure 6). These phases are operationalized through technical activities, including cadastral system assessment, review of international experiences and Iran’s legal–technical cadastral status, requirements extraction, LADM country-profile revision, integration of cadastral and architectural data, LADM–IFC mapping, BIM-based 3D modeling, implementation of the LADM–IFC mapping in the IFC model using Simplebim 11 (Datacubist Oy, Tampere, Finland), and functional testing of the integrated IFC output.



Note: In this study, artifact evaluation includes architecture analysis and functional black-box testing of the integrated IFC output.

Figure 6. Research methodology.

Table 2. Application of Hevner et al. [79]’s design evaluation methods to the proposed LADM–IFC artifact *.

Design Evaluation Method	Applied Assessment and Testing Component	Application and Evidence
Observational	Building-scale case demonstration	Applied to a real multi-story building using cadastral maps, architectural plans, title deeds, and building permit data to demonstrate building-scale feasibility.
Analytical	Static and architecture analysis	Assessed LADM–IFC mapping consistency, custom IFC Property Set definitions, and alignment with Iran-specific cadastral requirements.
Testing	Functional black-box and interoperability testing	Tested the integrated IFC output in Solibri Anywhere and BIMvision for visualization, legal-space inspection, Property Set preservation, basic legal-spatial queries, and interoperability.
Descriptive	Informed argument	Justified the artifact design using ISO 19152 (LADM) and ISO 16739 (IFC) standards, prior LADM–IFC literature, and Iran-specific legal, technical, cadastral, and institutional conditions.
Descriptive	Scenario-based testing	Used legal-spatial query scenarios to retrieve spatial units by registered area and identify model elements linked to specific parties.

* Methods not listed in the table, including controlled experiments, simulations, optimization, dynamic analysis, structural white-box testing, and quantitative spatial accuracy assessment, were beyond the scope of this proof-of-concept study.

To clarify how the utility, quality, and efficacy of the proposed artifact were assessed, Table 2 maps the assessment and testing components used in this study to Hevner et al. [79]’s design evaluation methods.

The selected assessment and testing components were determined by the nature and scope of the developed artifact. The proposed artifact is a standards-based LADM–IFC information model and building-scale IFC prototype rather than an executable software system, database-level implementation, or operational cadastral platform. Therefore, methods requiring executable code, runtime behavior, database-level deployment, operational use, or quantitative spatial accuracy benchmarking are identified as directions for future work, particularly for database-oriented LADM–IFC implementation, specialized integration tools, and larger pilot studies.

In the problem explication and requirements definition phases, the available resources in the cadastral domain were reviewed to identify the legal, technical, cadastral, and data requirements of the proposed artifact. This review was divided into two main parts. The first part focused on reviewing global experiences with the implementation of 3D cadastre and the use of the LADM standard. In this section, the integration of the LADM standard with other 3D standards was examined to identify various implementation methods, existing tools for creating country profiles, and approaches for integrating them with 3D models. The second part was dedicated to reviewing national experiences in both 2D and 3D cadastre, with a focus on technical and legal aspects. The objective of these phases was to identify the current requirements of the State Organization for Registration of Deeds and Properties, the primary authority for cadastre in the country, and to examine the laws and regulations related to apartment subdivision. The requirements extracted from this section were then used to adapt the previously developed LADM country profile for the proposed LADM–IFC integration and to guide the 3D building modeling process. After the requirements were identified, the methodology proceeded along two parallel paths: the development of the 3D building model and the preparation of the LADM-based integration component. These two paths are described separately below.

For 3D modeling, the existing cadastral maps, which are currently used as the basis for 2D property registration, were first obtained from the State Organization for Registration of Deeds and Properties. Additionally, legal documents such as title deeds and building

permits were obtained from the relevant authorities to serve as supporting resources for 3D modeling. According to the country's cadastral regulations, the obtained cadastral maps are in a single-line format, which creates many shortcomings and deficiencies in the 3D modeling process. Therefore, to address these issues, architectural drawings (as-designed) were obtained from the constructor and used to improve the as-built cadastral maps. In the next step, after integrating and completing the 2D maps, a 3D building model was created in Autodesk Revit 2025 (Autodesk Inc., San Francisco, CA, USA), including both physical and legal spaces of the building for private and common areas. Finally, the output model was generated in the IFC file format.

For the LADM-based component, the previously developed Iranian LADM country profile [76] was used as the legal-cadastral basis of this study. This profile focuses on the current state of cadastre in Iran and was adapted in this study to support the 3D cadastre use case and LADM-IFC integration. Additionally, the existing code lists, developed in accordance with Iranian legal amendments, need to be translated into English for international publication. Once the country profile was finalized, the integration of LADM classes and IFC entities was carried out based on previous studies and an examination of IFC entities in accordance with published standards [16,22,23,62,68,71,82,83], following the "extending the corresponding 3D physical model" approach. In this process, one or more IFC entities were assigned to each LADM class. After the LADM classes had been fully mapped to IFC entities and the 3D model IFC file had been generated, the next step was to implement the LADM-IFC mapping in the IFC model and prepare the integrated artifact. For this purpose, as suggested in previous research, software such as Simplebim 11 or other similar tools can be used [16]. After importing the IFC file into Simplebim 11, the corresponding LADM classes were manually added to one or more building model elements as Property Sets and linked to the corresponding IFC entities. The attributes of these classes were then defined as properties within the model. After each Property Set and its required data format had been defined, the actual values were entered based on available documents and measurements. Finally, a comprehensive LADM-integrated BIM model was produced, which can be displayed and utilized in any IFC-compatible software environment. This integrated IFC output was then used as the basis for the functional black-box and interoperability testing described in Table 2.

4. Development of an Integrated 3D Cadastre Model

This section details the process of developing and implementing an integrated 3D cadastre model by fusing Iran's LADM country profile with the IFC standard. This process consists of three main stages, each playing a crucial role in achieving the final objective. In the first stage, the LADM country profile of Iran, developed based on previous studies and necessary modifications for 3D cadastre implementation, is introduced. This profile is derived from the core components of the international LADM model and adapted to the country's legal and technical structure. The second stage describes the method for generating the 3D building model by integrating cadastral maps (as-built) and architectural drawings (as-designed). This integration is essential to overcome the limitations of conventional 2D maps and to provide comprehensive data for 3D modeling. Finally, in the third stage, the process of integrating cadastral information based on LADM with BIM is carried out by integrating LADM classes with IFC entities and using Simplebim 11. The functionality and interoperability of the resulting integrated model are tested in IFC-compatible software platforms. This integrated approach facilitates the simultaneous management of physical, geometric, and legal information within a unified framework. The Iran-specific legal, spatial, and data-related requirements that motivated the adopted modeling and integration decisions are summarized in Table 3.

Table 3. Iran-specific cadastral requirements and their implications for LADM–BIM integration.

Analytical Dimension	Iran-Specific Practices and Conditions *	Challenges for 3D Cadastre Implementation	Key Decisions in Integration of LADM and BIM
Legal framework and regulatory sources	Registration laws and regulations, the Comprehensive Cadastre Law, the dominance of official title deeds, and the central role of the State Organization for Registration of Deeds and Properties	Strong dependence of property rights on textual documents and 2D cadastral maps	Definition of new classes, attributes, and code lists in LADM and linking legal information to IFC using IfcDocumentInformation and IfcRelAssociatesDocument through dedicated Property Sets
Spatial unit and ownership definition	Definition of spatial units based on land and buildings, classification into private and common spaces, and absence of officially defined volumetric units	Inability to represent and manage volumetric ownership in the existing system	Use of IR_LegalSpaceBuildingUnit, IR_Parcel, and related classes in LADM and adoption of IfcSpace, IfcZone, and similar entities in IFC to represent and manage volumetric spaces
Representation of boundaries and extents	Use of single-line cadastral maps without capturing thickness and height	Lack of explicit 3D boundary definition	Use of IfcRelSpaceBoundary and IfcFace in IFC and introduction of IR_BoundaryFace and IR_BoundaryFaceString classes in LADM for managing boundaries and surfaces
Registration RRRs	Absence of formally structured RRR definitions and descriptive registration of rights and restrictions in official deeds; lack of direct linkage between legal and spatial data	Inability to perform spatially explicit analysis of RRRs	Remodeling legal concepts in RRR form within LADM, localization through attributes and code lists, and implementation in IFC via dedicated Property Sets
Spatial data capture and production practices	2D terrestrial survey-based maps with local coordinate systems; UTM coordinates available only at the property centroid, with property boundaries recorded in textual form in official title deeds; survey accuracy inside buildings ~1:100; cadastral boundary accuracy at an urban scale ~1:500	Insufficient cadastral data for reliable 3D modeling	Integration of cadastral maps with architectural As-Designed drawings, 3D modeling, and generation of IFC outputs containing both physical and legal spaces

* Source: Official laws, regulations, and administrative circulars published by the State Organization for Registration of Deeds and Properties of Iran (SSAA), available at <https://cadastr.ssaa.ir> (accessed on 6 May 2026).

4.1. Iran's LADM Country Profile

In this study, the previously developed country profile was used, with minor revisions to improve and adapt it for application in a 3D cadastre (see Appendix A). As part of this update, the class IR_BoundaryFace was added to the model to enable more accurate modeling of 3D boundaries and to represent the geometry of the spatial unit boundary surfaces. The country profile of Iran consists of 22 classes, derived from three main packages and one subpackage of the LADM model. Additionally, this profile includes 23 code lists, each designed to localize the concepts of the international model and align them with the country's legal and technical structures. The validation of the original country profile through conformance testing, surveys, and expert evaluation was reported in a previous study [76]. In the present study, the previously developed profile is used as a basis and is revised only to the extent necessary for application in a 3D cadastre.

4.2. Generation of the 3D Building Model (From 2D Map to Comprehensive 3D Model)

According to the laws governing property registration in Iran, the official property registration maps are 2D cadastral maps showing the residential-floor unit together with its related common spaces (Figure 7a) and the basement-level parking and service/common spaces (Figure 7b). These maps provide a vertical representation of land features and include information such as dimensions, area, property boundaries, neighboring properties, and border types. One of the most important features of these maps, which grants them legal validity and allows them to be used as official documents, is that the surveyor from the State Organization for Registration of Deeds and Properties is responsible for their preparation and signing. This signature provides the map with legal credibility, making it an official document within the country's property registration system. These maps are produced using conventional terrestrial surveying methods and are defined within a local coordinate reference system. In terms of geometry, these maps, known as single-line maps, feature boundaries drawn with a single line and limit the survey to features that have legal implications for private and common ownership. Despite their high geometric accuracy, these maps have limitations, such as the omission of height data, the disregard for feature thickness, and the lack of detailed surveying. Although the registration system does not currently require these details and the existing single-line maps are effective for 2D cadastral purposes, the absence of 3D data remains a major obstacle to the transition toward advanced cadastral systems and the realization of a 3D cadastre.

To address these limitations, the use of architectural drawings (as-designed) to enrich the single-line cadastral maps (as-built) is considered essential. These maps, which are prepared in the early stages and submitted to the municipality to obtain building permits, provide useful details for 3D modeling, including height, floor slab and wall thicknesses, and other geometric information through the architectural floor plan (Figure 8a) and building section (Figure 8b). However, they also have certain limitations, such as the possibility of changes during construction and the lack of official recognition and legal validity required for issuing property deeds.

For these maps to compensate for each other's weaknesses and to optimally leverage the advantages of both, a precise and comprehensive integration that considers all the details is necessary. In this approach, cadastral maps serve as the primary basis and are enriched with information from architectural drawings. The resulting enriched cadastral-architectural maps are shown for the residential-floor spaces (Figure 9a) and the basement-level parking and service/common spaces (Figure 9b) as examples of the maps prepared for 3D modeling. In cases where the property has undergone changes, the cadastral map is regarded as the final reference and the primary criterion. This process ensures the legal

validity of the cadastral maps while enabling the use of geometric and 3D details from the architectural drawings.

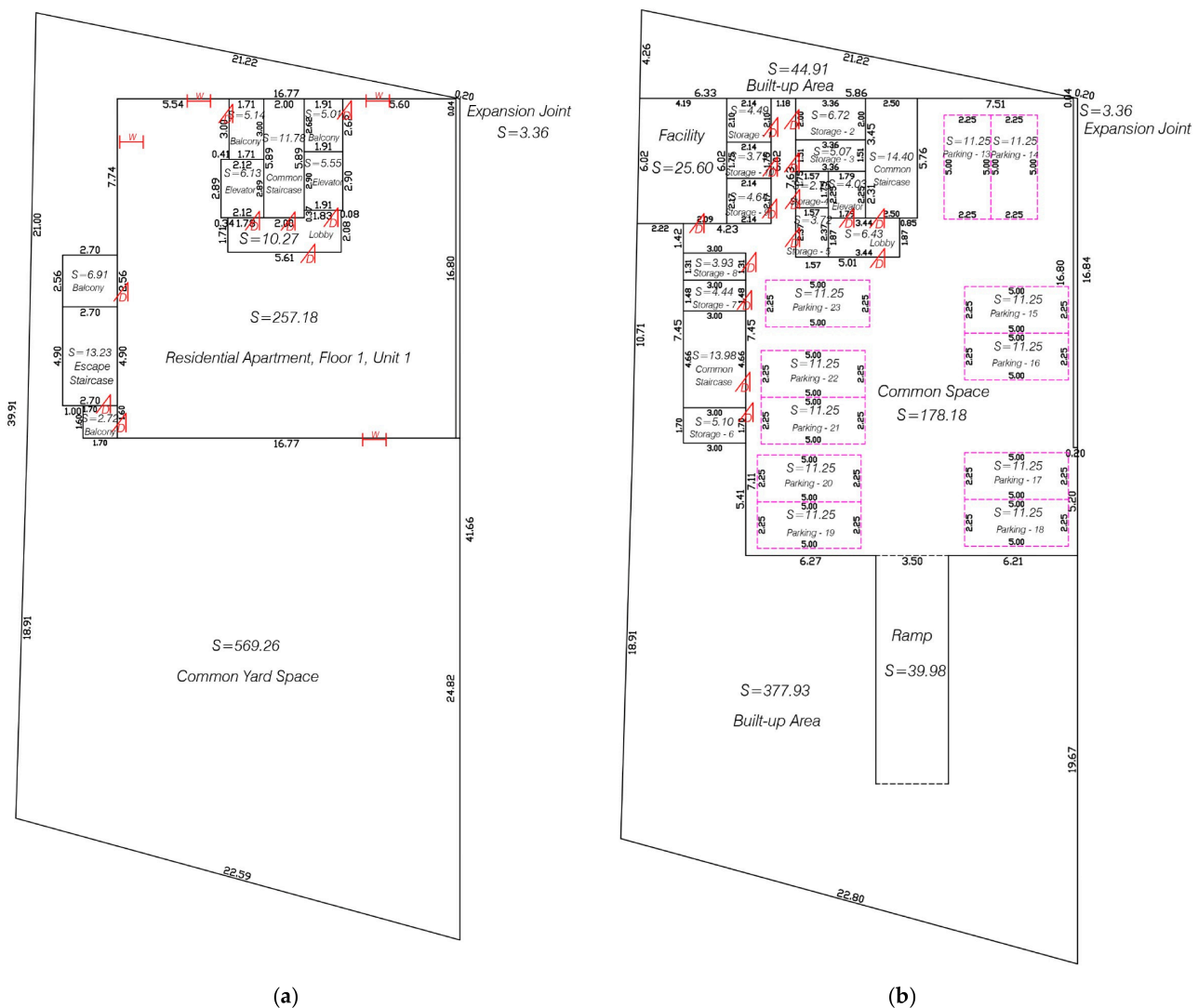


Figure 7. As-built single-line cadastral registration map: (a) residential-floor unit and related common spaces; (b) basement-level parking and service/common spaces.

After preparing the base map, the 3D modeling process begins in Autodesk Revit 2025. At this stage, utilizing the available information, including 2D maps, official title deeds (Figure 10a), building permits (Figure 10b), as well as existing laws and regulations related to boundary delineation and their assignment to both private and common spatial units, a 3D model is created for the physical and legal spaces of the building under study. Special attention was given to the modeling of walls, given their critical role in delineating boundaries between legal and physical spaces. In the 3D modeling process, wall representation and allocation were defined in accordance with the type of adjacent spatial units and the applicable legal and cadastral regulations in Iran. Specifically, for boundaries between spatial units of the same category (common–common or private–private), the wall thickness obtained from the as-designed architectural drawings was equally divided between the adjacent spaces. Conversely, for boundaries between spatial units of different categories (common–private), the entire wall thickness was assigned to the private unit, consistent with prevailing cadastral practices and legal requirements.

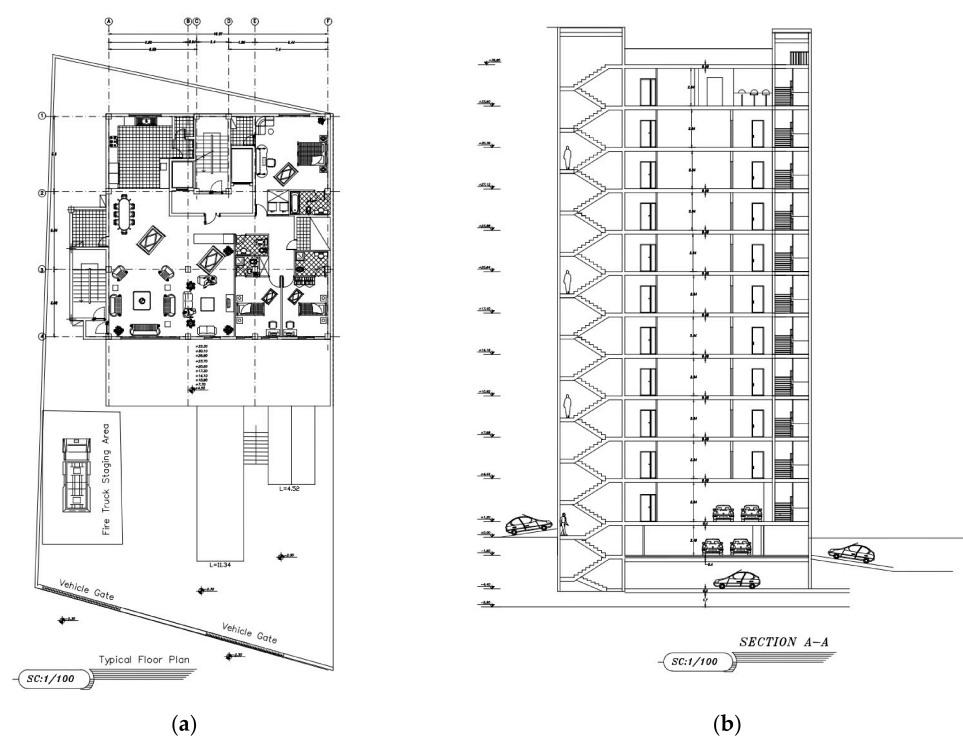


Figure 8. As-designed architectural drawings: (a) architectural floor plan showing internal layout, wall thicknesses, and geometric details; (b) building section showing floor heights and vertical details.



Figure 9. Integrated cadastral-architectural map generated for 3D modeling: (a) residential-floor spaces; (b) basement-level parking and service/common spaces.

In the Iranian legal and cadastral context, common parts refer to spaces and components intended for the collective use of residents, as opposed to those allocated to individual private units. Accordingly, areas such as staircases, corridors, shared access zones, common

parking spaces, service and utility areas, shafts, mechanical rooms, and similar elements were treated as common parts in the developed model. From a legal perspective, these areas were distinguished from private legal spaces and considered part of the shared condominium structure, in accordance with Iranian condominium law. From a geometric perspective, they were modeled as separate spaces and related building elements within the BIM environment and were exported in IFC together with the corresponding private units. This distinction ensured that the integrated model accurately reflects both the geometric configuration of shared building components and their legal differentiation from privately occupied units.

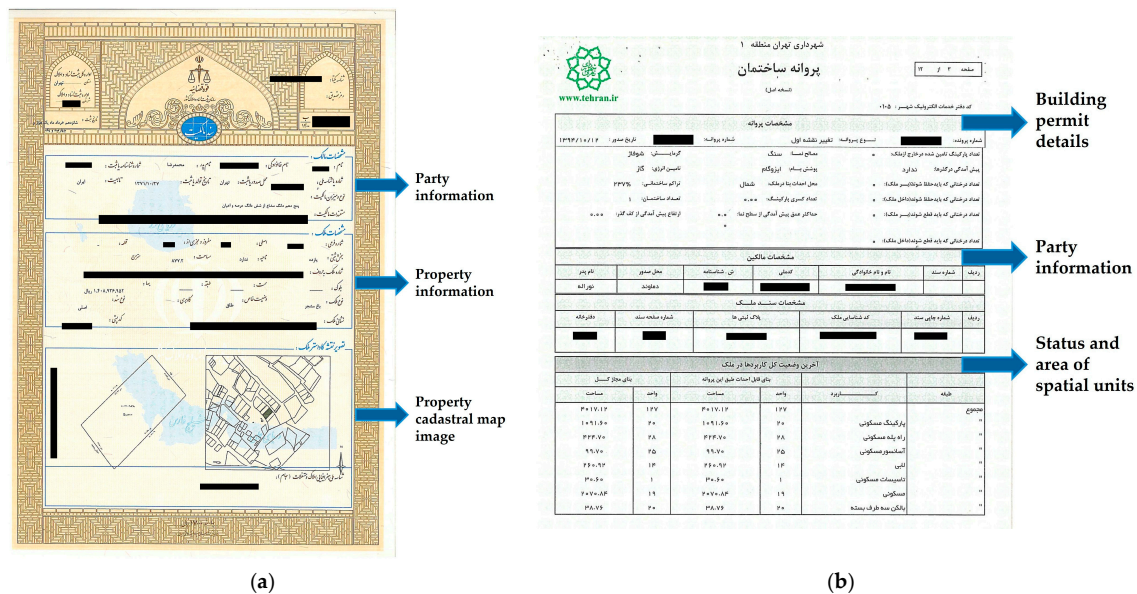


Figure 10. (a) Official title deed and (b) building permit of the modeled building.

Upon completion of this process, the 3D building model is exported in IFC format (Figure 11a), serving as a standardized interface that facilitates bidirectional data exchange between the physical environment (Figure 11b) and its digital counterpart within the BIM ecosystem.

To examine the use of the IFC model beyond the building environment and to support its visualization in a geospatial context, the model was also georeferenced. The georeferencing process of the IFC file was carried out as follows. In the first step, the UTM (Universal Transverse Mercator) coordinates of the property centroid were defined in Autodesk Revit 2025. These coordinates were the only available absolute reference for the as-built data, which had originally been captured in a local coordinate system. This approach ensures correct initial placement and visualization in geographic environments, but it is not sufficient for defining legally reliable boundaries. To improve the robustness of georeferencing at the urban scale, high-resolution cadastral maps (1:500) obtained via UAV surveys and referenced to UTM can be used to validate and adjust the model's position. Such data provide a foundation for enhancing spatial accuracy and supporting the development of a scalable 3D cadastre. Subsequently, as illustrated in Figure 12a, the generated IFC file was imported into FME Workbench 2024.0 (Safe Software Inc., Surrey, BC, Canada) and configured as a Reader. FME Workbench 2024.0 is a specialized platform for transforming, processing, and integrating spatial and non-spatial data across different formats and systems. The required parameters and entities for the conversion process were then specified. In the next step, KML (Keyhole Markup Language) was selected as the output format in the Writer section. To ensure complete data transfer, the KMLPropertySetter tool was used as a Transformer, enabling the export of all properties contained in the IFC file to the final output. As a result,

a georeferenced KML file was generated from the IFC model, which serves as a simple and preliminary demonstration of the model's interoperability in geospatial environments and at the urban scale using platforms such as Google Earth Pro and Cesium (Figure 12b) within the corresponding cadastral boundaries (Figure 12c).

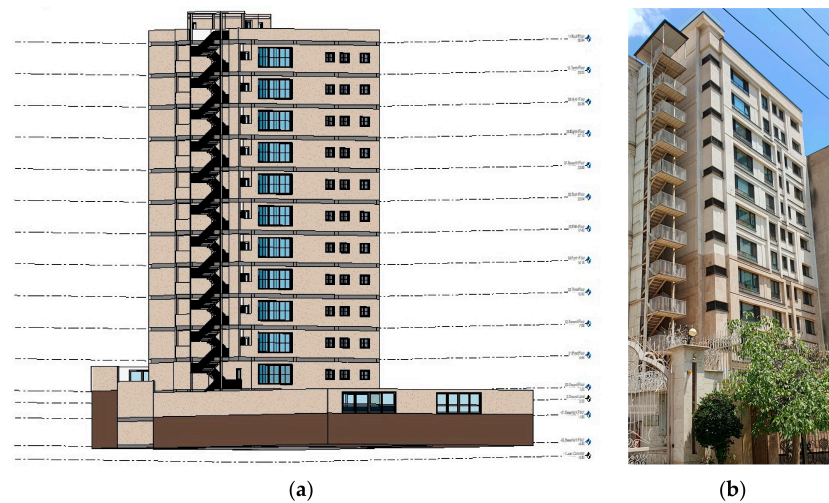


Figure 11. (a) 3D BIM model of the building developed in Autodesk Revit 2025, exported to IFC format; (b) real-world photograph of the study building.



Figure 12. (a) IFC to KML conversion method using FME Workbench 2024.0; (b) georeferenced 3D model of the building within the urban environment; (c) cadastral boundary of the study building on the satellite image (red box).

4.3. Integration of LADM and BIM and Functional and Interoperability Testing

To perform the integration process, the first step is to review existing research on mapping between LADM classes and IFC entities [16,22,23,68,71,82], as well as to examine the IFC entities according to the standards published by BuildingSMART [83] and ISO [62]. Based on this review, a mapping table between the LADM classes and their corresponding IFC entities was created (Table 4).

In this mapping, multiple IFC entities are considered for most LADM classes, as these classes can appear in different formats. For example, since the Party class in the LADM standard can be defined as either a natural person or a legal entity, the equivalents IfcPerson and IfcOrganization are considered alongside IfcActor. In addition, some BIM software does not support all IFC entities, and offering multiple equivalent options minimizes this limitation, providing greater flexibility in the mapping and data exchange process. Alongside the mapped classes, for some classes in the Administrative package, such as LA_RRR, LA_Right, LA_Restriction, LA_Responsibility, and LA_Mortgage, which have no direct equivalent in IFC, an independent Property Set in the Pset format is used. This approach allows for modeling legal and administrative information, which inherently differs from the entities of the IFC standard. As a result, information on rights, restrictions, responsibilities, and mortgages is added to the model as a collection of custom Property Sets.

After the mapping step, Simplebim 11 was used for its implementation and application. This software can be used to edit, merge, and georeference IFC data during the integration of cadastral information into the BIM model. It can modify, adjust, and add attributes to IFC data using the Property Value Editor tool. Another key feature of this software is its ability to maintain the structure of IFC elements, such as IfcGeographicElement and IfcBuilding, when integrating legal, physical, and surveying data [84].

Table 4. Mapping between the classes of the LADM country profile and the IFC entities.

Package	LADM Class	IFC Entity
Party	IR_Party	IfcActor IfcPerson IfcOrganization IfcPersonAndOrganization
		IfcGroup IfcOrganization
		IfcRelAssignsToGroup IfcPersonAndOrganization
Administrative	IR_BAUnit	IfcZone Pset *_LA_BAUnit
	IR_RRR	Pset_LA_RRR
	IR_Right	Pset_LA_Right
	IR_Restriction	Pset_LA_Restriction
	IR_Responsibility	Pset_LA_Responsibility
	IR_Mortgage	Pset_LA_Right Pset_LA_Restriction Pset_LA_Mortgage
		IfcDocumentInformation IfcDocumentReference IfcRelAssociatesDocument
	IR_AdministrativeSource	

Table 4. Cont.

Package	LADM Class	IFC Entity
Spatial Unit	IR_SpatialUnit	IfcSpace IfcSite IfcExternalSpatialElement
	IR_SpatialUnitGroup	IfcSpatialZone IfcZone
	IR_Level	IfcSpatialZone IfcZone
	IR_LegalSpaceBuildingUnit	IfcSpace IfcZone
	IR_CadastralUnit	IfcClassification + IfcClassificationReference
	IR_Parcel	IfcSite
	IR_LandImprovement	IfcBuilding IfcBuildingElement IfcProxy
Surveying and Spatial Representation	IR_SpatialSource	IfcDocumentInformation IfcDocumentReference IfcRelAssociatesDocument
	IR_Point	IfcCartesianPoint
	IR_BoundaryFaceString	IfcPolyLoop IfcEdgeLoop IfcPolyline
	IR_BoundaryFace	IfcFacetedBrep IfcConnectedFaceSet IfcRelSpaceBoundary IfcFaceSurface IfcFace
Source	IR_Source	IfcDocumentInformation IfcDocumentReference IfcRelAssociatesDocument

* Pset: Property Set.

First, the IFC output generated from Autodesk Revit 2025 was imported into Simplebim 11, and a Dataflow for defining LADM classes was created within the Dataflow Presets section. This process was carried out by defining a Property Set consisting of IFC entities and their corresponding attributes. The attributes were manually defined as properties within the created Property Sets. In this study, 22 LADM classes from Iran's country profile were incorporated as Property Sets, and 172 LADM attributes were defined as properties, with the data format also determined at this stage (Figure 13). This approach enables the systematic and organized structuring of cadastral information within the IFC standard, facilitating the complete integration of legal and physical data.

Next, after defining all the Property Sets, the Dataflow was executed, producing a BIM model along with LADM classes, each placed in its corresponding predefined spatial or descriptive section (Figure 14).

Finally, to test the functionality and interoperability of the model and assess its implementation in other software compatible with the IFC standard, as well as to enhance the visualization of legal spaces and examine the possibility of making changes to the model and performing analyses such as queries, an IFC output of the integrated model is extracted from the Simplebim 11 software. This output enables comprehensive model

testing, supports data exchange, and allows the model to be used across various platforms. For transparency, the interoperability of the IFC-based integrated model was tested across software platforms. A summary of the tested platforms and the testing aspects considered in each environment is provided in Table 5.

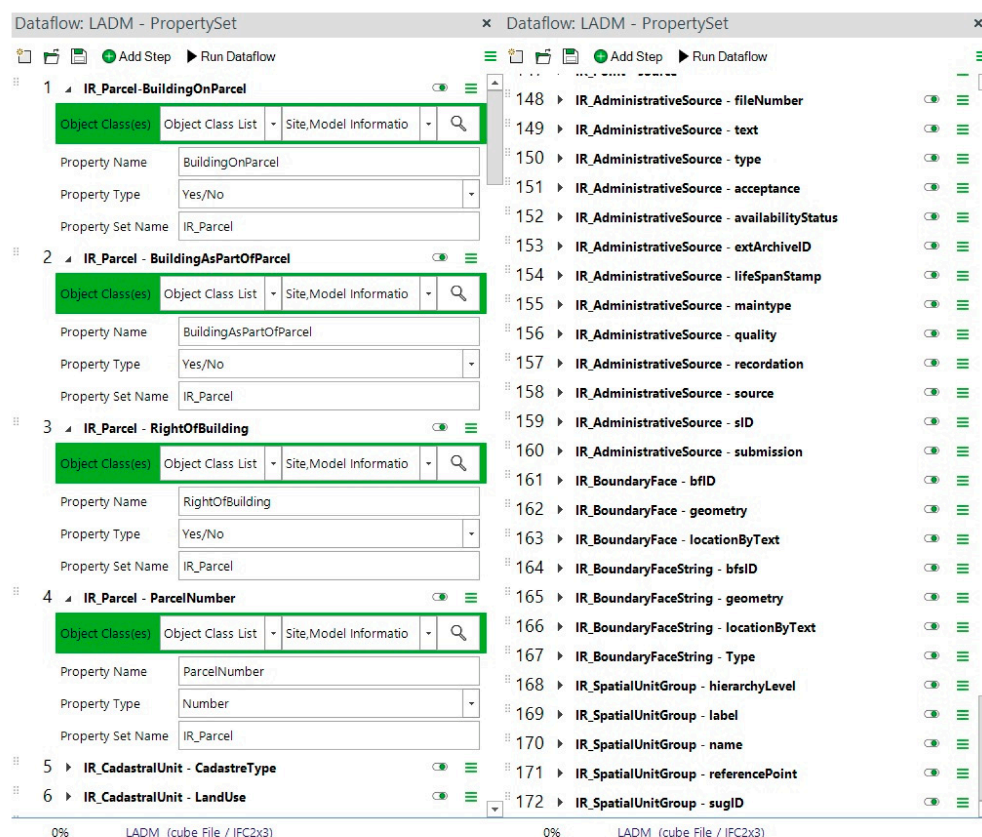


Figure 13. Definition of LADM classes in the form of Property Sets and properties within Simplebim 11.

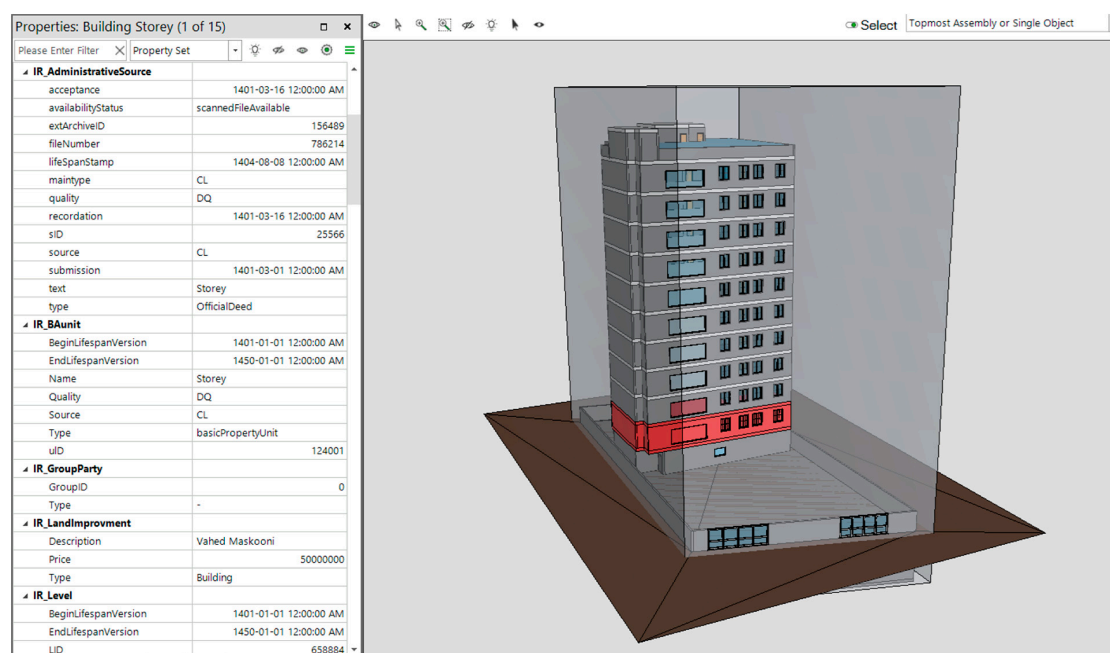


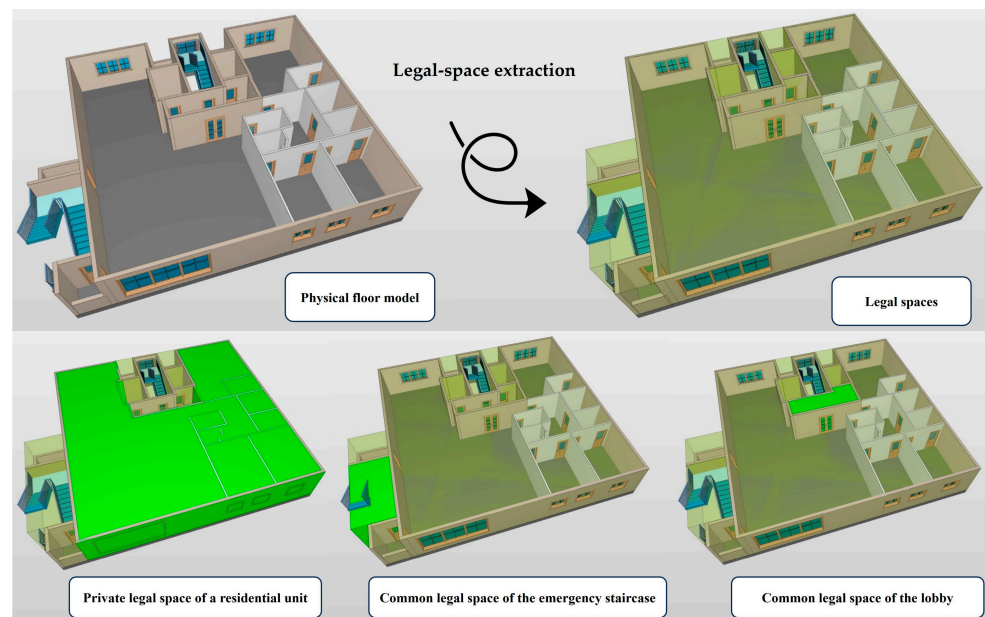
Figure 14. A subset of LADM classes defined for a single floor of the building.

Table 5. Interoperability and Functional Testing of the Integrated IFC Model Across Software Platforms (✓ = Supported; ✗ = Not supported).

		Solibri Anywhere 25.9.0	BIMvision 3.1.0
Merging projects	Support IFC	✓	✓
	IfcZIP	✓	✓
	Reviewing a few models	✗	✓
	Edit IFC	✗	✓ (with plugin)
	Export as IFC	✗	✓ (with plugin)
Model checking	Preview the IFC structure	✓	✓
	3D navigation	✓	✓
	Cut the view	✓	✓
	Mark	✓	✗
	Saving the model views	✗	✓ (with plugin)
	Finding and grouping objects from the model	✓	✓ (with plugin)
	Sliding floors of the model	✗	✓
	Checking changes between model revisions	✗	✓
	2D projection (in space)	✓	✓
	Legal space visualization	✓	✓
	Filling slice	✗	✓
	Selection area	✓	✓
	Query	✗	✓ (with plugin)
	Property Sets preserved	✓	✓
	API	✗	✓
Measurement	Edge	✓	✓
	Area	✓	✓
	Volume	✓	✓

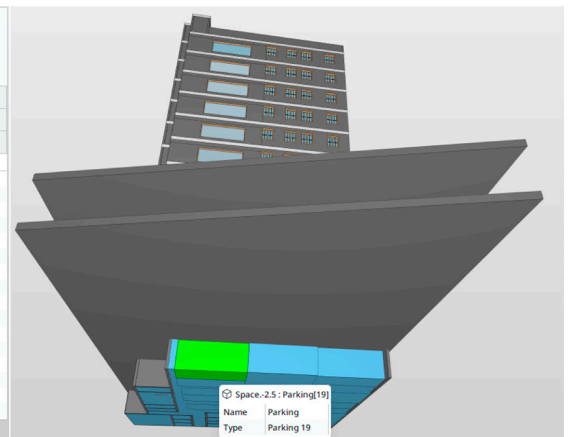
The following examples illustrate how the integrated IFC model and its cadastral Property Sets were visualized and inspected in Solibri Anywhere 25.9.0 (Solibri Inc., Helsinki, Finland) as one of the tested software environments. Figure 15a first clarifies the separation of physical spaces from legal spaces within one floor of the building, showing the distinction between private and common legal spaces. Figure 15b then presents the inspection of one representative legal space and its associated LADM classes, defined as Property Sets. As an IFC viewer, Solibri Anywhere 25.9.0 enables visualization of the 3D model, legal spaces, and cadastral attributes stored in the IFC model (Figure 15a,b).

BIMvision 3.1.0 (Datacomp IT Sp. z o.o., Kraków, Poland) was also used as one of the primary tools for viewing and analyzing IFC models. This software provides comprehensive model visualization features and, through specialized plugins, offers advanced functionality. For example, the IFC Edit plugin can be used to add, modify, or delete properties and Property Sets associated with model components. It also allows the edited model to be saved and exported as an updated IFC file (Figure 16a,b).



(a)

INFO	
Space-2.5 : Parking[19]	
BIM Data	IFC Standard Properties
IR_Right	IR_RRR
IR_GroupParty	IR_Party
ePset_ModelInfo	IR_AdministrativeSource
Other Properties	
IR_SpatialSource	
IR_SpatialUnit	
IR_SpatialUnitGroup	
IR_Point	
IR_Responsibility	
IR_Restriction	
IR_BoundaryFace	
IR_BoundaryFaceString	
Property	Value
Area	11.25 m2
BeginLifeSpanVersion	1401-01-01T00:00:00
Dimension	3D
EndLifeSpanVersion	1450-01-01T00:00:00
Label	Space
Quality	DQ
ReferencePoint	5,452,143,960,618
Source	CL
SurfaceRelation	below
TasbitCheck	True
Type	Registered
Volume	45.00 m3
ZoneRef	39
extAddressID	10,050,781
suID	125,699



(b)

Figure 15. Visualization of legal spaces and cadastral attributes in the integrated BIM/IFC model: (a) separation of physical spaces from legal spaces within one building floor, illustrating private and common legal spaces; (b) inspection of a legal parking space and its associated LADM classes and Property Sets in Solibri Anywhere 25.9.0.

Furthermore, the Search and Select plugin offers various tools for searching, filtering, highlighting, and color-coding different parts of the model, where the supported query mechanism conceptually follows the Select-From-Where paradigm and is implemented in BIMvision 3.1.0 through a Set-Name-Value structure, which aids in a more targeted analysis of model components and the extraction of necessary information (Figure 17a,b).

The testing results showed that the proposed model performs satisfactorily in terms of preserving geometric integrity, semantic information consistency, and the retention of legal Property Sets across the tested platforms. However, limitations were observed in analytical aspects, including query capabilities and advanced control mechanisms. In BIMvision 3.1.0, query functionality was limited, and the definition or execution of complex queries was not supported. In contrast, Solibri Anywhere 25.9.0, as a viewer tool, does not support direct property-based queries, and its functionality is primarily focused on visualization, navigation, and inspection of the IFC model structure. Furthermore, none of the software platforms used in this study provided the capability to define or perform topological checks to validate topological relationships among spatial units.

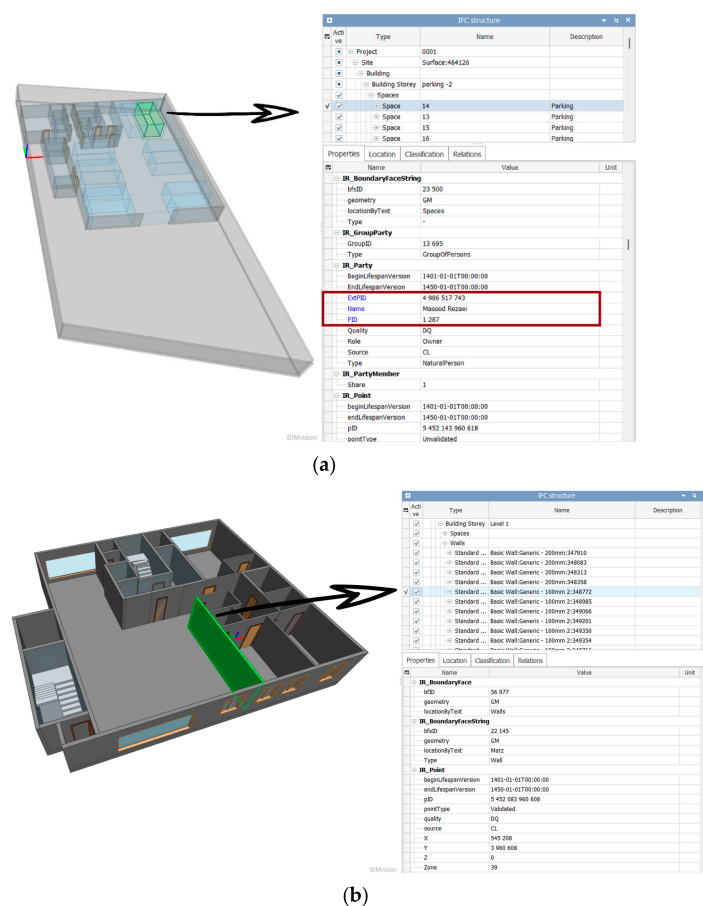


Figure 16. Visualization and editing of IFC property values in BIMvision 3.1.0: (a) legal space with its corresponding edited IFC properties; (b) boundary between physical spaces.

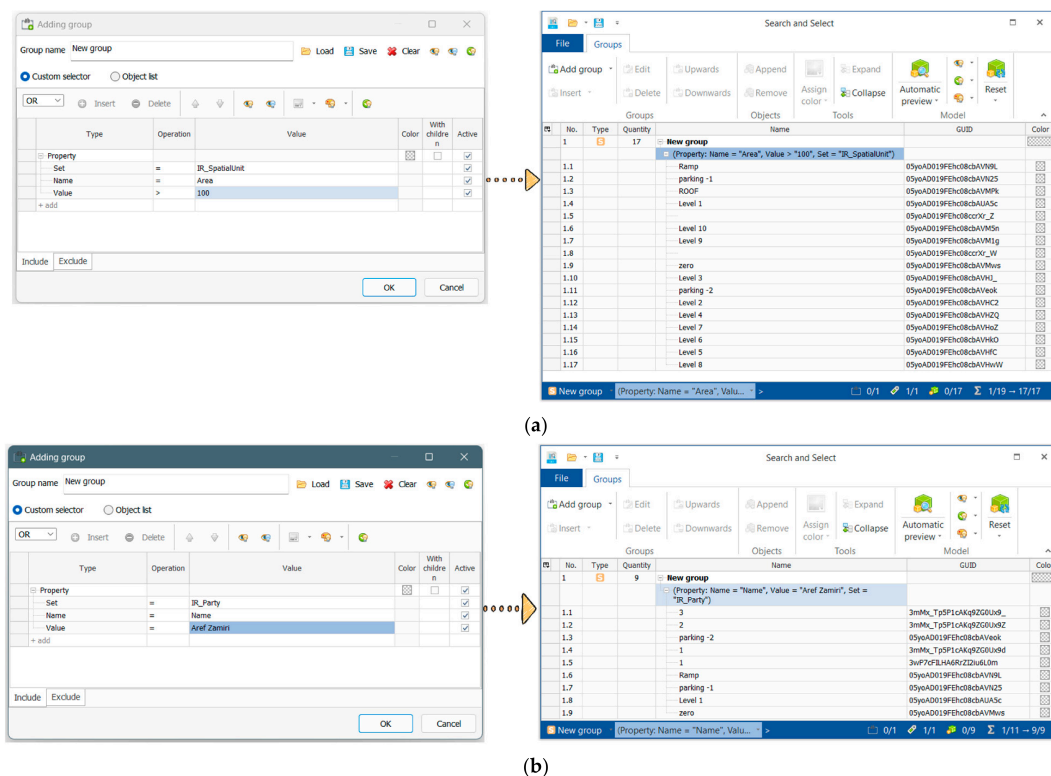


Figure 17. (a) Using BIMvision 3.1.0 to query Spatial Units whose registered area exceeds 100 m² and (b) querying model elements linked to a specific Party.

5. Discussion

This section interprets and analyzes the main findings of this research, which examined the feasibility of implementing a 3D cadastre system in Iran through the integration of the LADM country profile and the IFC standard within a BIM framework. The results obtained at the building scale show that this integration is achievable both conceptually and technically and can serve as the first step toward transitioning from the 2D cadastral system to a unified 3D framework. In this section, the analysis of the results, the advantages and challenges of the proposed approach, and its position in the development and implementation of a large-scale 3D cadastre system are discussed.

5.1. Achieving the Research Goals and Result Analysis

First, the LADM country profile of Iran, proposed with a focus on the country's current cadastral requirements, was revised with minor adjustments. Adding the IR_BoundaryFace class enabled more precise management of 3D boundaries. Second, the process of integrating as-built cadastral maps and as-designed architectural drawings for 3D model generation in Autodesk Revit 2025 was carried out. Using the cadastral map as the final reference and the architectural drawings as the source for geometric enrichment provided a practical solution for linking legally valid data with geometrically enriched data. A critical comparison between the as-designed architectural drawings and the as-built cadastral data was conducted to assess the accuracy of the integrated 3D model. Minor deviations due to construction modifications were observed and accounted for by prioritizing legally valid cadastral maps while using as-designed data solely for geometric enrichment. Larger discrepancies, however, would require correction or official verification before the property could proceed to cadastral registration and title deed issuance. This approach ensures that the resulting 3D model maintains legal reliability while reflecting the intended spatial design, though the remaining discrepancies highlight areas for further refinement in evaluation procedures. Therefore, the proposed integration strategy can be particularly useful for creating 3D models of buildings that cannot be resurveyed. Third, the mapping between the LADM country profile classes and IFC entities was performed and implemented in Simplebim 11 software. Defining Property Sets for all LADM classes individually, defining their attributes as Properties, and creating specific Property Sets for the Administrative package (including RRR, Right, Restriction, Responsibility, and Mortgage) allowed legal information to be added to the BIM model without altering the fundamental structure of IFC. The functional and interoperability testing of the integrated model in software such as Solibri Anywhere 25.9.0 and BIMvision 3.1.0, along with the possibility of performing selected legal-spatial queries, demonstrated that the proposed approach is not only conceptual but also practically viable.

5.2. Position of the Proposed Model in the Literature and Innovative Aspects

Given this practical viability, the approach adopted in this research, using LADM as the legal framework and IFC as the spatial framework, aligns with the prevailing trends in international studies, particularly research that suggests integrating these two standards through Property Sets. However, several innovative aspects of this work merit attention:

- Operational implementation, adaptation, and mapping of the LADM country profile within an IFC-based workflow for 3D cadastre: Unlike prior studies that mainly focus on generic LADM-IFC mappings using core standard classes, this study uses and adapts the LADM country profile of Iran to support 3D cadastral requirements and implements it within a practical, end-to-end IFC-based workflow aligned with national legal and institutional procedures. The integration explicitly relies on country-specific classes, code lists, and relationships, ensuring consistency with Iran's legal

and organizational cadastral structure and resulting in a model that is practically applicable to 3D cadastre implementation.

- Integration of as-built and as-designed maps: The integration of as-built and as-designed maps, while keeping the cadastral map as the reference, provides a framework consistent with existing legal regulations and allows architectural data to be used in a 3D cadastre.
- Functional and interoperability testing across independent software platforms: The integrated IFC model was tested in two independent software platforms, Solibri Anywhere 25.9.0 and BIMvision 3.1.0, using a functional black-box testing approach. The testing confirmed model readability, visualization, and preservation of LADM-based Property Sets across the tested environments.

5.3. Advantages and Achievements of the Proposed Model

The results of the prototype implementation highlight several fundamental advantages of the proposed model, which, when combined, make it a viable option for developing a 3D cadastre in Iran.

The first advantage is the integration of legal and spatial data. The LADM-IFC model presented in this study demonstrates that information on rights, restrictions, responsibilities, mortgages, and the characteristics of stakeholders (parties) can be combined with geometric data such as building units, common spaces, parking areas, and other physical components within a unified framework. This integration shifts the interpretation of legal rights and ownership relationships from reliance solely on textual documents toward a direct connection with the actual geometry of spaces. This reduces ambiguity, increases transparency, and facilitates legal-spatial analyses.

The second advantage is the model's full compatibility with relevant global standards. Relying on ISO 19152 (LADM) and ISO 16739 (IFC) ensures that the proposed model aligns with the mainstream standardization efforts in land administration and BIM. This compatibility not only enables the use of existing international experiences, guides, and tools but also increases the likelihood that the model will be used within broader ecosystems such as 3D GIS systems, smart cities, and digital twins. Additionally, using the IFC format as the common data carrier ensures that the model can be transferred to a wide range of BIM software, minimizing dependence on any single platform. Although the workflow developed in this study is based on the Iranian LADM country profile and national cadastral requirements, its general methodological logic can be adapted to other national LADM country profiles. This adaptability is possible because the workflow relies on standard-based integration between LADM and IFC through class mapping and IFC Property Sets. However, the detailed implementation would remain country-specific and would need to be adjusted according to each country's legal framework, cadastral concepts, code lists, RRR definitions, spatial unit types, and institutional procedures.

The third advantage is the potential to extend the model to larger projects and to integrate it with other 3D standards at the urban scale, covering both surface and sub-surface environments. Although the implementation in this research was conducted at the building scale, the model structure, based on the LADM standard packages and the layered architecture of IFC, allows it to be extended to the block, neighborhood, and city scales without altering the core logic. The use of spatial units, spatial unit groups, and various cadastral data registration levels in the LADM country profile, combined with the modeling capabilities of IFC, creates a foundation that not only prevents the prototype from being limited to a single instance but also positions it as a core for larger pilot designs and, ultimately, the establishment of national 3D cadastre systems.

Furthermore, relying on LADM and IFC enables their coexistence and integration with standards such as CityGML at the city scale and LandInfra for infrastructure and subsurface applications. By using mapping definitions and ADEs, the model presented in this research can be applied within urban and subsurface frameworks, providing a common foundation for linking 3D cadastre, smart cities, and infrastructure management systems.

5.4. Practical Challenges and Limitations

Alongside the aforementioned advantages, the process of designing and implementing the proposed model revealed a series of challenges and limitations that must be seriously considered in any efforts to establish a 3D cadastre in Iran.

(a) *Data Limitations.* One of the main challenges relates to the cadastral maps, which are in a single-line format. These maps, designed for the 2D system, depict only land boundaries and some legally significant features as single lines, with no consideration of element thickness, internal space division, floor height, or 3D geometry. As a result, while they are legally valid and accurate in two dimensions, they are not reliable on their own for creating 3D models and require enhancement through architectural drawings, 3D survey data, or other information sources. This dependency necessitates the definition of new procedures for data control, alignment, and integration. Substantial discrepancies between as-designed drawings and actual construction conditions would prevent the map from being approved for cadastral registration in Iran. Such cases require correction, field verification, or officially revised documents before the property can proceed to title deed issuance.

(b) *Software/Tool Limitations.* Another challenge highlighted in this study concerns the limitations of BIM software in providing full and consistent support for the IFC standard, particularly for complex structures such as cadastral Property Sets. Not all software can interpret and display all the entities and relationships of IFC uniformly. In some cases, semantic information may be lost during import, export, or conversion processes. This issue means that the design and implementation of LADM-IFC models require careful selection of tools, precise parameter settings, and in some cases, the development of customized procedures or plugins to ensure that the legal and cadastral meaning of the data is maintained throughout the model's lifecycle. It should be noted that the long-term maintenance, updating, and automation of IFC Property Sets require a dedicated database implementation. In the current proof-of-concept prototype, these tasks are performed manually, either individually for each element or in groups of similar elements. For large-scale or national implementation, these manual procedures should be replaced by a database-driven and semi-automated approach, in which cadastral attributes are managed in an LADM-based spatial database and linked to IFC elements as Property Sets when needed. Developing a database-driven system in the future would enable efficient and automated management of legal attributes across the entire 3D model.

(c) *Institutional/Legal Limitations.* Beyond the data and software levels, the lack of a clear official framework for 3D cadastre in Iran is one of the most significant limitations identified in this research. The current division of responsibilities, guidelines, and regulations is based on a 2D logic, where 2D cadastral maps and textual documents play the central role. The introduction of 3D models, in which legal spaces are defined volumetrically, and ownership relationships are presented in three dimensions, inevitably requires revisions to processes, redefinition of organizational responsibilities, and, in some cases, amendments to legal texts and regulations. Until such an institutional and legal framework is clearly designed and approved, advanced technical models will remain merely auxiliary tools and will not be able to become part of the formal registration system.

In summary, this section demonstrates that the integrated LADM–IFC model presented in this research, while offering key advantages such as the integration of legal and spatial data, compatibility with global standards, and the potential for expansion to larger projects, faces significant challenges at the levels of data, tools, and institutions. The review of these advantages and challenges sets the stage for the next section, where the final conclusions of the research and specific recommendations for the continued implementation of 3D cadastre in Iran will be provided.

6. Conclusions and Recommendations

In this section, the main findings and achievements of the research, derived from the development and implementation of the integrated LADM–IFC model at the building scale, are summarized. Based on these findings, recommendations for future research directions and the necessary steps for the practical implementation of 3D cadastre in Iran are provided.

6.1. Conclusions

The rapid growth of complex and dense construction in Iranian metropolitan areas, coupled with the emphasis on transparency in land and housing sectors in higher-level documents, has increasingly highlighted the need to transition from a 2D cadastre to a 3D cadastre. In this research, a prototype of an integrated 3D cadastre model was developed, implemented, and functionally tested at the building scale based on the LADM country profile of Iran and the IFC standard. Overall, the research findings indicate that integrating LADM and IFC into a BIM model is conceptually and technically feasible in Iran’s legal and technical context. The developed country profile can serve as a reference framework for 3D cadastre, and using the IFC format as a common data carrier enables interoperability with a wide range of BIM software and potential smart city and digital twin platforms.

At the same time, the research shows that the full realization of a 3D cadastre at the national level is not solely a technical issue. Until a clear formal institutional and legal framework is developed for the acceptance of 3D models within the official registration system, such models will remain at the level of proposed technical solutions rather than becoming part of official cadastral practice. However, the presented prototype can serve as a practical and documented first step, providing a basis for designing larger-scale pilots and making policy decisions in the process of establishing a 3D cadastre in Iran.

6.2. Recommendations for Future Work

The scope of this research was limited to a proof of concept, with the aim of demonstrating feasibility rather than designing and implementing an operational system at the national scale. However, the results show that the conceptual and technical framework used can be extended and scaled to larger applications. Given the proof-of-concept scope of this research and its limitations, the following areas are proposed for future research and action:

- Extension to Complex and Mixed-Use Building Models

The case study presented in this research focuses exclusively on residential spaces. Future research should apply the proposed LADM–IFC integration framework to more complex building models involving mixed land use functions, such as residential–commercial buildings or other buildings with mixed functional uses. This would enable a more comprehensive evaluation of the model’s capability to represent heterogeneous legal spaces and ownership structures in real-world 3D cadastral scenarios.

- Expansion from Building Scale to Urban Scale

It is recommended that the presented prototype be extended from the scale of a single building to a cluster of buildings in a block and eventually to an urban neighborhood. This expansion will enable the examination of challenges related to legal relationships between neighboring properties, easements, common spaces between buildings, and the relationship between land and improvements at the urban scale. It would represent an essential step toward designing a 3D urban cadastre pilot.

- Enhancement of Data Acquisition for 3D Cadastre Implementation

In the absence of officially available BIM models, future efforts to implement a 3D cadastre in Iran should focus on improving data-acquisition practices during surveying. In particular, cadastral surveyors may be required to collect and register a defined minimum set of 3D attributes, including floor heights, element thicknesses, and boundary surface details, as part of the surveying and registration procedures. These data could be obtained through conventional surveying methods, terrestrial measurements, or emerging techniques such as photogrammetry and laser scanning. Establishing such requirements would provide a reliable geometric basis for 3D modeling while maintaining the legal authority of cadastral data and enabling a gradual transition from a 2D to a 3D cadastral system.

- Alignment of the Country Profile with the LADM Edition II

Since the second edition of the LADM standard has recently been officially published, it is suggested that the proposed country profile be compared and aligned with this new edition. Such alignment is particularly important because Edition II introduces a revised structure with stronger support for 3D land administration and domain-specific extensions, which could provide a more robust basis for future refinement of the Iranian profile and its integration with IFC. In this regard, the class structures, packages, and relationships in the second edition should be adapted to meet the needs of Iran's 3D cadastre, and the implications for spatial unit modeling, parties, and complex rights should be explored. If necessary, the mapping between LADM and IFC should be redesigned to align with the updated version. This alignment will facilitate the integration of research results into international standard development and support their use in the formal process of country profile development. Future research can further update and align the LADM country profile of Iran with newer editions of the standard without affecting the applicability of the proposed integration approach. Since the presented model relies on the mapping between LADM classes and IFC entities, updates to the country profile would primarily require revising the class mappings or defining additional classes using IFC Property Sets. Therefore, the proposed LADM–IFC integration approach remains applicable and extensible even as the country profile evolves.

- Full Implementation of the Model at the Database Level

Although the integrated model was produced as an IFC file and functionally tested in two independent IFC-compatible software platforms, for practical implementation the LADM–IFC integration logic needs to be implemented at the database level. In this regard, a structure can be designed in which IFC serves only as an exchange format layer, with the core information stored and managed in a 3D database. Such a database-oriented architecture is essential for supporting more complex legal–spatial queries that reflect real cadastral conditions, including multi-level ownership and dependent rights. Moreover, this structure enables version management, systematic updating of cadastral information, and the incorporation of changes resulting from formal cadastral processes over time.

- Development of a National Database for 3D Cadastre

Beyond implementing the integration logic at the database level, a broader national database structure is also required for operational deployment. This research demon-

strated that it is feasible to store both legal and spatial data in IFC format. However, for national-scale applications, this structure needs to be extended to the database level. It is recommended to design a schema for a national 3D cadastre database based on LADM, capable of storing data extracted from BIM/IFC models, supporting query operations, versioning, and national-level updates.

- **Improvement of Tools and Processes for BIM Integration**

This research experience showed that while tools such as Simplebim 11 can be practical on small scales, the process of defining and managing Property Sets remains somewhat manual and prone to errors. Future work should focus on developing specialized tools and plugins for LADM–BIM integration. These tools should enable semi-automatic generation of Property Sets based on the national LADM profile, connect them to IFC elements, and manage and validate the data. This would not only increase the accuracy of the work but also reduce implementation time and cost. In addition to improving 3D cadastral processes, the integrated IFC/LADM model can be used as a base data source for generating 3D cadastral map products for legal and administrative use. In this process, legal spatial units can be selected and classified based on ownership attributes, and cartographic rules such as symbolization, transparency, and boundary highlighting can be applied.

Overall, this research shows that integrating LADM and BIM within the IFC standard can support the gradual transition from 2D to 3D cadastre in Iran. Although the proposed model was implemented as a building-scale proof-of-concept prototype, it provides a basis for future urban pilot projects, the development of national data infrastructure, and further review of institutional and legal frameworks. Further research and coordinated policy decisions are therefore needed before this technical capacity can be developed into an operational cadastral system.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy and legal restrictions. The datasets include maps and documents obtained from the State Organization for Registration of Deeds and Properties and the Municipality, which are subject to confidentiality requirements and cannot be publicly shared.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

This appendix provides a concise overview of the classes and code lists defined in the revised LADM country profile of Iran. The aim is to support the reader in understanding the legal, administrative, and spatial structure used in this study by briefly summarizing the main classes of each package and subpackage, without duplicating the detailed model definitions. The figures presented in this appendix were newly created based on the revised LADM country profile of Iran and the updated code lists developed in this study. These figures are not reproduced from previous publications.

Appendix A.1. Party Package

The Party package (Figure A1) in the LADM country profile of Iran consists of three main classes that play a crucial role in modeling the individuals and entities associated with the cadastral system. The IR_Party class represents legal or natural persons involved in the country's cadastral system and includes basic information on ownership or rights held by these entities. The IR_GroupParty subclass is designed to define and represent a group of legal or natural persons who jointly share a right, restriction, or responsibility. Additionally, the IR_PartyMember subclass identifies the individual members of the stakeholder groups and specifies each member's relationship with the corresponding group. This structure enables a precise and coherent description of both individual and group relationships within the country's legal and ownership registration systems.

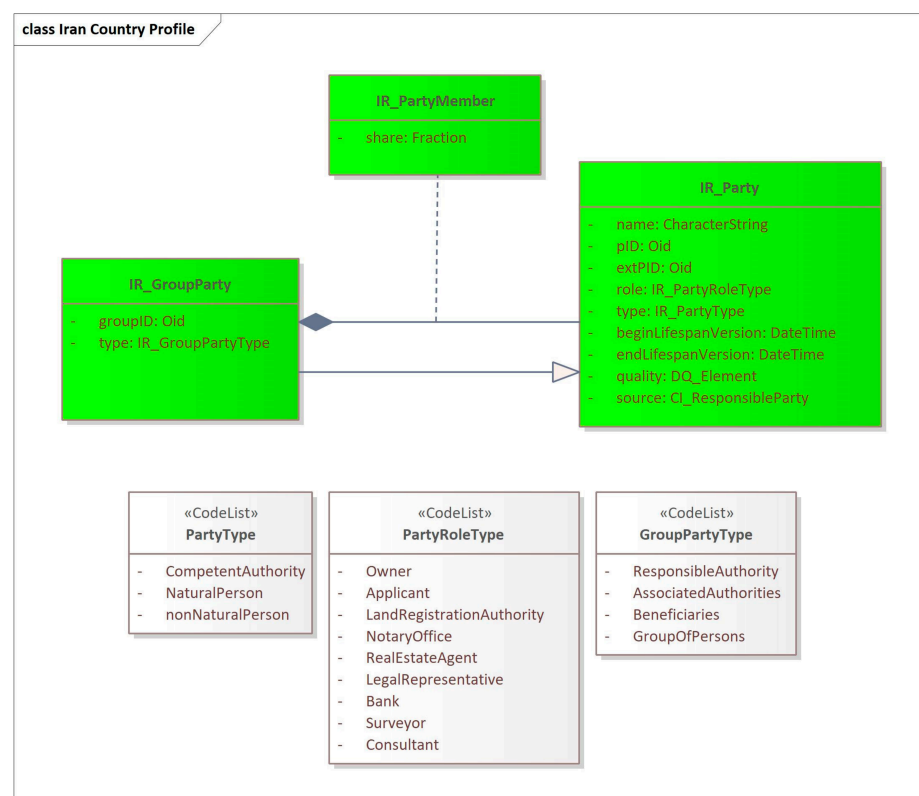


Figure A1. Party package classes and code lists in the LADM country profile of Iran.

Appendix A.2. Administrative Package

The Administrative package (Figure A2) includes the IR_RRR class, which is used to manage rights, restrictions, and responsibilities related to properties in the country's cadastral system. This class includes four subclasses: IR_Right, IR_Restriction, IR_Responsibility, and IR_Mortgage. The IR_BAUnit class represents the basic administrative unit and may include one or more spatial units. Other classes in this package, such as IR_AdministrativeSource, act as sources for managing documents and information resources within the country's cadastral system.

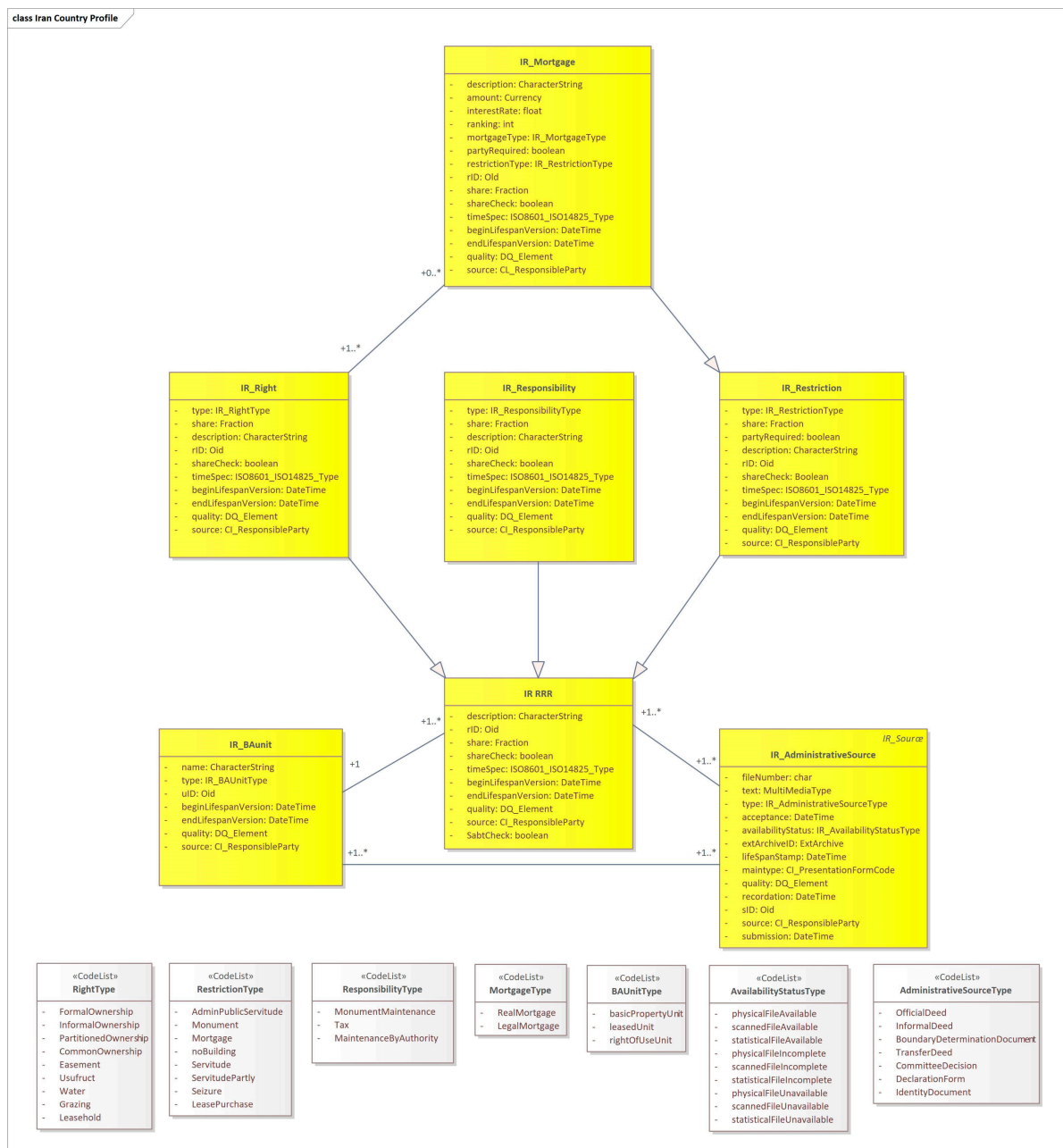


Figure A2. Administrative package classes and code lists in the LADM country profile of Iran. The multiplicity labels follow the UML notation defined in ISO 19152 (LADM).

Appendix A.3. Spatial Unit Package

The Spatial Unit package (Figure A3) defines the cadastral spatial components of the model through the IR_SpatialUnit class. This class is used to represent spatial units in the country's cadastral system and includes several subclasses for different related functions. The IR_LegalSpaceBuildingUnit subclass is responsible for defining and managing legal spaces associated with building units in the country's cadastral system. The IR_CadastralUnit subclass handles the registration and management of spatial units from the perspective of various cadastral registrations within the national cadastral system. The concept of Cadastre Type is used for management and layering within the existing cadastral system. Based on this concept, different parcels can be categorized into four main cadastre types: urban, rural, agricultural, and national. Each of these categories can have a predefined land use. The IR_Parcel subclass is designed to manage land plots and parcels within

the country's cadastral system. In contrast, the IR_LandImprovement subclass pertains to improvements on land within Iran's cadastral system. In Iranian law and regulations, the concept of "A'yan" exists, referring to anything that is located on a parcel of land and is visibly observable. This includes constructed elements, such as buildings, wells, and fences, as well as natural features, such as trees, which are located on the land and increase its value. Additionally, the IR_SpatialUnitGroup class is used to manage groups of spatial units that are considered collectively within the country's cadastral system. The IR_Level class is used to separate and organize different levels of cadastral data within the country's cadastral system.

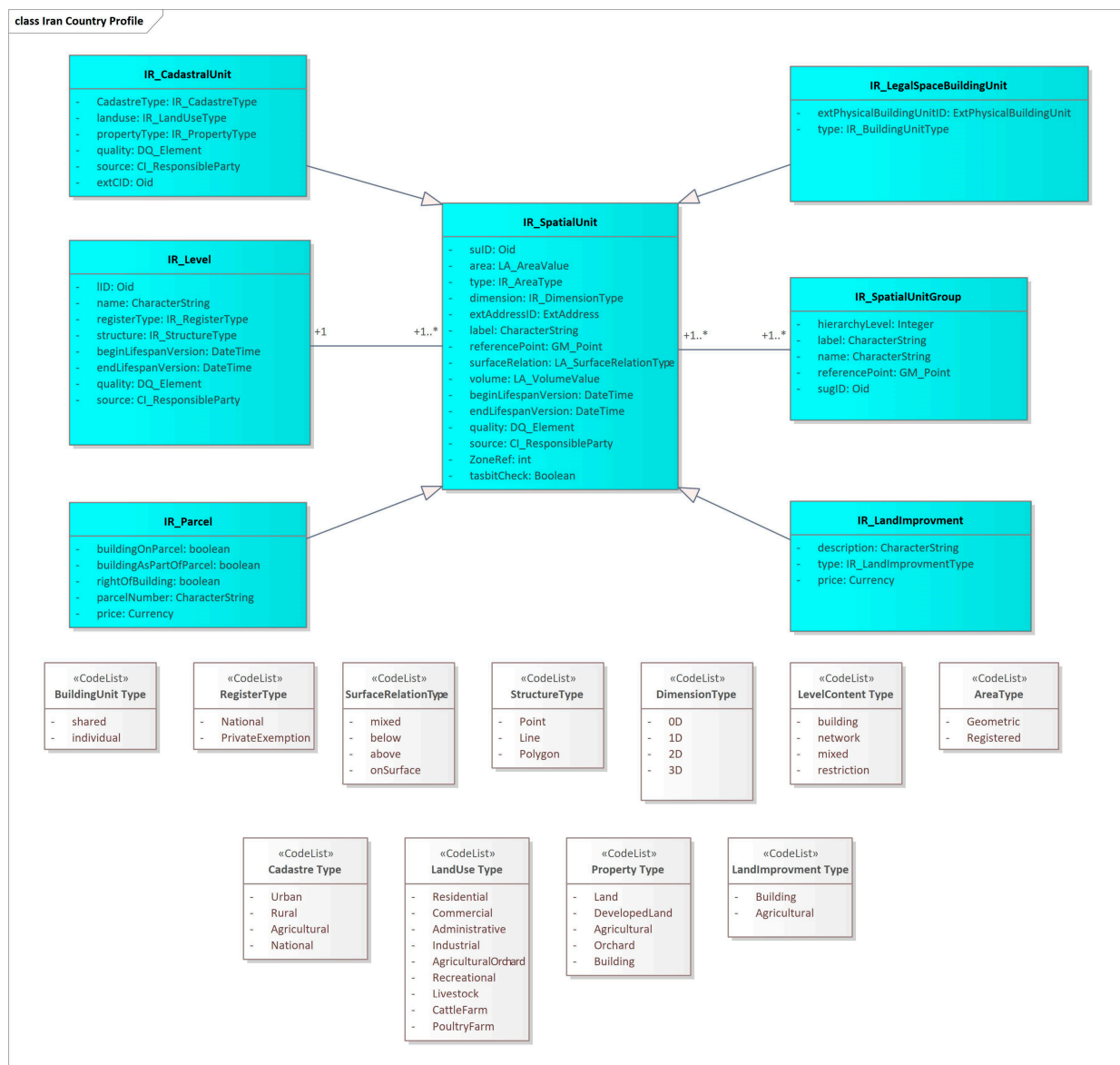


Figure A3. Spatial Unit package classes and code lists in the LADM country profile of Iran. The multiplicity labels follow the UML notation defined in ISO 19152 (LADM).

Appendix A.4. Surveying and Representation Subpackage

The Surveying and Representation subpackage (Figure A4), which is a subpackage of the Spatial Unit package, includes four main classes. The IR_Point class is responsible for managing all points within the national cadastre system. The IR_BoundaryFaceString class is used to represent the lines that form the boundaries of spatial units in the cadastre system. The IR_BoundaryFace class is designed to represent and manage the surfaces that

constitute 3D spaces in the national cadastre system. Finally, the IR_SpatialSource class manages the sources and references of spatial information for the spatial units within the cadastre system.

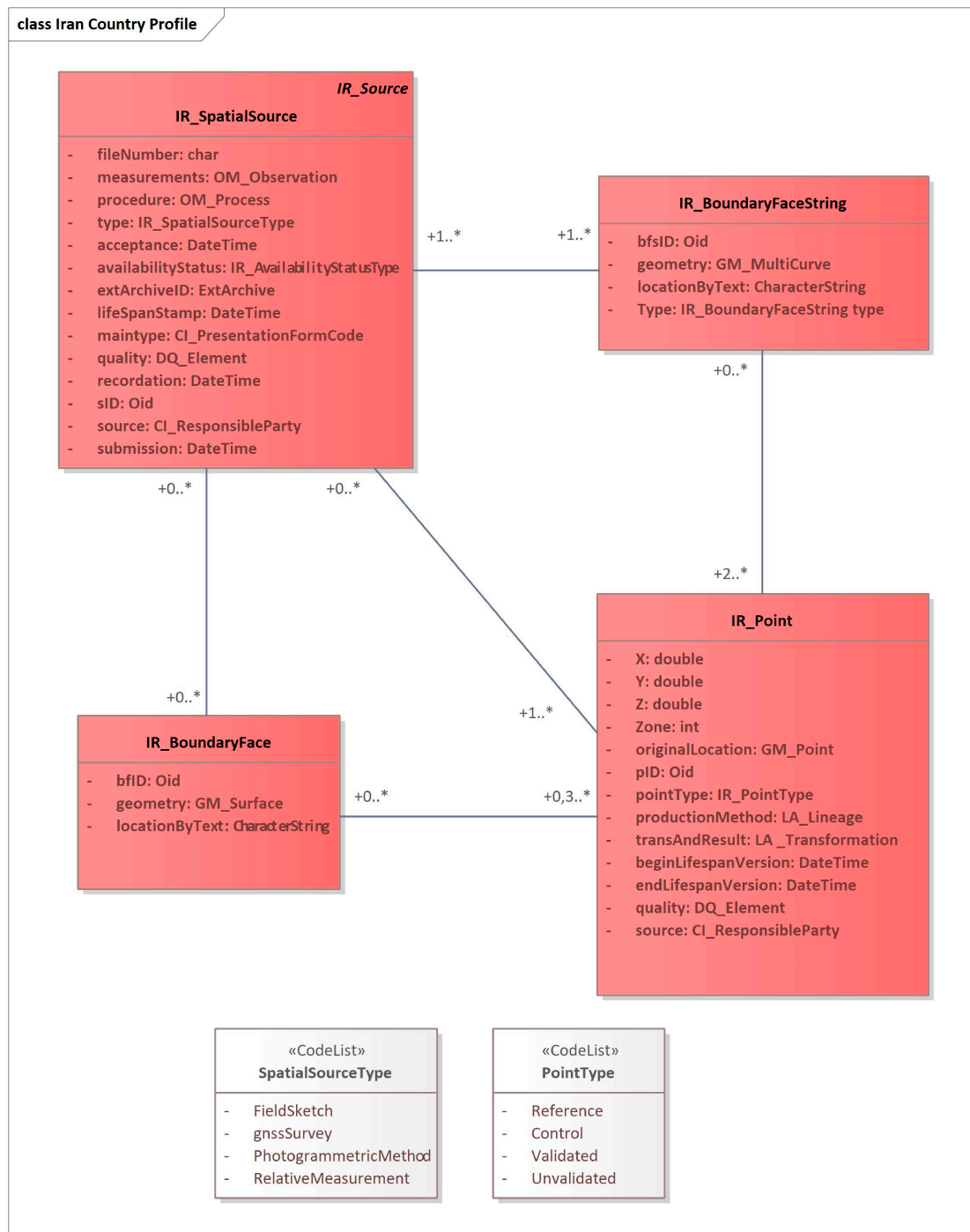


Figure A4. Surveying and Representation subpackage classes and code lists in the country profile of Iran. The multiplicity labels follow the UML notation defined in ISO 19152 (LADM).

Appendix A.5. IR_Source Class

The IR_Source class (Figure A5), which is intended for managing legal and spatial information sources in the cadastre system, is independent and does not belong to any specific package. It is considered an abstract class. The IR_AdministrativeSource and IR_SpatialSource classes, which appear as independent classes in their respective packages and subpackages, are regarded as subclasses of IR_Source in the final profile.

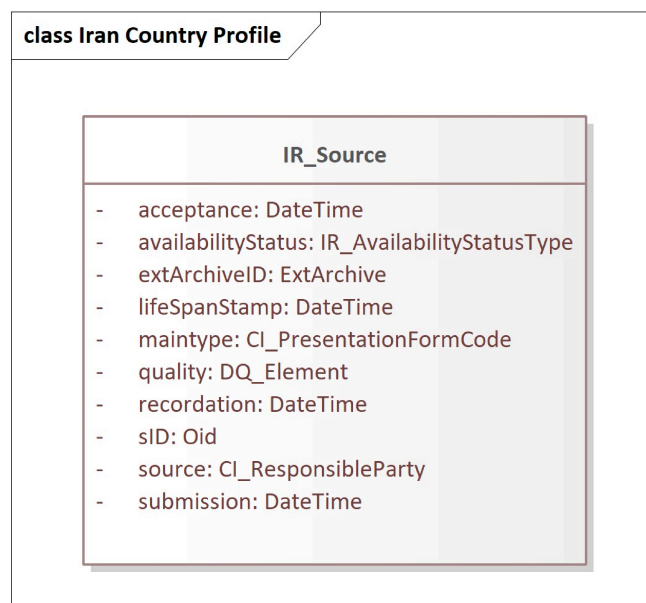


Figure A5. IR_Source class.

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