BIM-LADM AMALGAMATION — A REVIEW

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ABSTRACT:

This paper discussed two International Organization for Standardization (ISO) standards, namely, ISO 19152 – Land Administration Domain Model (LADM) and ISO 16739 – Industry Foundation Classes (IFC), to identify three-dimensional (3D) multi-floor building rights. These days, it is challenging to characterize all multifunctional structures due to the increase in complex buildings. High-rise building land and property information management is recommended through building information modeling (BIM). Countries like the Netherlands, Australia, and Turkey have considered adopting BIM for their land administration. A land administration standard, such as LADM, offers better legal and physical representation in identifying the rights, restrictions, and responsibilities (RRRs) of the spatial units and stakeholders. However, LADM falls short in representing all building elements, such as semantic information and invisible functional spaces. Hence, this paper reviews incorporating additional information from BIM to create a comprehensive three-dimensional building representation including legal information from LADM. Issues and challenges also being highlighted with some recommendations for possible future works.

1. INTRODUCTION

1.1 The motivation

The objective of this paper is to review the amalgamation of Building Information Modelling (BIM) and Land Administration Domain Model (LADM). The integration of BIM and LADM has become a promising area for enhancing efficient land administration, including the management of 3D property ownership (Emamgholian et al., 2021; Andritsou et al., 2022; and Liu et al., 2023). For the past 10 years, LADM has been known as a standard in representing legal aspect of land administration objects encompassing land tenure, land value, land use, and land development (Enemark, 2005). However, the limitation of LADM in depicting semantic components warrants open data standard like Industry Foundation Classes (IFC) in fostering interoperability across diverse domains such as architecture development (Gursoy et al., 2022). IFC is a standard for BIM used in construction and building industry to store and exchange information on semantic materials as well as the spatial relationships between them (Eastman et al., 2011; Jazayeri et al., 2014; and Isikdag et al., 2007). BIM serves as a comprehensive digital model, capturing both the physical and functional attributes of a structure, fostering collaboration among diverse project stakeholders. However, information about ownership rights within buildings has poorly defined in BIM models (Atazadeh et al., 2016; Durdyev et al., 2022; and Brooks, 2023).

Previous works pointed to the usefulness of BIM–LADM integration where these two models could provide a better-integrated model that enables to answer the questions on rights, restrictions, and responsibilities (RRRs). Currently, there is no collaboration between the organizations, leading to a disconnected system, different software, distinct data formats, and improper integration. Introducing LADM to support multiple pillars or organizations could lead to improved collaboration, reduced confusion, and the availability of up-to-date information. People possess valuable information about a piece of land and the building's 3D aspects (BIM/IFC) which rely not only on land tenure or property ownership, but also on factors like land value and spatial planning (Indrajit et al., 2021). Combining these diverse pieces of information (LADM and BIM) can offer a more holistic view of legal and physical situations, leading to better-informed decision-making processes.

This paper begins with an introduction and motivation on amalgamating BIM with LADM, followed by a discussion of related works on BIM/IFC and LADM in Section 2. Some recommendations of future works from researchers also included. Section 3 discusses on findings (benefits and challenges) concerning the integration of BIM and LADM, while Section 4 serves as the conclusion and discuss this paper's findings.

2. RELATED WORKS

2.1 Previous works on BIM

Countries like the Netherlands, Australia, Turkey, Singapore, and Sweden have been working on integrating BIM principles into their land administration (LA) practices. Song et al., (2017) discussed the possibilities of incorporating 3D data from BIM. She claimed that BIM data is significant and valuable data source and can be utilized for detailed analysis and major project applications in a geographical information system (GIS) because BIM data rich in geometric and semantic information. Due to the growing interest in BIM, several researchers have underscored the use of BIM in the context of 3D LA in various nations, including Sweden (Sun et al., 2019), Australia (Atazadeh et al., 2017), Serbia (Sladić et al., 2018), Saudi Arabia (Alattas et al., 2021), Turkey (Gursoy et al., 2022), and the Netherlands (Broekhuizen et al., 2021).

Atazadeh et al., (2017) proposed an extension to the BIM standard through integration into BIM model (e.g., complex

building) to check on potential of leveraging BIM for high-rise buildings and modelling 3D ownership rights. He investigated how to store legal property in an IFC model and created a prototype model for a 3D Land Administration System (LAS) with input from the model. Figure 1 shows IFC models' physical data entities in a hierarchical data structure. In this figure, the most abstract entities are depicted in grey. Two main entities have been defined to model physical information in the IFC standard, namely *IfcSpatialStructureElement* and *IfcBuildingElement*. Meanwhile, Figure 2 shows the legal entities defined within IFC schema. The proposed entities are depicted in yellow. The *IfcLegalPropertyObject* entity represents all types of legal property objects such as 3D ownership spaces for units, common properties, and easements. The prototype model demonstrates the potential benefits of BIM in high-rise LA. This extension aims to provide richer information about ownership and rights, supporting stakeholders that already using BIM. He recommended for more further development on IFC files to cater related information on high-rise building such as on topological aspect.

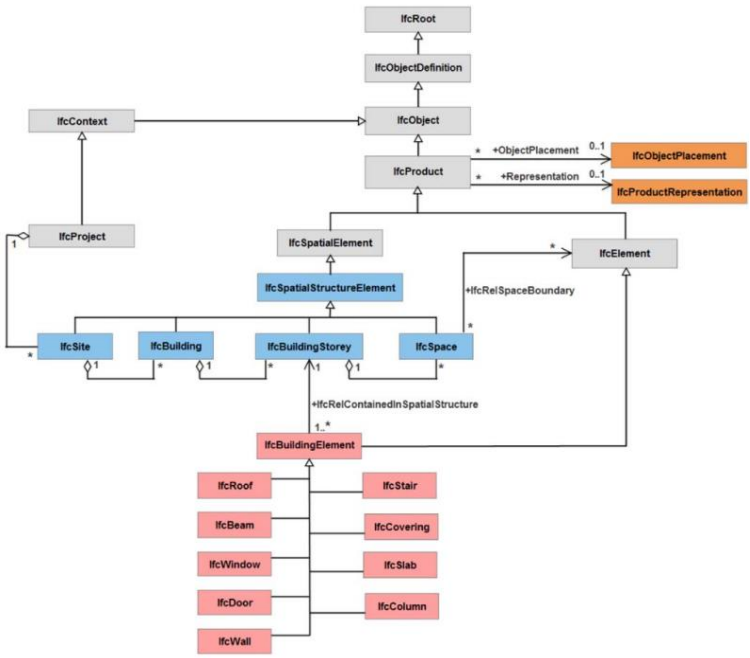


Figure 1. Physical data entities in IFC model (Atazadeh et al.,2017)

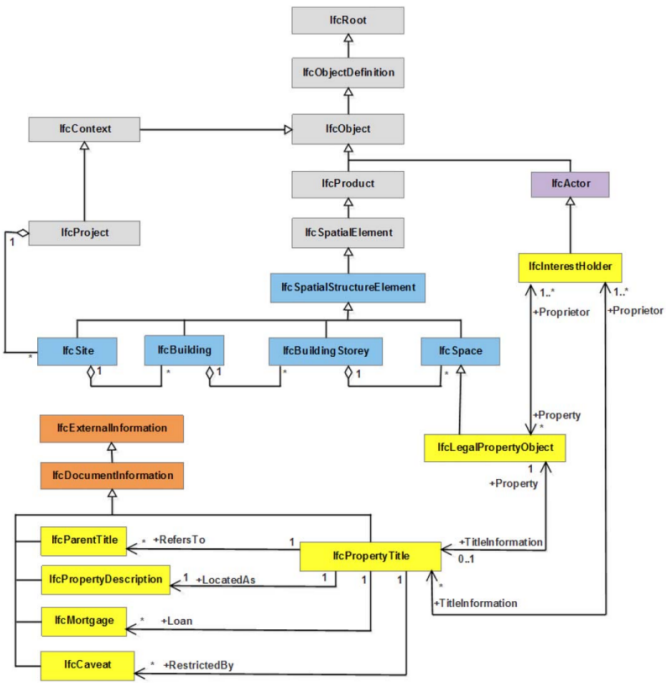
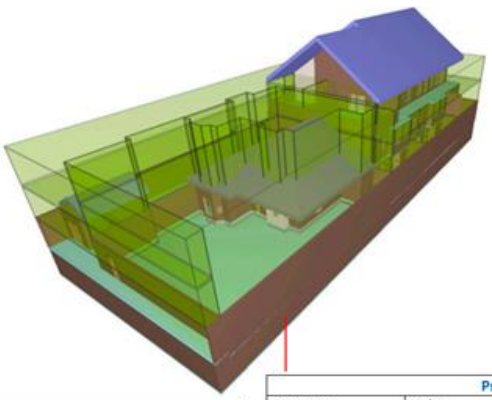


Figure 2. Legal entities defined within IFC schema (Atazadeh et al.,2017)

Then, Oldfield et al., (2018) investigated the possibilities of using BIM as input for 3D LAS. They proposed using IfcSpace as legal space and IfcZone for grouping spaces into legal zones. The integration utilized Information Delivery Manual (IDM) ISO 29481 Part 1 and 2. Part 1 coordinates processes such as building regulation conformance, rates assessment, topographic mapping, and asset management. Part 2 guidelines help in modelling an XML-based interaction framework for digital implementation.

Besides, Olfat et al., (2019) explores the potential of utilizing a BIM to enhance 3D digital building subdivision workflows. Current workflows often rely on fragmented and document-centric approaches, leading to information silos. This research also contributes on extending the open BIM standard to incorporate subdivision lifecycle information, creating a 3D digital common data environment for sharing and exchanging information among stakeholders. The research aims to explore the feasibilities of constructing a BIM-enabled cadastral plan lodgment system for handling 3D digital data submission, storage, validation, visualization, examination, and map base updates. Figure 3 visualizes the integration of legal and physical objects as well as administrator information. This study primarily focuses on the Victorian jurisdiction; however, the approach can be adapted for other jurisdictions by modifying it to align with the specific workflow and data elements defined in specific regions.



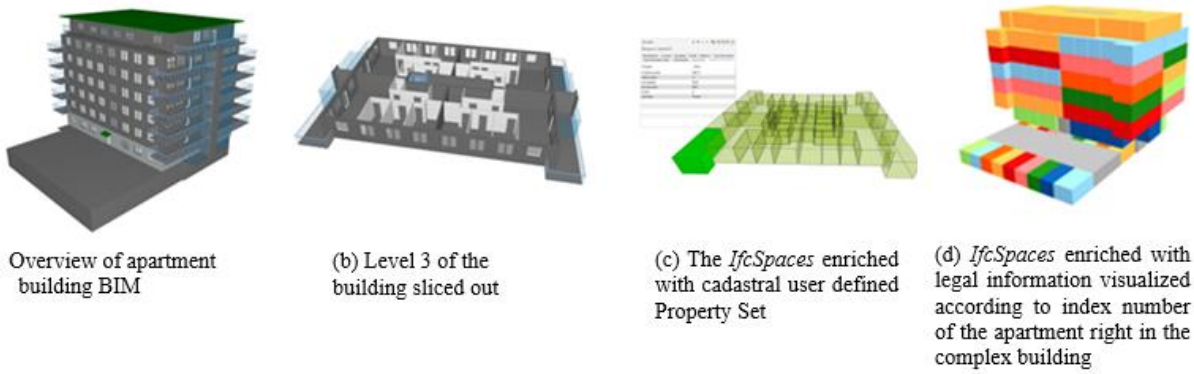
Site Attributes	
Property	**Value**
RefEleveation	22.5m
RefLatitude	-37° 51′ 43.13413″
RefLongitude	144° 59′ 53.94939″
SiteAddress	138 Alma Road, St Kilda East 3183

Pset_PlanInfo	
Property	**Value**
AdministrativeDate	2014-07-15
Head Of Power	Subdivision Act 1988 and Owners Corporation Act 2008
Lot No	12
Plan No	PS704971N
Stage No	Not Applicable
Status	Planning Permit Applied
Survey Type	Surveyed

Figure 3. Integrated BIM model comprising legal and physical objects, as well as administrative information for the case study building (Olfat et al.,2019)

Meulmeeste, (2019) enriched an IFC model with legal data as a property set and transferred it into a conceptual 3D LAS. He investigated the requirements for IFC models to be defined as legal spaces within Dutch LAS. The investigation involves a thorough examination of both IFC data format and Dutch laws pertaining to apartment rights. Legal space, in the context of apartment rights, was conceptualized as the exclusive usage and access rights to a specific area within a building (see Figure 4).

According to Dutch law, an owner of an apartment right possesses the entire building but is restricted to accessing only the areas explicitly defined in the notarial deed. These areas are typically visualized through 2D floorplans, encompassing shared spaces like hallways and private spaces such as dwelling areas, storage units, or parking spaces.



(a) Overview of apartment building BIM

(b) Level 3 of the building sliced out

(c) The *IfcSpaces* enriched with cadastral user defined Property Set

(d) *IfcSpaces* enriched with legal information visualized according to index number of the apartment right in the complex building

Figure 4. BIM enriched with legal space through a user defined property set visualised with Solibri Model Viewer. Figure (d) visualised with QGIS (Meulmeeste, 2019)

Next, Sun and Paulsson, (2019) proposed a framework (see Figure 5) for integrating BIM with LA, where both IFC and CityGML models were stored in a LADM database. The research connects IFC and CityGML models to generate a 3D cadastral model. The study acknowledges limitations, such as incomplete property descriptions, and recommends further research to test models, validate the framework, and develop collaborative workflows.

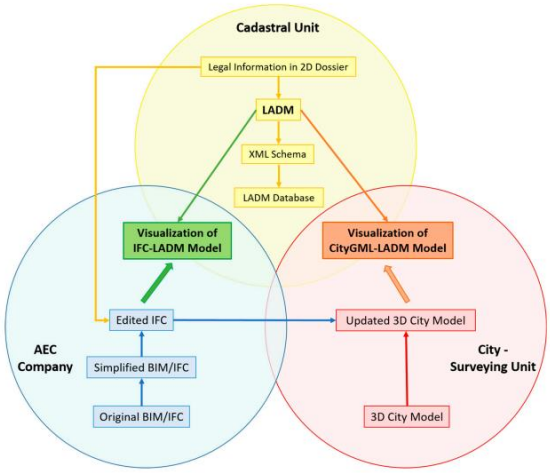


Figure 5. The general framework for integrating cadastre with BIM and GIS (Sun and Paulsson, 2019)

Meanwhile, Barzegar et al., (2019) introduced a method for identifying various property boundaries (see Figure 6) in 3D using topological relationships and a BIM-based plugin. The approach is user-friendly, enabling individuals without cadastre expertise to understand and address boundary issues. It proves valuable for developers in multi-owned developments, aiding in informed decision-making and preventing potential disputes. An exploration for querying boundaries related to common properties and oblique walls, developing methods for constructing volumetric legal spaces, and implementing the algorithm in a web-based environment for broader stakeholder usability were recommended by the same author.

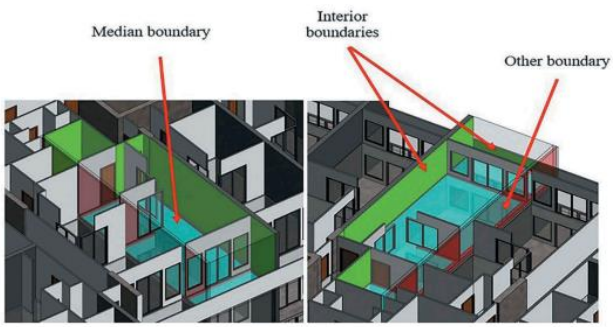


Figure 6. Boundary detection algorithm (Barzegar et al., 2019)

Noardo et al., (2020) investigated the implementation of CityGML and IFC standards in the GeoBIM benchmark, focusing on the integration of 3D city models with BIM. It highlights flaws in georeferencing storage in IFC files and calls for collaboration to address the issue. Challenges in conversion tasks reveal the needs for explicit constraints, use-case-based considerations, and improved mapping of semantics and geometric features. The study underscores the lack of validation methods for IFC output models and suggests further exploration in this area. While limitations exist, the paper identifies key areas for development in software tools and standards, emphasizing the need for awareness and control of georeferencing methods, models between CityGML and IFC. Coordination between research, standardization efforts, and implementations is crucial for future progress in integrating geoinformation and 3D city models with BIM.

Furthermore, Alattas et al., (2021) developed an approach that integrates IFC and LADM to represent the legal spaces of properties in Saudi Arabia. The approach refines models with private, common, and exclusive common spaces. The hybrid approach integrates legal information into the 3D model while extending the LADM-based country profile with physical counterparts. The research addresses issues in the 3D IFC model related to spaces, floor slabs, and additional attributes, enhancing the definition of ownership rights. Recommendations for building subdivision authorities include using 3D 'as-built' models and providing clearer regulations for spaces and directions, together with extending the 3D country profile, improving administrative elements, and testing the hybrid approach in various country profiles and building types.

Moreover, Atazadeh, et al., (2021) used the IFC schema to model features and attributes in LADM. They plan to integrate real-world case studies by focusing on building developments with complex architectural designs. The authors also aim to refine the proposed approach, making it more feasible for integrating legal and physical dimensions of buildings in a 3D digital environment. Figure 7 shows different sections of the IFC standard, in which the legal and physical components are highlighted. In upcoming work, the creation process of legal boundaries referencing building elements can be automated within the integrated IFC file. An algorithm is recommended to empower users to choose which face (interior, median, or exterior) of a building element is utilized for delineating the legal boundary.

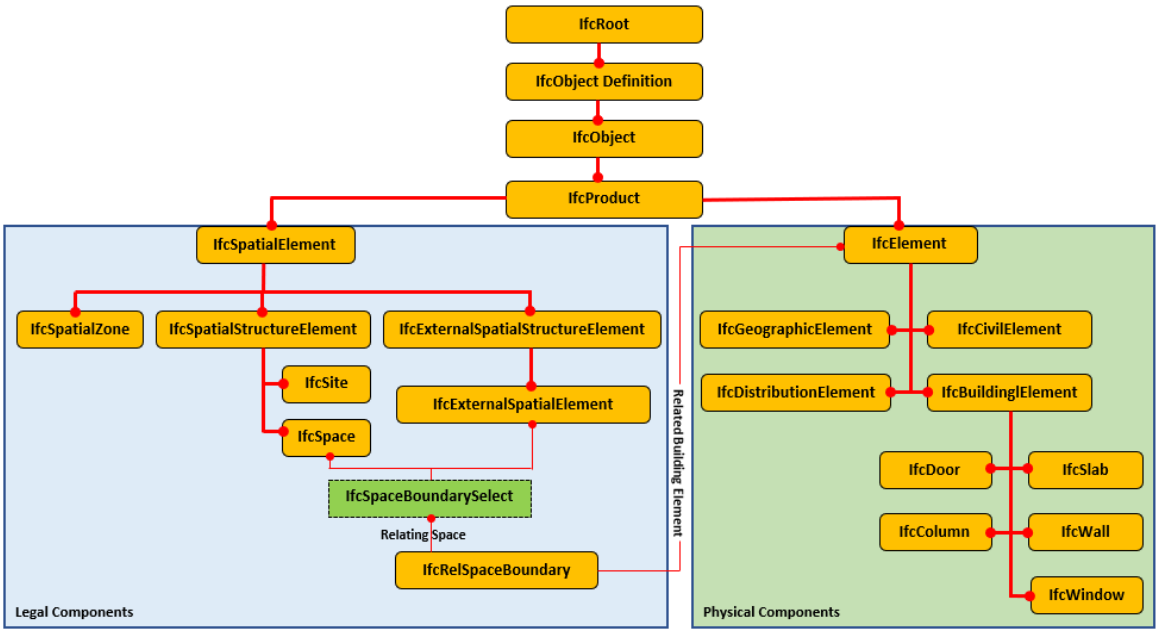


Figure 7. Different sections of the IFC standard used for modelling legal and physical components (Atazadeh et al., 2021)

Simsek and Uzun, (2021) proposed calculating property valuations based on BIMs in Turkey within the context of condominium ownership. This study utilized a 3D virtual BIM model to visualize topographic surfaces, analyze factors such as floor location and facade orientation for condominium units, and assess annexes. Energy analysis was performed using precise measurement data in Revit with the Insight 360 plug-in, considering factors like daylight and sun exposure. The calculation of nominal values and factor weights for real estate valuation requires expertise, often provided by estate surveyors. Factor weights were determined through interviews, and land shares were obtained using a valuation method based on a comparative or relative approach. The study challenged the assumption that real values of condominium units facing difficulties to be accurately calculated in the initial phase of establishing condominium easement. The study also suggests establishing common standards within the Turkish property valuation system for broader acceptance of the proposed model.

Broekhuize et al., (2021) evaluated BIM/IFC models in terms of IfcSpace existence, geometric validity, overlap, and the ability to georeferenced. There are several technical issues that still need to be addressed. This research utilized five BIM/IFC models as prototypes 3D LAS, incorporating LADM components. Notably, only IfcSpace entities were modelled as legal units due to legal constraints, and most of the BIM/IFC models utilized were based on the original design rather than the actual construction. Technical challenges were identified, such as lack of room entities, insufficient identification for linking legal units with the Dutch LAS, and lack of attributes for georeferencing. Recommendations and guidelines for effective BIM/IFC model design for 3D LAS include:

a) Inclusion of rooms as IfcSpace entities.
b) IfcSpace entities should contain a property set with key information.
c) Consideration of grouping IfcSpace entities, avoiding duplicate volumes.
d) Inclusion of attributes for georeferencing in the BIM/IFC model.

She suggested to expand the dataset with diverse BIM/IFC models, assessing incentives for designers to share models, testing BIM/IFC models from other countries, and exploring software tools for topology and boundary validation. Addressing legal and organizational challenges is crucial for implementing recommendations and establishing a legal mandate for BIM models as input for 3D LAS in the context of apartment registration.

Further, Guler et al., (2022) suggested a conceptual framework for Turkey that integrates digital building permitting and 3D representation of condominium rights using BIMs. The extended model aims to depict legal spaces and physical objects. Demonstrations using a BIM/IFC model illustrate its applicability for various condominium rights cases. Guidelines for implementation in Turkey as follows:

a) *Enhance Data Interoperability:* Improve data exchange between the Architecture Engineering Corporation (AEC) industry and land administration sectors to ensure accurate information in BIM models.
b) *Raise AEC Industry Awareness:* Increase awareness about legal spaces in the AEC industry, emphasizing the importance of accurate condominium plans during building permitting.
c) *Build Capacity in Land Registry Offices:* Train personnel in land registry offices to understand and verify BIM models for property rights in buildings.
d) *Facilitate Digital Information Flow:* Enable digital information exchange between applications related to buildings, ensuring the reuse of BIMs without loss of information.
e) *Publish Legal and Technical Guidelines:* Central cadastral organizations should publish documents specifying legal and technical requirements for BIM models.

These suggestions aim to contribute to a full 3D digital cadastre in Turkey by fostering efficient collaboration between sectors, ensuring accurate BIM model reuse.

The BIM environment plays a significant role in addressing the spatial and functional complexities of various dimensions in multistory developments Salman et al., (2012); Atazadeh et al., (2018); Shin et al., (2020); Ren and Zhang, (2021); Ramlakhan et al., (2023). The integrated approach (BIM with LADM) enables stakeholders to efficiently share spatial and semantic information about complex building structures. Table 1 shows the other part of the preceding works on BIM. Some new classes in the IFC schema have been introduced to represent the legal spaces in complex buildings.

Table 1. Prior research related to BIM (revised from Guler et al., 2022)

Prior Research	Description
(Atazadeh et al., 2016)	Proposes *IfcRelReferencedInPrivateProperty* and *IfcRelReferencedInCommonProperty* for legal rights in 3D
(Atazadeh et al., 2021)	Establishes a correlation between the features of the LADM and entities present in the IFC schema to facilitate 3D land administration
(Petronijevic et al., 2021)	Extends IFC schema by new entities – *IfcBuildingPropertyUnit* for representing legal spaces in complex buildings
(Barzegar et al., 2021)	Suggests methodology for identifying the boundaries of legal spaces and storing them in a spatial database
(Brooks, 2023)	Provides a comprehensive overview of BIM, emphasizing its evolution, collaborative potential, and challenges within the Architecture, Engineering, Construction, and Operations (AECO) industry.
(Vaart et al., 2023)	Evaluates the applicability of Biljecki et al., (2016) framework in specifying BIM-derived building models. The comparison involves two BIM shell extractors—IFC BuildingEnvExtractor and BIMShell—against the Levels of Detail (LoDs) defined in the framework.

Several countries, including the Netherlands, Australia, Turkey, Singapore, and Sweden, have actively integrated BIM principles into their land administration practices. Researchers from various nations, such as Sweden, Australia, Serbia, Saudi Arabia, Turkey, and the Netherlands, have explored the potential of BIM in the context of 3D LA. These studies propose extensions, frameworks, and methods to enhance BIM's role in representing legal spaces, ownership rights, and property boundaries. They also addressed issues like interoperability, standards, and the integration of BIM with existing land administration models and showcasing the diverse applications of BIM/IFC across the globe. These efforts contribute to a growing body of knowledge aimed at leveraging BIM for efficient and accurate 3D representation of land and property-related information (Kitsakis et al., 2022).

2.2 Potential IFC schema for amalgamating land administration practice

IFC schema holds significant potential for amalgamating land administration practices, providing a framework for representing complex relationships between physical and legal entities within the built environment. Its comprehensive structure allows for the integration of key elements, such as legal spaces, ownership rights, and property boundaries.

In the context of land administration, the IFC schema can serve as a common language for exchanging information between various stakeholders, including surveyors, land administrators, and urban planners. It offers a standardized way to represent 3D spatial information, enabling accurate modeling of cadastral data, property rights, and land use. The schema's flexibilities accommodate diverse requirements of different jurisdictions, making it adaptable to various legal frameworks and administrative practices. Some potential IFC schema that can be amalgamated into land administration practices can be seen in Figure 8.

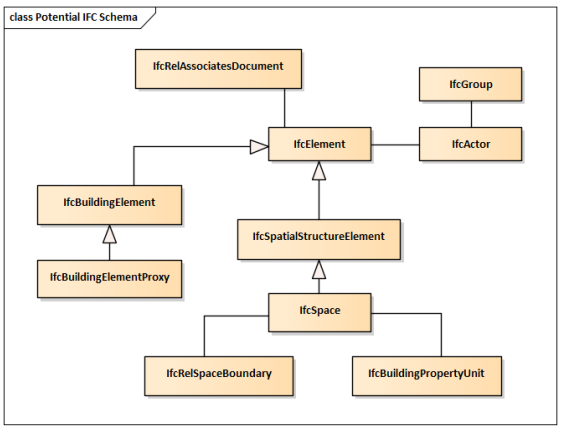


Figure 8. Potential IFC schema for amalgamating land administration practice (Guler et al., 2022)

Figure 8 illustrates the potential IFC schema that can be adopted into LADM. *IfcElement* represents the physical elements or components of a building. *IfcBuildingElement* is generalized to *IfcElement*, which defines the properties and associations of physical building elements, such as walls, columns, beams, doors, windows, and other tangible components. *IfcBuildingElementProxy* serves as a subtype of *IfcBuildingElement* to delineate a non-predefined building's elements, for instance, lifts (elevators). *IfcRelAssociatesDocuments* is associated with *IfcElement* for linking between elements in buildings and external documentation relevant to those elements. This association will be beneficial in tracking and managing relevant documentation related to building elements, ensuring important information can be accessed and integrated. *IfcActor* is a class representing any person, organization, or role involved in a construction or building, where it serves as fundamental entity for capturing information about various stakeholders associated with a building. In this case, *IfcActor* is associated with *IfcElement*. *IfcSpatialStructureElement* is generalized to *IfcElement* to depict spatial elements, such as building stories, sections, components, spaces, and zones. *IfcSpace* is a potential class to be adopted to represent spaces with distinct characteristics and attributes, encompassing essential information, such as area, volume, height, and occupancy information. *IfcSpace* is

associated with *IfcRelSpaceBoundary* and *IfcBuildingProperty* to define individual spaces and the spatial boundary between two spaces, such as apartments that are owned or leased. These IFC elements can be mapped into LADM according to its packages (Party, Administrative and Spatial Unit).

When mapping party package to IFC, LA_Party is represented by the *IfcActor* entity, which encompasses pertinent information about the involved parties. *IfcActor* includes details such as roles, contact information, and the legal representation of these parties.

In administrative package of LADM, LA_RRR class and its subclasses, encompassing LA_Right, LA_Restriction, LA_Responsibility, and LA_Mortgage, embody various types of rights, restrictions, responsibilities, and mortgages. In IFC, there is no direct equivalent entity for LA_RRR. Nevertheless, the attribute information of RRR can be documented in the legal file within IFC and linked to the *IfcSpace* attribute set. To represent legal documents, entities such as *IfcPropertyTitle*, *IfcParentTitle*, *IfcPropertyDescription*, *IfcMortgage*, and *IfcCaveat* can be utilized. Each *IfcLegalPropertyObject* can be linked to a legal file (*IfcPropertyTitle*), encapsulating ownership or other pertinent RRRs details.

LADM introduces the concepts of LA_SpatialUnit and LA_SpatialUnitGroup to depict the spatial units and their grouping within a condominium building. LA_LegalSpaceBuildingUnit represents the 3D legal space of LA_SpatialUnit. When translating to IFC, the *IfcSpace* entity is employed to correspond to LA_LegalSpaceBuildingUnit, symbolizing the individual spatial units within a condominium. A collection of spatial units (LA_SpatialUnit) is represented by LA_SpatialUnitGroup. In IFC, the *IfcZone* entity is utilized to match LA_SpatialUnitGroup, portraying the grouping or zones within the condominium.

This implementation requires translating LADM concepts to their corresponding IFC entities and relationships. This mapping is crucial to seamlessly integrate ownership information from LADM into the 3D representation of the condominium or another complex building in IFC.

2.3 Land Administration Domain Model

Land Administration Domain Model (LADM) Edition I has been developed on 2012 (Lemmen, 2012) as a standard for land administration. This standard has been applied by various countries as a conceptual legal information model for 3D land administration as agreed by Lemmen et al., (2021); Kalogianni et al., (2021) and Sun et al., (2019). It provides a basic and standardized terminology for describing entities and their relationships, including RRRs of land properties which can be expanded to fit a nation's needs (Hjelmblom et al., 2019).

Now, LADM has been extended become Edition II that covers basis land administration which are land tenure, land value, land use, and land development (Lemmen et al., 2019; Kalogianni et al., 2020) as illustrated in Figure 9.

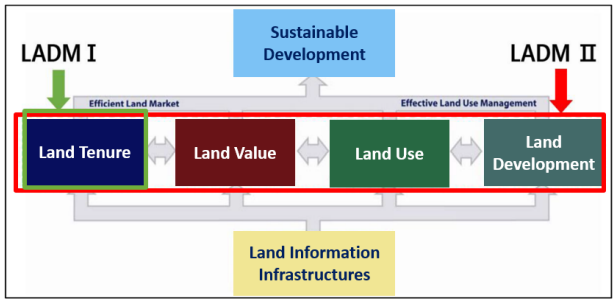


Figure 9. The basis of land administration (Enemark, 2005)

Land tenure represents the assigning and security of land rights, legal surveys to establish parcel boundaries, sale or rental of property, and management of land rights and parcel boundaries. Land value represents land and property value assessment, the gathering of revenues through taxation, and the management of land valuation and taxation disputes. Land use comprises the control of land use by adopting planning policies and land use regulations at national, regional, and local levels. Land development comprises building new physical infrastructure, implementing construction planning, and changing land use through planning permission and granting permits (Enemark, 2005).

Now, LADM Edition II becomes multipart standard as indicated below:

Part 1 – Generic Conceptual Model
Part 2 – Land Registration
Part 3 – Marine Georegulation
Part 4 – Valuation Information
Part 5 – Spatial Plan Information
Part 6 – Implementation Aspects

Part 1 and 2 are the components in LADM Edition I and Part 3,4,5, and 6 were added into LADM Edition II. By expanding the scope of LADM, this standard aims to aid in developing and refining LA functions as stated by Kara et al., (2023). Different colors (see Figure 10) describe different packages:

a) Green – Party Package
b) Yellow – Administrative Package
c) Blue – Spatial Unit Packages
d) Light Pink – Surveying and Representation sub-package
e) Grey – Part 3 (Marine Georegulation)
f) Orange – Part 4 (Valuation Information)
g) Light Blue – Part 5 (Spatial Plan Information)

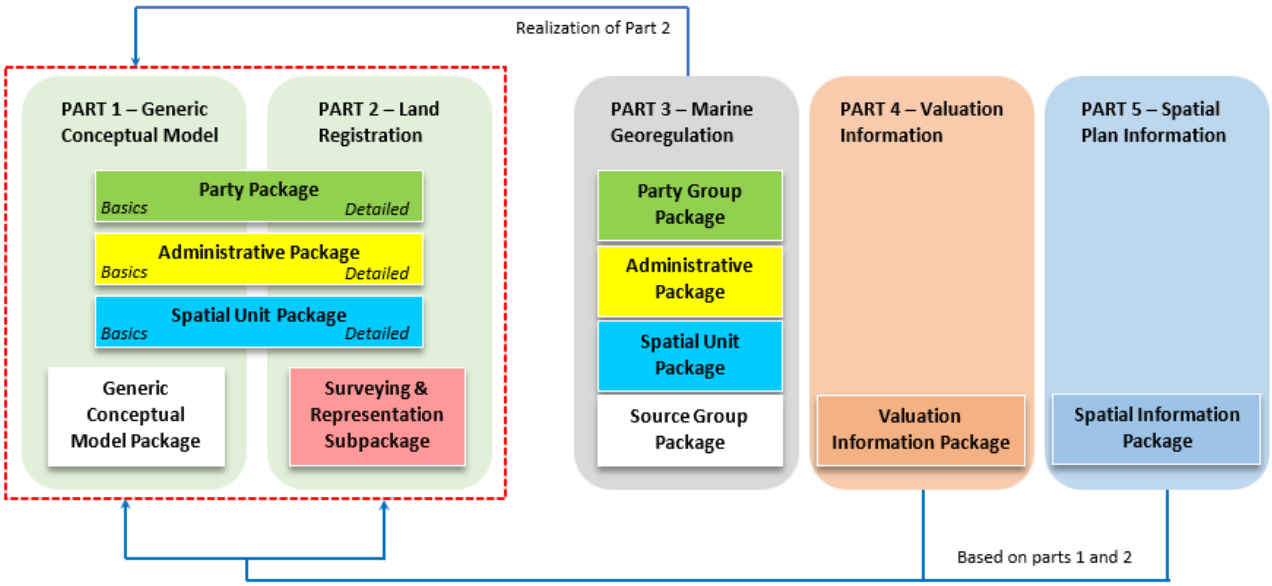


Figure 10. Part of LADM Edition II (adapted from Kara et al., 2023)

LADM framework defines a clear and standardized way to represent legal and administrative aspects of land including properties' RRRs. By incorporating LADM concepts into BIM, the legal context of buildings and land parcels can be accurately captured. This ensures that, the representation of structures in BIM aligns with the legal framework defined by LADM. It ensures the cadastral boundaries and legal ownership rights are accurately reflected in the BIM model. Since LADM has been extended, it can give more information (e.g., RRRs, valuation, land use) to be integrated within BIM/IFC. This is particularly crucial for 3D land administration. Integration with BIM allows for the creation of comprehensive 3D cadastral models, where legal and administrative information is embedded within the BIM model, providing a more accurate representation of the legal context in a 3D environment.

3. LADM–BIM AMALGAMATION

3.1 Needs and Benefits

The integration of BIM with LADM has emerged as a promising field for 3D digital cadastre and efficient land administration, including 3D ownership (RRRs) management. The content of RRRs can be modeled based on the LADM standard national while BIM provides rich semantic information for land management activities. Combining BIM/IFC with LADM creates a correlation that enhances our understanding of the legal space in complex building Guler et al., (2022); Ying et al., (2021); Olfat et al., (2021). BIM is increasingly applied to 3D condominium ownership management, offering advantages like semantic relationships between legal spaces and together with ownerships.

Furthermore, architects and urban planners could leverage BIM data to create more informative and efficient designs, considering legal constraints and land administration requirements from LADM. The integration may improve interoperability between BIM and LADM allows for seamless data exchange, reducing data silos and enhancing communication between stakeholders. Government authorities able to make efficient decisions and develop policies that align with both physical and legal aspects of land and building development. Finally, the integration supports the delivery of enhanced public services related to land and property information, benefiting citizens, businesses, and government agencies.

3.2 Issues and Challenges

BIM models that meant to be for the registration of apartment rights should be in as-built form, otherwise incorrect cadastral information would be registered to the cadastral database. These models should have adequate information for the 3D registration of apartment rights.

Based on the previous works, some challenges (as stated) need to be considered when amalgamating BIM and LADM:

- IFC models' inability to do georeferencing (Tauscher H. et al., 2023)
- Absence of IfcSpace in most IFC models (Broekhuizen et al., 2021)
- Lack of interrelation between different sectors in which BIM is utilized (Wong and Gray, 2019)
- Missing information due to the semantic integration of BIM and GIS (Zhu et al., 2019)

It is quite challenging to integrate both LADM and BIM where LADM widely used as a conceptual legal (ownership) information model meanwhile BIM represents semantic building information with their own hierarchical data structure. One of the ways to address the challenge as mentioned above has been proposed by Sun and Paulsson (2023) where Cadastral Level of Detail (CLOD) for representing both legal information, RRRs together with semantic information for 3D cadastral models could be utilized. Both legal and geometrical details are represented in five classifications: CLOD0, CLOD1, CLOD2, CLOD3 and CLOD4. The classes can be seen in Table 2.

Table 2. Classification of the CLODs, ranging from CLOD0 to CLOD 4, adapted from, Sun & Paulsson (2023)

Geometry (BIM model)	Cadastral Level of Details (CLOD)	Legal Information
A collection of multiple land parcels with 2D index maps	CLOD0 (2D)	Administrative division
A single land parcel including the entire building and outside property boundary	CLOD1 (3D)	Land parcel
Inside property lines and large zones (grouped from small zones or spaces)	CLOD2 (3D)	Property units, boundaries and RRRs of the entire building
Small zones or spaces, space lines and related building elements	CLOD3 (3D)	Property units, boundaries and RRRs of each floor
Spaces, space lines and related building elements	CLOD4 (3D)	Parts of property units, boundaries and RRRs of property units (e.g., condominium unit)

Since neither LADM nor BIM has an Application Domain Extension (ADE) mechanism, the integration between these two domains does pose challenges. Achieving interoperability without a standardized extension mechanism may lead to ad-hoc solutions, reducing the ability to seamlessly exchange information between the two systems. However, the integration may involve focusing on specific aspects where alignment is critical, such as incorporating key legal boundaries into BIM models. This selective approach helps to address certain use cases effectively. The limited integration provides practical and valuable solutions by focusing on specific use cases, key integration points, and collaborative efforts between stakeholders.

4. DISCUSSIONS & CONCLUSION

LADM and BIM are two different standards that serve different purposes where LADM is a standard for land administration and BIM focuses on modelling information related to build environments, for instances, buildings and infrastructures. Mapping LADM concepts into IFC presents a significant benefit by enabling the linkage of legal information with building lifecycle data. The IFC standard serves as the foundation for managing building lifecycles in an open and interoperable manner, extending the value of legal information beyond property registration. This integration facilitates the determination of legal RRRs in property management. It also enhances communication and information exchange between land development stakeholders and land administration actors, such as land surveyors or registries. The strategy for extending LADM with IFC is particularly relevant in jurisdictions where building structures play a role in boundary delineation and essential to legal arrangements. By incorporating physical elements, this approach expands the scope of the LADM standard, accommodating diverse jurisdictional approaches to 3D property registration. It is clear that the integration leads to various advantages.

Besides the plus points, it also has limitations such as georeferencing, too many entities of BIM for LADM, the absence of IfcSpace for legal area, and no authoritative policy from national players on BIM-LADM integration. Thus, requires a thorough understanding for both standards in establishing effective interactions.

Based on the previous works, there are possibilities to integrate BIM/IFC into current land administration based on LADM. Several countries have utilized BIM as part of their land administration practices. We believe that a review of this interesting domains — LADM and BIM — would lead to better insights and understanding of land administration. Further investigation on BIM-LADM can be conducted based on the recommendations that have been suggested by the researchers.

REFERENCES

Aien A., Rajabifard A., Kalantari M., & Shojaei D. (2015). Integrating Legal and Physical Dimensions of Urban Environments. ISPRS Int. J. Geo-Inf. 2015, 4. 1442-1479; doi:10.3390/ijgi4031442

Alattas, A., Kalogianni, E., Alzahrani, T., Zlatanova, S., & van Oosterom, P. (2021). Mapping private, common, and exclusive common spaces in buildings from BIM/IFC to LADM. A case study from Saudi Arabia. Land Use Policy, 104. https://doi.org/10.1016/j.landusepol.2021.105355

Andritsou, D., Gkeli, M., Soile, S., and Potsiou, C. (2022). A BIM/IFC – LADM Solution Aligned to the Greek Legislation. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLIII-B4-2022 XXIV ISPRS Congress (2022 edition), 6–11 June 2022, Nice, France.

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S., & Champion, T. (2016). Extending a BIM-based data model to support 3D digital management of complex ownership spaces. *International Journal of Geographical Information Science*, *31*(3), 499–522.

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S., & Ngo, T. (2017). Building information modelling for high-rise land administration. Transactions in GIS, 21(1), 91–113. https://doi.org/10.1111/tgis.12199

Atazadeh, B., Rajabifard A., Kalantari M. (2018). Connecting LADM and IFC Standards – Pathways towards an Integrated Legal-Physical Model. 7th International FIG Workshop on the Land Administration Domain Model 12-13 April 2018, Zagreb, Croatia

Atazadeh B., Rajabifard A., Kalantari M. and Shin J. (2018). A BIM-Driven Approach to Managing Common Properties within Multi-Owned Developments. 6th International FIG Workshop on 3D Cadastres. Delft, the Netherlands

Atazadeh, B., Olfat, H., Rajabifard, A., Kalantari, M., Shojaei, D., & Marjani, A. M. (2021). Linking land administration domain model and BIM environment for 3D digital cadastre in multi-storey buildings. *Land Use Policy*, *104*, 105367.

Barzegar, M., Rajabifard, A., Kalantari, M., & Atazadeh, B. (2019). 3D BIM-enabled spatial query for retrieving property boundaries: A case study in Victoria, Australia. International Journal of Geographical Information Science, 34(2), 251–271. https://doi.org/10.1080/13658816.2019.1658877

Barzegar, M., Rajabifard, A., Kalantari, M., & Atazadeh, B. (2021). Identification of property boundaries using an IFC-based cadastral database. *Land*, *10*(3), 300.

Biljecki, F., Ledoux, H., Stoter, J. (2016): An improved LOD specification for 3D building mod-els. Computers, Environment, and Urban Systems, vol. 59, pp. 25-37

Broekhuizen, M. J. M., Kalogianni, E., & van Oosterom, P. J. M. (2021). BIM models as input for 3D LASs for apartment registration. In 7th International FIG Workshop on 3D Cadastres (pp. 53–74). International Federation of Surveyors (FIG). https://doi.org/10.4233/uuid:5e240a06-5fdf-4354-9e6d-09c675f1cd8b

Brooks K. P. (2023). The Current Practice of Building Information Modelling. Masters Theses. University of Massachusetts Amherst

Durdyev, S., Ashour, M., Connelly, S., & Mahdiyar, A. (2022). Barriers to the implementation of Building Information Modelling (BIM) for facility management. Journal of Building Engineering, 46, 103736. https://doi.org/10.1016/j.jobe.2021.103736

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors. www.EngineeringBooksPdf.com

Einali, M., Alesheikh, A. A., & Atazadeh, B. (2022). Developing a building information modelling approach for 3D urban land administration in Iran: A case study in the city of Tehran. *Geocarto International*, 1–20.

Emamgholian, S., M. Taleai, and D. Shojaei. (2021). Exploring the Applications of 3D Proximity Analysis in a 3D Digital Cadastre. Geo-Spatial Information Science 24 (2): 201–214. https://doi.org/10.1080/10095020.2020. 1780956

Enemark, S. (2005). Understanding the land management paradigm. https://www.researchgate.net/publication/228342504

Guler, D., van Oosterom, P., & Yomralioglu, T. (2022). How to exploit BIM/IFC for 3D registration of ownership rights in multi-storey buildings: Evidence from Turkey. Geocarto International, https://doi.org/10.1080/10106049.2022.2142960

Gursoy, S., H., Alkan, M., & Koeva, M. (2022). Towards investigation of integrating LADM, BIM, and CityGML of 3D condominium rights for cadastral purposes: The case of Turkish cadastral system.

Hjelmblom, M., Paasch, J., Paulsson, J., Edlund, M., Bökman, F. (2019). Towards automation of the Swedish property formation process: A structural and logical analysis of property subdivision. Nordic Journal of Surveying and Real Estate Research, 14(1), 29-63.

Isikdag, U., Aouad, G., Underwood, J., & Wu, S. (2007). Building information models: A review on storage and exchange mechanisms.

Indrajit A., van Loenen B., Suprajaka, Jaya V. E., Ploeger H., Lemmen C. and van Oosterom P. (2021). Implementation of the spatial plan information package for improving ease of doing business in Indonesian cities. Land Use Policy 105 (2021) 105338. Published by Elsevier Ltd.

Jazayeri, I., Rajabifard, A., & Kalantari, M. (2014). A geometric and semantic evaluation of 3D data sourcing methods for land and property information. Land Use Policy, 36, 219– 230. https://doi.org/10.1016/j.landusepol.2013.08.004

Kalogianni, E., van Oosterom, P., Dimopoulou, E., & Lemmen, C. (2020). 3D land administration: A review and a future vision in the context of the spatial development lifecycle. ISPRS International Journal of Geo-Information 9(2). https://doi.org/10.3390/ijgi9020107

Kalogianni, E., Janečka, K., Kalantari, M., Dimopoulou, E., Bydłosz, J., Radulović, A., Vučić, N., Sladić, D., Govedarica, M., Lemmen, C., & van Oosterom, P. (2021). Methodology for the development of LADM country profiles. Land Use Policy, 105. https://doi.org/10.1016/j.landusepol.2021.105380

Kara, A., Lemmen, C., van Oosterom, P., Kalogianni, E., Alattas, A., & Indrajit, A. (2023). Design of the new structure and capabilities of LADM Edition II including 3D aspects. http://pakhuis.tudelft.nl:8080/edu/Cesium-1.43/Apps/3dcad

Kitsakis D., Kalogianni E. and Dimopoulou E. (2022). Public Law Restrictions in the Context of 3D Land Administration—Review on Legal and Technical Approaches., 11, 88. https://doi.org/10.3390/land11010088. Academic Editor: Rohan Bennett

Lemmen C. (2012). *A Domain Model for Land Administration.* PhD thesis, University of Twente. July 2012. https://www.researchgate.net/publication/258324815 A Domain Model for Land Administration

Lemmen, C., van Oosterom, P., Kalogianni, E., & Shnaidnman, A. (2019). The scope of LADM revision is shaping-up. https://www.researchgate.net/publication/335867359

Lemmen, C., Alattas, A., Indrajit, A., Kalogianni, E., Kara, A., Oukes, P. van Oosterom, P. (2021). The Foundation of Edition II of the Land Administration Domain Model. In Proceedings of the FIG e-Working Week 2021: Challenges in a New Reality, Virtual, 21 June 2021.

Liu, C., Zhu, H. Z., Ma, J. and Li F. (2023). BIM/IFC-based 3D spatial model for condominium ownership: a case study of China. Geospatial Information Science, DOI: 10.1080/10095020.2023.2246518

Meulmeester, E. (2019). BIM legal proposal for defining legal spaces for apartment rights in the Dutch cadastre using the IFC data model. TU Delft.

Noardo, F., Harrie, L., Arroyo Ohori, G. A. K., Biljecki, F., Ellul, C., Krijnen, T. F., Eriksson, H., Guler, D., Hintz, D.,

Stoter, J. E., & More Authors (2020). Tools for BIM-GIS Integration (IFC Georeferencing and Conversions): Results from the GeoBIM Benchmark 2019. ISPRS International Journal of Geo-Information, 9(9), [502]. https://doi.org/10.3390/ijgi9090502

Olfat, H., Atazadeh, B., Shojaei, D., & Rajabifard, A. (2019). The feasibility of a BIM-driven approach to support building subdivision workflows—Case study of Victoria, Australia. ISPRS International Journal of Geo-Information, 8(11), 499. https://doi.org/10.3390/ijgi8110499

Olfat, H., Atazadeh, B., Badiee, F., Chen, Y., Shojei, D. & Rajabifard, A. (2021). A Proposal for Streamlining 3D Digital Cadastral Data Lifecycle. Land 2021, 10(6), 642; https://doi.org/10.3390/land10060642

Oldfield, J., Bergs, R., van Oosterom, P., Krijnen, T. F., & Galano, M. M. (2018). 3D cadastral lifecycle: An information delivery manual ISO 29481 for 3D data extraction from the building permit application process. http://bimloket.nl/BasisUSO

Petronijevic. M., Visnjevac, N., Prascevic, N., & Bajat, B. (2021). The extension of IFC for supporting 3D cadastre LADM geometry. *International Journal of Geo-Information, 10*(5), 297.

Ramlakhan R., Kalogianni E., van Oosterom P. and Atazadeh B. (2023). Modelling the legal spaces of 3D underground objects in 3D land administration systems. https://doi.org/10.1016/j.landusepol.2023.106537

Ren R. and Zhang J. (2021). A New Framework to Address BIM Interoperability in the AEC Domain from Technical and Process Dimensions. Volume 2021 | Article ID 8824613 | https://doi.org/10.1155/2021/8824613

Salman A., Khalfan M. and Maqsood T. (2012). Building information modeling (BIM): Now and beyond. Australasian Journal of Construction Economics and Building. DOI: 10.5130/ajceb.v12i4.3032

Shin J., Rajabifard A., Kalantari M. and Atazadeh B. (2020). Applying BIM to support dispute avoidance in managing multi-owned buildings. Journal of Computational Design and Environment. DOI: 10.1093/jcde/qwaa057. Published by Oxford University Press on behalf of the Society for Computational Design and Engineering.

Simsek N. C. & Uzun B. (2021). Building Information Modelling (BIM) for property valuation: A new approach for Turkish Condominium Ownership. Survey Review, DOI: 10.1080/00396265.2021.1905251

Sun, J., Mi, S., Olsson, P. O., Paulsson, J., & Harrie, L. (2019). Utilizing BIM and GIS for representation and visualization of 3D cadastre. ISPRS International Journal of GeoInformation, 8(11), 503. https://doi.org/10.3390/ijgi81105

Sun, J. & Paulsson, J. (2023). Towards 3D Cadastral Level of Detail. FIG Working Week 2023. Orlando, Florida, USA.

Sladić, D., Radulović, A., & Govedarica, M. (2018). Processes in cadastre: Process model for Serbian 3D Cadastre 6th International FIG 3D Cadastre Workshop

Song, Y., Wang, X., Tan, Y., Wu, P., Sutrisna, M., Cheng, J. C. P., & Hampson, K. (2017). Trends and opportunities of BIM-GIS integration in the architecture, engineering and construction industry: A review from a spatio-temporal statistical perspective. ISPRS International Journal of Geo-Information, 6(12). https://doi.org/10.3390/ijgi6120397

Tauscher H., Heigener D., Krishnakumar S., Graichen T., Schmidt R., and Richter J. (2023). IFC georeferencing for OSM. Recent Advances in 3D Geoinformation Science - Proceedings of the 18th 3D GeoInfo Conference

van der Vaart, J., Stoter, J., Diakite, A., Biljecki, F., Ohori K. A. & Hakim A. (2023). Assessment of the LoD specification for the integration of BIM-derived building models in 3D city models. Recent Advances in 3D Geoinformation Science - Proceedings of the 18th 3D GeoInfo Conference.

Wong S. Y. and Gray J. (2019). Barriers to implementing Building Information Modelling (BIM) in the Malaysian construction industry. IOP Conf. Ser.: Mater. Sci. Eng. 495 012002

Ying, S., Y. Xu, C. Li, R. Guo, and L. Li. 2021. "Easement Spatialization with Two Cases Based on LADM and BIM." Land Use Policy 109:105641. https://doi.org/10.1016/j.landusepol.2021.105641.

Zhu J., Wang X., Chen M., Wu P., and Kim M. J. (2019). Integration of BIM and GIS: IFC geometry transformation to shapefile using enhanced open-source approach. https://doi.org/10.1016/j.autcon.2019.102859