Transactions in GIS

Research Article

Transactions in GIS, 2017, 21(1): 91–113

Building Information Modelling for High-rise Land Administration

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Abstract

Current land administration systems mainly use 2D plans to define and secure ownership rights associated with properties in high-rise buildings. These 2D plans may not effectively communicate and manage the spatial complexity associated with multi-layered and stacked properties in such buildings; additionally, multiple pages of plans (representing sections of the building) are required to represent all ownership boundaries. In response, land administration organizations have been investigating a 3D digital approach to managing information about ownership rights in high-rise building structures. In this article, Building Information Modeling (BIM) is proposed as a feasible approach for managing land and property information in high-rise buildings. BIM provides a collaborative, digital and intelligent 3D data environment for managing building information throughout the lifecycle of buildings. However, there is currently no capacity in BIM for recording and representing information about ownership and boundaries of properties, which is core land administration information. Therefore, this article proposes an extension to the BIM standard, which is implemented in a prototype BIM model of a complex building to showcase the potential capability of using BIM for high-rise land administration and for modeling 3D ownership rights.

1 Introduction

Land administration systems lay the foundation for supporting the processes of determining, recording and disseminating information about the tenure, value and use of land (Williamson et al. 2010). These systems utilize cadastral data models to manage the spatial dimension of rights, restrictions, and responsibilities (RRRs) associated with a piece of land or property (Kalantari 2008). According to Enemark (2009, p. 1), "rights are normally concerned with ownership and tenure whereas restrictions usually control use and activities on land. Responsibilities relate more to a social, ethical commitment or attitude to environmental sustainability and good husbandry".

Every land administration system has its own cadastral data model for managing RRRs. However, major cadastral data models that have been developed are the core cadastral data model (Henssen 1995), ArcGIS Parcel Data Model (Meyer 2001), Legal Property Object (Kalantari et al. 2008), US Cadastral Data Content Standard for the National Spatial Data Infrastructure (FGDC 2008), ePlan model (ICSM 2010), and ISO 19152-LADM (ISO 2012b). The differences between these cadastral data models mainly stem from the fact that each jurisdiction has its own requirements and expectations for managing RRR information and therefore implement these models variably. However, most cadastral data models have one thing in

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doi: 10.1111/tgis.12199

Figure 1 An example of future complex building structures (Arbre Blanc tower, Courtesy of the Nicolas Laisné* Architecte agency)

common: they rely on two-dimensional (2D) land parcels as the basis for recording and communicating RRR information (Kalantari 2008, McDougall 2006).

Over the last few decades, rapid urbanization has resulted in substantial pressure on development and use of land in urban environments. The growth in complex and high-rise building structures, such as the one shown in Figure 1, poses new challenges for current 2D-based land administration systems. In order to address these challenges, land administration agencies are now supporting research on three-dimensional (3D) digital management of land and property information in high-rise buildings (Rajabifard et al. 2012).

3D digital management of land and property information in high-rise buildings requires two main dimensions, namely legal and physical information (Aien et al. 2013, Jazayeri et al. 2014). Legal information refers to ownership information, boundaries of properties, common properties and easements. Legal information is a prerequisite for managing RRRs in the building subdivision process and is associated with concept of legal spaces which include fiat (invisible) cadastral objects (Karabin 2014, Ying et al. 2014). Physical information includes geometric and semantic components. Geometric information refers to the shape and geometrical aspects of building elements such as precise surveying data, coordinate systems and measurements. Semantic information is defined as physical descriptions about building elements with examples being thickness and materials of building elements, roof data, and facade data (Jazayeri et al. 2013). Physical information is related to the concept of physical spaces which consist of bona fide (visible) and real world spatial objects (Karabin 2014, Ying et al. 2014).

Recent advancements in techniques for 3D digital modeling have accelerated the production of 3D physical models of buildings and other urban infrastructures worldwide (Becker et al. 2013). The most comprehensive and intelligent 3D digital approach for managing information during the lifecycle of complex and high-rise buildings is Building Information Modeling (BIM) (Krygiel and Nies 2008). BIM is a rich and shared knowledge resource for managing building information in three physical dimensions and enables multi-disciplinary collaboration among different stakeholders involved in the development of high-rise buildings (Eastman et al. 2011). BIM provides many benefits and resource savings during design, planning, and construction phases of a building (Azhar 2011, Forbes and Ahmed 2010). The open data model for BIM is the Industry Foundation Classes (IFC), which facilitates interoperability in the Architecture, Engineering, and Construction (AEC) industry (Liebich 2013). IFC is an object-oriented data model and it includes a comprehensive set of entities describing the geometric and semantic aspects of a building throughout its lifecycle. From a land administration perspective, IFC provides highly detailed physical information about buildings; however, it does not specify legal information associated with ownership of properties inside those buildings.

The ability to encapsulate legal information in BIM can potentially address current challenges of high-rise land administration. Therefore, this article aims to investigate how IFC can be extended to accommodate legal information as a first step towards leveraging BIM for managing land and property information in high-rise buildings.

2 Background

2.1 Current Challenges in High-rise Land Administration

In this section, City of Melbourne (CoM) has been selected as a case study area to contextualize challenges currently experienced in high-rise land administration. It has been recently reported that the density of buildings in the central area of the CoM is four times more than other major cities around the world (Hodyl 2015). Figure 2 indicates that the majority of new apartment dwellings in the CoM are in buildings with more than five stories built between 2006 and 2012; towers with more than 30 levels have had the fastest rate of increase (Birrel and Healy 2013).

The high-rise building subdivision process in the CoM includes five main phases: design, planning, construction, registration and strata management (Ho et al. 2015). There are two

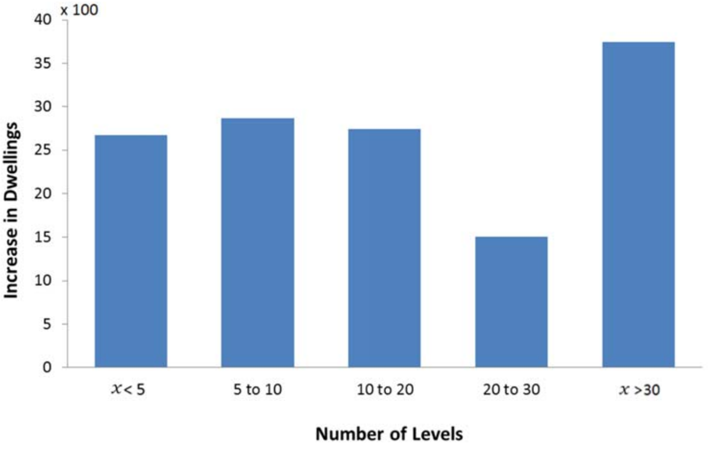

Figure 2 Rate of increase in apartment dwellings in City of Melbourne between 2006 and 2012, adapted from Melbourne City Council (2012)

categories of technical challenges associated with recording, managing and communicating ownership rights in this process: 1) challenges with subdivision plans prepared in the planning phase to delineate boundaries of each individual ownership property; 2) challenges with cadastral data models used in the registration phase. These challenges are discussed in detail in Sections 2.1.1 and 2.1.2, respectively.

2.1.1 Delineating boundaries in building subdivision plans

The first technical challenge associated with delineating boundaries in building subdivision plans is that the complex reality of ownership spaces with interweaving and irregular shapes may not be effectively recorded and managed via 2D paper-based drawings or even 2D digital plans. These subdivision plans also include complicated textual information which is difficult for non-specialized actors (with limited background on land administration) to understand (Shojaei et al. 2013). Secondly, although 2D subdivision plans are functional, it might be costly because multiple pages of 2D diagrams are used to describe RRR information associated with superimposed properties in high-rise buildings (Jazayeri et al. 2014, Shojaei 2015). For instance, over 50 pages of 2D plan drawings are required to represent the overall parcel as well as individual property boundaries for a 40-storey apartment building in the CoM (Rajabifard et al. 2013).

Although multiple 2D plans can represent ownership boundaries for properties restricted to one level, utilizing these plans to communicate the ownership boundaries of properties encompassing parts of several levels is a very difficult task. This challenge is more severe than the two previous ones. In Figure 3, a common property area, comprising the corridors, lobbies and stairs of a building, is highlighted in red to provide an example of this challenge.

As shown in Figure 4, some property boundaries can be defined by referencing a building's physical structures such as walls, windows or doors. The boundary lines are defined using one of three relationships with the physical structure: either the interior or exterior face, or the median of the structure itself. This could potentially be misunderstood by a person without sufficient knowledge to interpret what the lines mean and who could easily misinterpret the boundary and, hence, the RRR information.

Figure 3 An example of a complex property covering parts of four levels

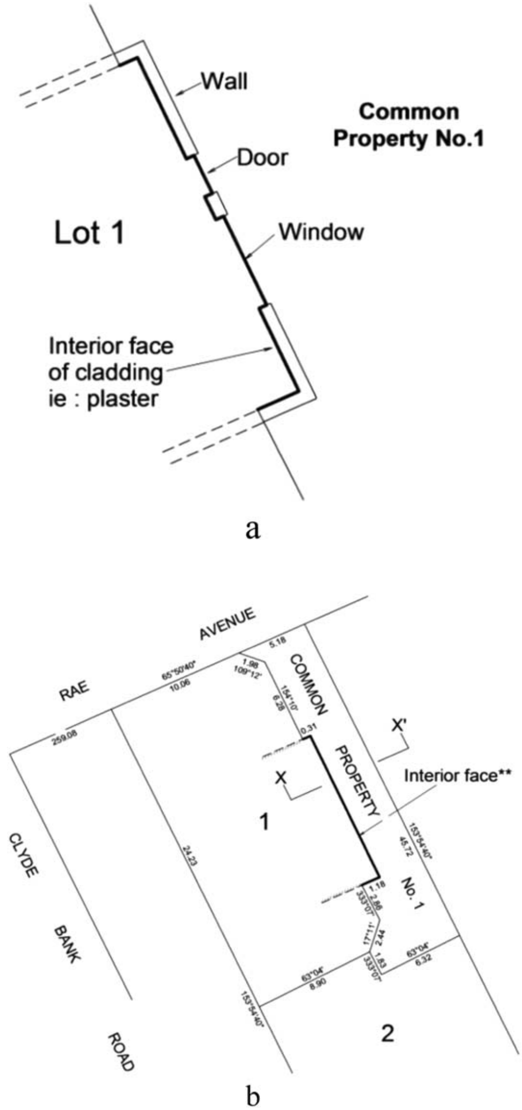

Figure 4 Boundaries referencing physical structures: (a) Physical elements within building; and (b) Plan depiction (LandVictoria 2012)

2.1.2 Challenges of cadastral data models used in registration phase

The first issue with most cadastral data models is inefficient communication of the spatial dimension of 3D RRR. In these data models 2D land parcels usually provide the basic spatial units to map ownership boundaries (Kalantari et al. 2008). This mode of communication is efficient for simpler buildings and developments but may not effectively communicate ownership boundaries of properties inside complex and vertical urban developments such as high-rise buildings (Aien et al. 2013). Currently, few cadastral data models support spatial representation of 3D RRR, and those that do, do so with limited capabilities. These include the Land Administration Domain Model (LADM) (ISO 2012b) and the recently proposed 3D Cadastral

Data Model (3DCDM) (Aien 2013). LADM uses a multi-surface approach, which is not as strong as solid models for visualising 3D spatial objects (Pouliot et al. 2011, 2013). Solid models can facilitate visualization of 3D spatial objects (Jarroush and Even-Tzur 2004) and enable volumetric computations and various 3D analyses required in land administration, such as 3D visibility analysis of properties which is useful in valuation and taxation of properties (Navratil and Fogliaroni 2014). In response to these limitations, 3DCDM utilizes both multi-surface and solid models for modelling the geometry of 3D spatial objects (Aien 2013). However, the geometry of spatial objects in 3DCDM is developed based on a GML profile (ISO 2007), which only supports boundary representation (B-Rep) and not other types of solid models such as Constructive Solid Geometry (CSG) – both CSG and B-Rep are relevant solid models for 3D cadastral applications (Peres and Benhamu 2009). In addition, 3DCDM is a conceptual data model and has not yet been implemented for modelling a high-rise building in a real case study scenario.

The second issue is that most cadastral data models in use do not include sufficient semantic information about 3D properties. In high-rise buildings, boundaries of ownership spaces are mainly defined based on physical structures such as walls, doors, windows or ceilings. In LADM, the "LA_BoundaryFace" entity, which is used to represent the boundary surfaces (Lemmen et al. 2015), does not distinguish a wall boundary surface from a ceiling boundary surface; neither does not specify whether the boundary is located in the interior, exterior or median of the physical structure. Such ambiguity in defining various boundaries can be resolved by enriching cadastral data models with more semantic information. In addition, sufficient semantic information would eliminate spatial data integration issues and facilitate interoperability of land administration systems with other urban systems (Aien et al. 2013).

The last issue is that cadastral data models mostly include legal entities and do not internally incorporate physical information. LADM supports connecting legal objects to their corresponding physical structures via external links. This means that physical information is kept and maintained in other databases with different data structures. In order to integrate two spatial data sets from different sources, two main issues need to be resolved: transforming geometric information and harmonizing semantic information (Isikdag et al. 2008). Even though these issues are addressed, there might be some inconsistencies in matching 3D legal objects with their physical counterparts (Aien 2013, Stadler and Kolbe 2007). This is why cadastral data models should be internally extended with physical entities. This was proposed by Aien (2013) in 3DCDM, but the proposed integration of physical information with legal information is still yet to be tested using real data and 3DCDM has not been implemented to represent physical entities together with legal entities in an integrated data environment.

2.2 BIM

The widely-used acronym BIM refers to two distinct contexts: product and process. As a process, BIM (Building Information Modelling) is an approach to create, manage, derive and share building information among different actors involved in the building development process in order to facilitate collaboration and communication among them (Eastman et al. 2011). Consequently, the result of the BIM process is a BIM product (Building Information Model) which includes 3D digital spatial information as well as semantic information about a building to support decision making throughout its lifecycle (Smith and Tardif 2009). The main characteristics of a BIM product are object-oriented data structure, rich semantic and spatial information, models spatial relationships between building elements and extensibility of its standard data model (Isikdag et al. 2007).

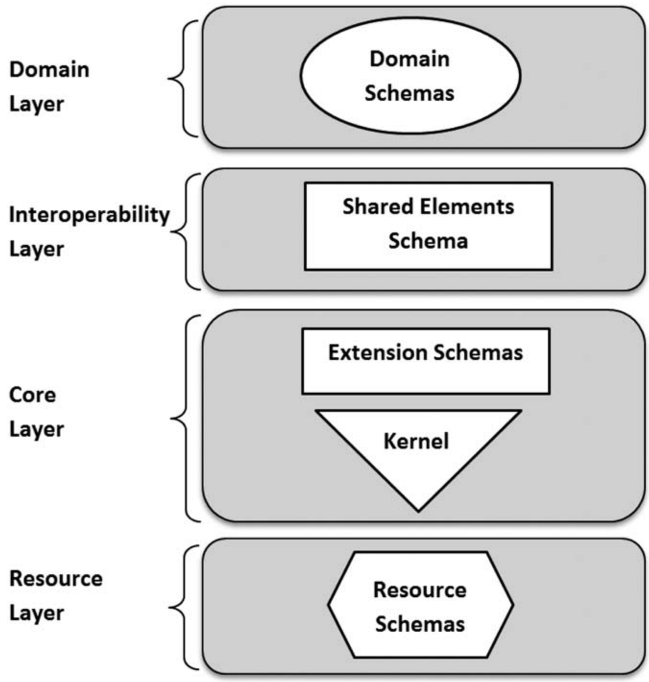

Figure 5 Simplified conceptual data schema of the IFC standard, adapted from (ISO 2013)

Within the AEC industry, BIM has had a significant impact on resolving issues associated with 2D drawings or even 3D CAD models (Arayici et al. 2011, Mihindu and Arayici 2008). Although BIM brings many benefits for productivity within the AEC industry, some challenges associated with adoption of BIM need to be addressed. The most important challenge is the interoperability between different BIM tools since each tool has its own data format for manipulating BIM data (Isikdag et al. 2007). This issue can be addressed by developing an open data model which facilitates data transfer issues between different BIM tools (Eastman et al. 2011). The international BuildingSMART organization therefore developed the IFC standard to facilitate interoperability between BIM tools (Liebich 2013).

2.2.1 IFC and relevant 3D spatial data models

IFC is an open BIM data model which includes physical entities describing the whole lifecycle of buildings. As indicated in Figure 5, the IFC standard includes four main conceptual layers, each of which has several subschemas (ISO 2013). The resource layer includes subschemas which hold basic concepts and generic entities like time, date, geometry and cost (ISO 2013). These entities are utilized in the higher layers to define value type of attributes. The core layer contains the "Kernel" subschema and the other core extension subschemas (ISO 2013). The "Kernel" subschema includes "IfcRoot" entity which is the most abstract entity in the IFC standard. This subschema also includes general entities like object, property and relationship which are the subclasses of "IfcRoot" entity. Interoperability layer includes the subschemas which usually used for sharing and exchanging building information across AEC disciplines (ISO 2013). For instance, "Shared Building Elements" subschema includes entities such as

Figure 6 A high-rise building with 3D holes (The Elephant building located in Bangkok, Thailand)

"IfcWall", "IfcDoor", "IfcWindow", "IfcSlab" and "IfcRoof". In domain layer, the entities related to a specific AEC discipline is defined within each subschema. Currently, the domain layer includes subschemas for nine AEC disciplines, namely building controls, plumbing and fire protection, structural elements, structural analysis, heating, ventilation, and air conditioning (HVAC), electrical, architecture, construction management, and facilities management domains (ISO 2013).

Besides IFC, there are other open data models developed for exchanging 3D spatial information. 3D spatial data models can be classified into three main categories: pure geometric models, models with structured geometry but limited semantic information, and models comprising structured geometry as well as comprehensive semantics (Kolbe et al. 2009, Stadler and Kolbe 2007). VRML (ISO 2004), X3D (ISO 2005), COLLADA (ISO 2012a) and KML (Wilson 2008) are examples of the first category. The geometry of models in the second category can be constructed through automatic interpretation of photogrammetric data or laser scan point cloud (Kolbe et al. 2009). The constructed geometry can then be enriched with limited semantic information. Examples of the last category are CityGML as well as IFC. CityGML standard is an open 3D spatial data model for managing and visualizing urban objects in five Levels of Detail (LoD) (Kolbe 2009).

Here, the reasons for selecting IFC rather than CityGML will be discussed. First, CityGML only utilizes the B-Rep method for representing geometry of 3D objects (Kolbe 2012). However, IFC is more flexible in modelling the geometry of 3D objects and it not only supports B-rep but also other types of solid models such as CSG and swept solids (Gröger and Plümer 2012). B-rep more effectively supports 3D topology relationships in comparison with CSG (Ekberg 2007); however, CSG is more flexible in constructing complex spatial objects (Jarroush and Even-Tzur 2004). For instance, CSG can efficiently model a spatial object with a hole inside in comparison with B-rep. To illustrate this situation, a real world building with two holes has been shown in Figure 6. These holes can be created in CSG by using one subtraction operation for each hole, which is subtracting the whole building object from the shape of the hole. In contrast, if the building model is constructed by the B-rep model, topological primitives must be appropriately defined, namely vertices, edges and faces, which is a time consuming and difficult task. The second reason is that although LoD4 of CityGML provides all the entities needed to represent legal information, the data of LoD4 does not exist for most cities. Another reason is that in the design phase of a high-rise subdivision process, land surveyors currently use 2D CAD files, which they receive from architects, as the basis for creating subdivision plans for high-rise buildings (Ho et al. 2015). It is highly likely that this workflow would continue, i.e. if land surveyors are to create a 3D digital plan of subdivision for a building, they would likely request a 3D digital model of the building from architects. Currently, given that 3D building data in IFC format is very prevalent among architects (Shojaei 2015), it is perhaps more feasible that in future land surveyors would receive 3D building models from architects in IFC format, rather than CityGML, which they might use to create 3D digital building subdivisions.

2.2.2 Related BIM work in land administration

One of the opportunities of bringing BIM into the spatial domain is to enable 3D registration of ownership rights in apartments in a digital environment (Isikdag et al. 2011, Isikdag and Zlatanova 2009) and facilitate land management in urban areas. This section reviews related work investigating the role of BIM in land administration in order to distinguish the difference between the work presented here and relevant research projects. Some of the earliest researches on utilizing BIM for land administration was by Clemen and Gründig (2006), who indicated the need to import different entity types into IFC files based on processed surveying measurements and observations to manage indoor cadastral information. However, they did not provide the data model for managing cadastral information within the IFC schema. More recently, El-Mekawy and Östman (2012, 2015) investigated the extension of Unified Building Models (UBM) with four types of boundary surfaces to represent 3D properties for a hospital building in Sweden. These boundary surfaces are "Building Elements Surfaces", "Digging Surfaces", "Protecting Area Surfaces", and "Real Estate Boundary Surfaces". UBM is a reference data model for bi-directional mapping between the IFC and CityGML standard (El-Mekawy 2010). However, the extended cadastral UBM only represents how legal boundaries can be defined and does not model other main cadastral entities, which include information about interest holders and legal documents. In a further study by El-Mekawy et al. (2014), the authors proposed that enriching BIM with those four boundary surfaces could facilitate the interaction between BIM and the 3D property domain but they did not showcase a BIM model enriched with 3D property information. Finally, Isikdag et al. (2014) investigated linking 3D cadastral models with 3D semantically enriched building models such as IFC, arguing that this could potentially improve property valuation practices in different countries around the world.

Although the studies outlined above all show different degrees of leveraging BIM for supporting land administration functions, none of the studies has explored how the IFC standard can be extended to accommodate legal information, which is critical for the adoption of BIM for land administration purposes. In the next section, this article proposes to extend this standard with cadastral entities.

3 BIM-based Approach for High-rise Land Administration

The IFC standard includes a rich amount of 3D physical entities but cannot yet accommodate 3D cadastral or legal entities. To do so requires firstly, an investigation into how this standard manages physical information. Subsequently, in line with the logic of the data model, this article proposes an extension to the standard to manage legal information. Finally, the proposed extension is implemented in a prototype BIM model and the results are discussed in the context of whether BIM can be feasibly adopted to support high-rise land administration.

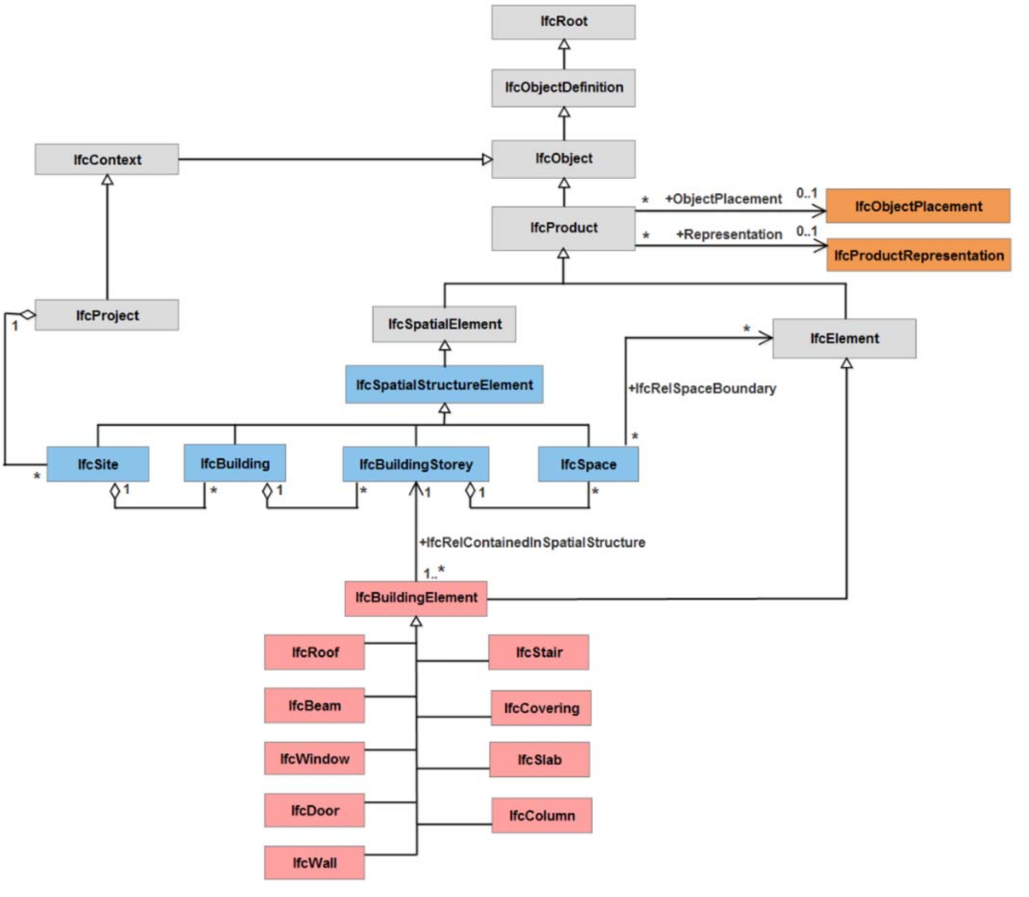

Figure 7 Physical data entities in IFC data model

3.1 Modelling Physical Information in IFC

Physical entities in IFC are defined as subclasses of the "IfcProduct" entity. Also, it is noticeable that all physical entities are aggregated into the "IfcProject" entity. This means that "IfcProject" is the uppermost container for all information in an IFC exchange file (Liebich 2009). In addition, this entity provides context information such as default measurement units, the coordinate system, the accuracy of geometric information, and direction of true north with respect to the world coordinate system. There is only a single instance of the "IfcProject" entity within each IFC exchange file. Figure 7 shows that 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". The "IfcSpatialStructureElement" is the superclass for concepts which define the spatial structure of an IFC standard file. This class and its subclasses are shown in blue in Figure 7. These spatial elements are (Liebich 2009):

1. "IfcSite": Any IFC project can include several sites which may be connected or disconnected from each other. This entity models supplementary information, such as land title

number and site address, about the site of the building and may represent the topography of the terrain around the building site.

2. "IfcBuilding": This entity includes supplementary information about the whole building itself. This information includes the elevation of ground floor relative to the sea level, the minimum elevation for the terrain at the perimeter of the building, and the address of the building. Normally, there is no shape representation for the "IfcBuilding" since its constituting sub-elements determine its shape (cf. Figure 8).
3. "IfcBuildingStorey": This IFC class is defined to provide information about the stories of the building such as the elevation for each storey of the building. This entity also does not have its own shape representation and its constituting components determine its shape (cf. Figure 8).
4. "IfcSpace": This entity is used for managing spaces as functional volumes. For indoor spaces, "IfcSpace" is related to an "IfcBuildingStorey" entity. However, for outdoor spaces, it can be directly related to an "IfcSite" entity. This entity can be considered as a good candidate for managing 3D legal property objects. In the next subsection, how defining a subclass of "IfcSpace" entity can facilitate managing 3D legal properties will be described .

The abstract class "IfcBuildingElement" is the superclass for all the physical building elements. This entity and its subclasses are represented in red in Figure 7. Physical building elements constitute the primary parts of the buildings. These elements include windows (IfcWindow), doors (IfcDoor), walls (IfcWall), slabs (IfcSlab), stairs (IfcStair), and similar components (as shown in Figure 8).

The geometry of both spatial elements and physical building elements is inherited from "IfcProduct" entity. This entity utilizes two main entities for modeling the geometry, namely "IfcObjectPlacement" and "IfcProductRepresentation". These entities are shown in orange in Figure 7. The "IfcObjectPlacement" entity models the placement of a spatial or physical building element in the space. The placement of physical elements can be done through three approaches: (1) Absolute placement relative to the world coordinate system; (2) Relative placement to the other building elements; and (3) Constraint placement relative to the grid axes. The "IfcProductRepresentation" entity is used for modeling the shape of spatial elements and physical building elements.

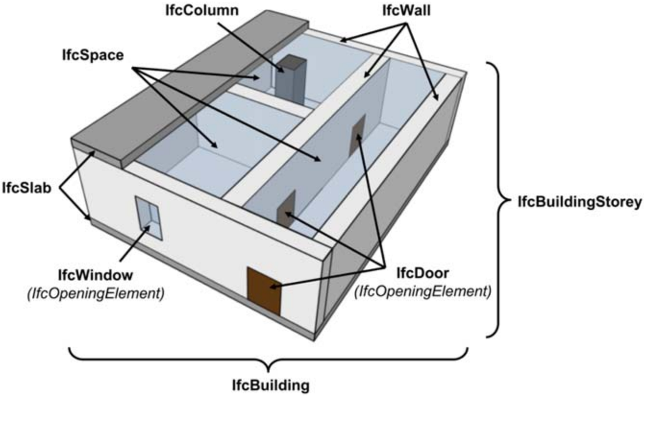

Figure 8 Physical information in the IFC standard, adapted from (Nagel 2014)

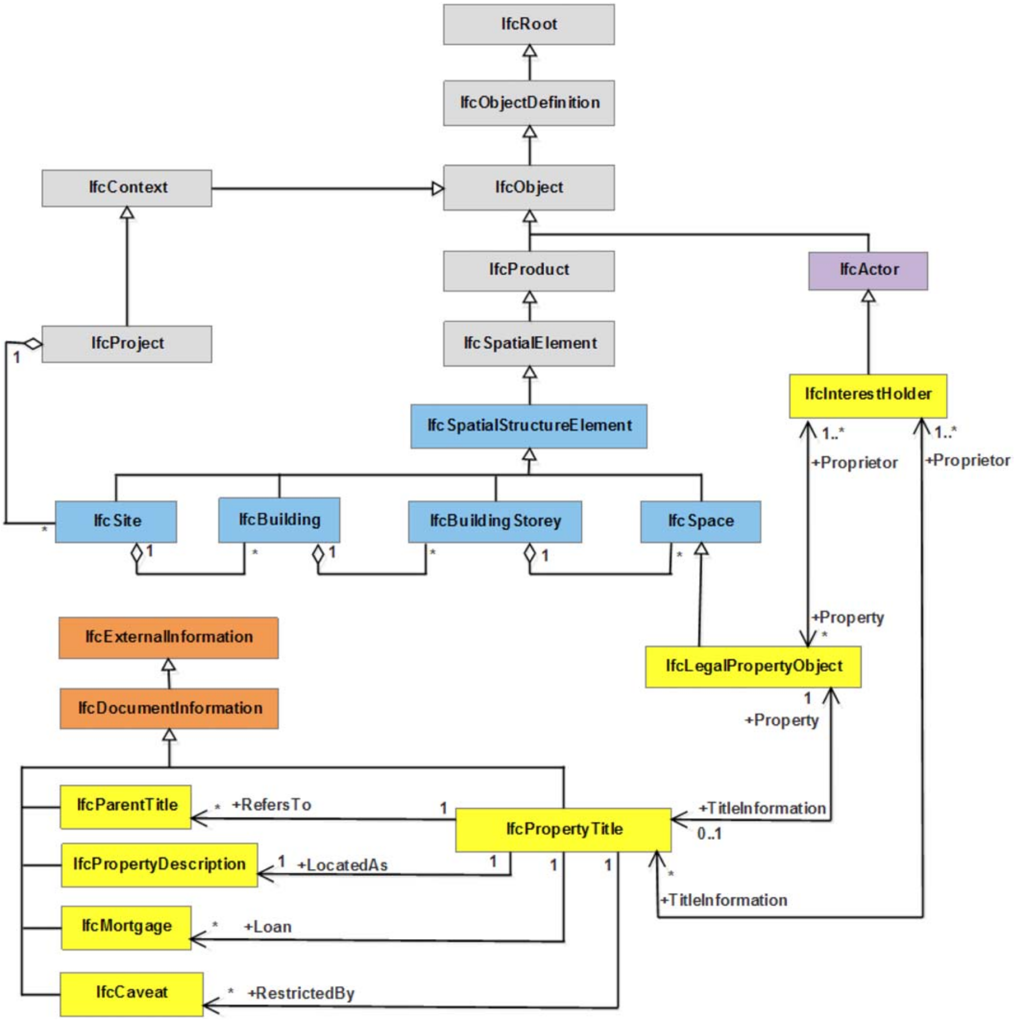

Figure 9 Legal entities defined within IFC schema

3.2 Extending IFC with Legal Information

In order to enrich the IFC data model with legal information, the necessary legal entities should be identified. In this article, the main legal entities identified in Aien (2013) will be adopted as those required for managing legal information. These entities include 3D legal property objects, different types of legal documents, and interest holders. Each of these entities should be appropriately defined within the IFC data model and this requires selecting proper IFC entities to define relationships between them and legal entities. Figure 9 shows the legal entities defined within IFC schema. The proposed entities are depicted in yellow.

3.2.1 3D legal property objects in IFC

3D legal property objects have been envisaged as 3D volumes representing the legal spaces for properties. Therefore, they can be considered a subclass of "IfcSpace" entity, inheriting all the

Table 1 Attributes of the 'IfcLegalPropertyObject' entity

Attribute	Description	Value Type	Multiplicity
RRR	The type of the legal object	IfcRRREnum	1
LegalObjectUnit	The unit of the legal object	IfcLegalObjectUnitEnum	1
LegalObjectClass	Describes the class of the legal object	IfcLegalObjectClassEnum	1
Volume	The volume of the legal object	IfcSolidMeasure	0..1
LotEntitlement	The entitlement portion of the legal object	IfcText	0..1
LotLiability	The liability portion of the legal object	IfcText	0..1
LandUse	The land use of the legal object	IfcLandUseEnum	0..1
LegalObjectState	The state of the legal object	IfcLegalObjectStateEnum	0..1

Table 2 Enumeration values for some attributes of the 'IfcLegalPropertyObject' entity

Value Type	Enumeration Values
IfcRRREnum	Ownership, Common Ownership, Easement, Covenant, License
IfcLegalObjectUnitEnum	Administrative, Single, Multipart, Part
IfcLegalObjectClassEnum	Lot, Easement, Common Property, Air Space
IfcLandUseEnum	Residential, Commercial, Mixed Use
IfcLegalObjectStateEnum	Adjoining, Affected, Created, Extinguished

general characteristics of space objects (cf. Figure 9). However, 3D legal property objects have their own semantic information which differentiates them from the other types of space objects in IFC. The "IfcLegalPropertyObject" entity represents all types of legal property objects such as 3D ownership spaces for units, common properties and easements. Table 1 shows the specific attributes associated with "IfcLegalPropertyObject" entity. Some attributes have enumeration values listed in Table 2.

3.2.2 Legal documents in IFC

Text documents, such as reports or spreadsheets, are not part of IFC files and their actual contents are not modeled within IFC files. However, they can be referenced externally in IFC. In the resource layer of the IFC schema, there is "External Reference Resource" subschema which includes entities used for referencing external resources as well as managing meta-information about these resources (BuildingSMART 2013a). Within that schema, the "IfcExternalInformation" entity is the superclass for managing meta-information about external resources. The "IfcDocumentInformation" is a subclass of "IfcExternalInformation" entity and it is utilized for managing meta-information about documents associated with an IFC file. Therefore, meta-information about legal documents can be modelled by defining new subclass entities for the "IfcDocumentInformation" entity. There are five legal documents associated with each 3D legal property object: title, parent title, property description, mortgage and

Table 3 Attributes of the 'IfcPropertyTitle' entity

Attribute	Description	Value Type	Multiplicity
Volume	The volume number of the title for the property	IfcInteger	1
Folio	The folio number of the title for the property	IfcInteger	1
SecurityNumber	The security number of the title for the property	IfcText	0..1
CreationDate	The date and time when the title for property is produced	IfcDateTime	0..1
NumberOfParentTitle	The number of the parent title for the property	IfcInteger	0..1

Table 4 Attributes of the 'IfcParentTitle' entity

Attribute	Description	Value Type	Multiplicity
Volume	The volume number of the parent title	IfcInteger	1
Folio	The folio number of the parent title	IfcInteger	1

Table 5 Attributes of the 'IfcPropertyDescription' entity

Attribute	Description	Value Type	Multiplicity
LotNumber	The lot number in the title	IfcText	1
PlanNumber	The plan number in the title	IfcText	1
TypeOfPlan	The type of the plan	IfcPlanTypeEnum	1
DescribeInfo	Provides additional information about the lot in the title	IfcText	1

caveat documents. Therefore, the entities for legal documents are "IfcPropertyTitle", "IfcParentTitle", "IfcPropertyDescription", "IfcMortgage", and "IfcCaveat" (cf. Figure 9).

"IfcPropertyTitle" entity includes meta-information about the title, deed or agreement associated with each 3D legal property object. The attributes of the "IfcPropertyTitle" are listed in Table 3. Only the "CreationDate" attribute is inherited from the "IfcDocumentInformation" entity.

Each title can refer to zero or more parent titles. The "IfcParentTitle" entity is used for managing meta-information about parent titles. The attributes for this entity are listed in Table 4.

The specifications for each 3D legal property object, such as the plan number or the plan type, are managed through the "IfcPropertyDescription" entity (Cf. Table 5). The enumeration values for the "IfcPlanTypeEnum" value type are "Title Plan", "Strata Plan", "Cluster Plan", "Subdivision Plan", and "Consolidation Plan".

Table 6 Attributes of the 'IfcMortgage' entity

Attribute	Description	Value Type	Multiplicity
MortgageReference	The reference number for the mortgage	IfcText	1
MortgageDate	The date for the mortgage	IfcDateTime	1
BankName	The name of the bank providing the mortgage	IfcText	1

Table 7 Attributes of the 'IfcCaveat' entity

Attribute	Description	Value Type	Multiplicity
CaveatReference	The reference number for the caveat	IfcText	1
CaveatDate	The date for the caveat	IfcDateTime	1
Caveator	The name of the caveator	IfcText	1

Table 8 Attributes of the 'IfcInterestHolder' entity

Attribute	Description	Value Type	Multiplicity
Name	Interest holder's name	IfcLable	0..1
Share	The share of ownership	IfcInteger	0..1
InterestHolderType	The type of the interest holder	IfcInterestHolderTypeEnum	0..1

Each title can be associated with zero or more mortgages. Mortgages are registered as restrictions on the title. The "IfcMortgage" entity is used for providing information about the mortgages (cf. Table 6).

Similar to mortgages, each title can be associated with caveats which are registered as restrictions on the title. Information about the caveats is managed through "IfcCaveat" entity (cf. Table 7).

3.2.3 Interest holders in IFC

Interest holders are the actors who have a particular interest (RRR) in 3D legal properties. There are various types of interest holders such as a person, an organization or a group. In order to define an entity for interest holders, this entity should be considered as a subclass of the "IfcActor" entity in the IFC schema because "IfcActor" represents all stakeholders and human agents involved in the development cycle of an IFC project (BuildingSMART 2013b) (cf. Figure 9). The specific attributes for the "IfcInterestHolder" entity are provided in Table 8. The enumeration values for the "IfcInterestHolderTypeEnum" value type are "Person", "Group", "Organization", "Association", "Tribe" and "Family".

3.3 Implementation of a Prototype Model

In order to realize the extended IFC data model, a prototype BIM model for four floors of a complex high-rise building located in the City of Melbourne was developed and visualized. The

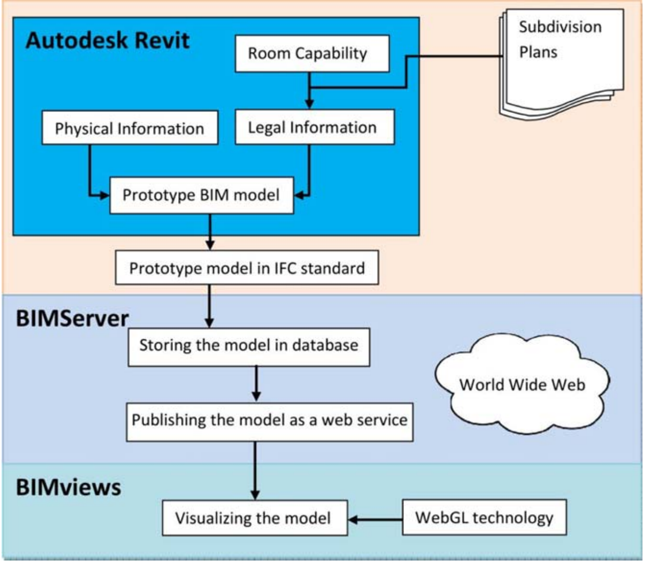

Figure 10 The approach for preparing and visualizing the prototype BIM model

data of the prototype model was prepared in Autodesk's Revit software environment. Firstly, the geometry of all the essential physical structures were created, namely interior walls, exterior walls, sliding doors, single-flush doors, awning windows, fixed windows, stairs and slabs. After that, the created physical building elements were enriched with semantic information such as thickness, material and so on. 3D legal property objects were then created to show the legal status of private property units as well as common properties in the building. Legal property objects were modelled using the "Room" capability in Revit and their boundaries were delineated based on 2D subdivision plans. Revit software does not have the capability to show both physical elements and legal property objects simultaneously; therefore the created BIM model was exported as an IFC file from Revit, then published as a web service using the open source BIMServer[1] software (Beetz et al. 2010). The open source JavaScript client "BIMviews[2]" was used to connect to the BIMServer to visualize both physical objects as well as legal spaces. BIMviews software utilizes WebGL technology, which is a powerful, platform independent and plug-in free approach for representing 3D objects on the web browsers. This process is summarized in Figure 10.

Figure 11 shows the prototype with 3D legal property objects visualized together with physical building elements. 3D legal property objects are represented in 3D volumes. Each volume shows the ownership space for individual property units and common properties. As an example, one legal property object is highlighted and associated legal information is shown in the "Properties" section. The prototype showcases that how semantic information associated with 3D legal property objects can be managed and accessed within BIM environment. For instance, the user can easily find information about the title, such as its number and volume, as well as the owner of the property. Additionally, it is indicated that BIM can facilitate representation of the spatial complexity of 3D legal property objects within high-rise buildings. Such representation of 3D legal property objects in a 3D digital environment of BIM can help non-technical people, such as owners, to easily understand the delimitation of 3D properties.

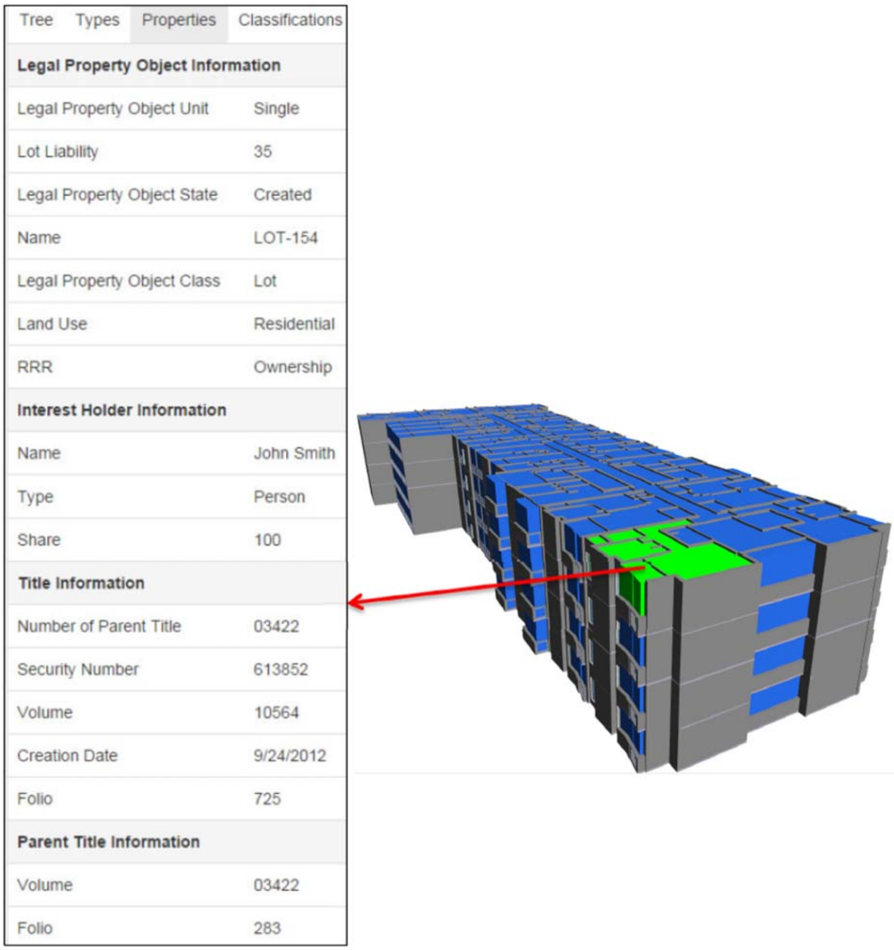

Figure 11 Managing the legal information in the developed prototype BIM model

Figure 12 shows how the prototype model can represent different types of boundaries. In Figure 12a, only the legal spaces for two 3D properties have been shown and it is difficult to find the position of the boundary between 3D properties. This means that pure legal representation of 3D properties itself cannot adequately communicate the spatial extent of ownership spaces within high-rise buildings. However, incorporating physical information facilitates communication of ownership boundaries. As indicated in Figure 12b, the boundaries of both green and grey property units touch the interior faces of the wall. This means that both owners do not have any right to or responsibility for the wall and it belongs to the common property area of the building. Figure 12c shows that the boundary between property units is a median one and each owner has a right or responsibility on the half of wall on their side. Figure 12d represents that the boundary touches the exterior face of the wall and the owner of the green property unit has the full rights to or responsibilities for the wall. These examples illustrate that physical structures can be utilized as auxiliary elements to resolve ambiguity in understanding various ownership boundaries within high-rise buildings.

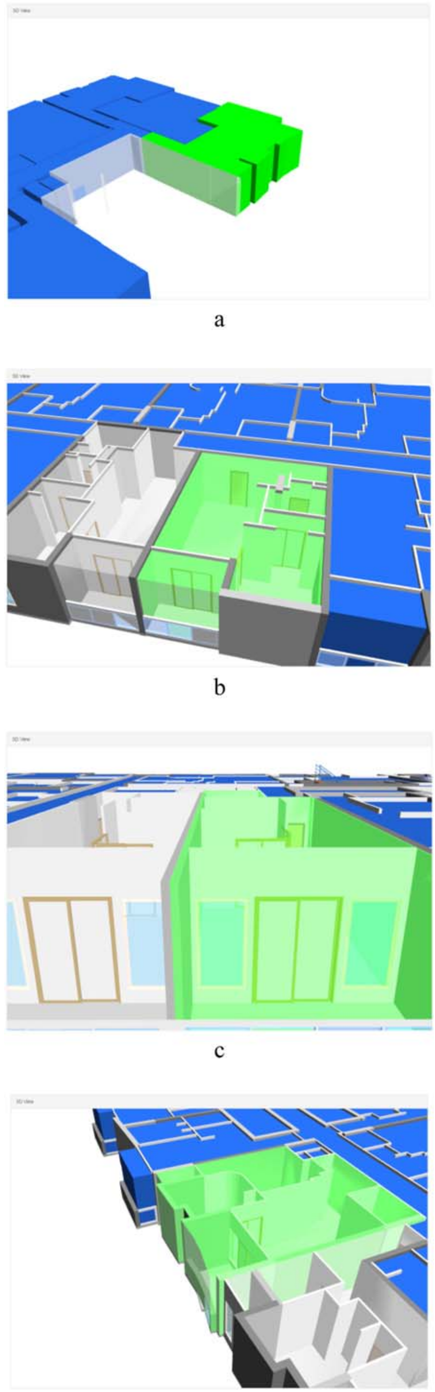

Figure 12 Significance of physical information in communicating different ownership boundaries: The type of boundary cannot be determined by only legal spaces (a); interior wall boundary (b); middle wall boundary (c); and exterior wall boundary (d)

4 Discussion

The proposed BIM-based approach for high-rise land administration would bring the following advantages:

1. It would provide improved visualization of ownership boundaries of multi-layered and stacked properties in high-rise buildings.
2. The IFC standard supports entities for modelling both CSG and B-rep solid models, which means that 3D building models constructed through both CSG and B-rep approaches can be stored within the IFC schema. This means that the proposed approach can address current limitations of cadastral data models in modelling complex spatial objects. It can effectively support representation of complex building structures. In addition, the volume of 3D properties can be computed through utilizing solid models. The computed volume can be useful in valuation and taxation of 3D properties.
3. There are entities within the IFC standard that support some topological relationships between building elements and space elements. Among these entities, the "IfcRelSpaceBoundary" relationship is relevant since it defines the connectivity relationship between an ownership space and its bounding building elements (cf. Figure 7). For instance, by using this relationship, it would be possible to extract which walls or slabs provide the 3D boundaries of an apartment unit.
4. The IFC standard has the capacity to support a rich amount of semantic information. Encoding 3D legal property objects into this standard would provide sufficient semantic information about 3D properties, which can facilitate interoperability of land administration systems with other urban systems.
5. The prototype showcased the potential capability of the proposed extension in representing and managing legal information with physical information internally in an integrated data environment. Integration of legal information and physical information within the same dataset would prevent data integration issues and inconsistencies.

On the other hand, incorporating legal information into BIM also provides benefits for the BIM domain since legal information plays an important role throughout the lifecycle of buildings. For instance, legally defined entitlements and liabilities of properties are fundamental to building and property management: lot entitlement is a number expressing the extent of each private property owner's interest in any common property; lot liability is a number expressing the proportion of the administrative and general expenses that each private property owner is obliged to pay. In the ongoing management of the common properties of a building, entitlements and liabilities provide the legal basis for dealing with disputes and dissatisfaction. Therefore, the proposed extension emphasizes that enrichment of the IFC standard with legal information would increase the functionality of BIM in terms of managing the lifecycle of buildings.

The proposed extension and realization of connected 3D digital data representing both legal and physical attributes of land and property is likely to facilitate collaboration between the land administration industry and the land development and facilities management industries. The proposed extension can potentially advance current cadastral data environments from one based on 2D digital data to a 3D digital and interactive environment. In turn, this information is likely to lead to better management and governance of the built environment.

The major barriers for using the proposed extension are likely to be institutional ones. The current institutional arrangements for managing ownership rights in high-rise buildings are highly entrenched in using 2D subdivision plans. Ho et al. (2015) identified a range of "invisible" constraints, namely regulatory, normative and cultural-cognitive, which are impeding the move towards 3D-enabled land administration practices and would arguably apply to the adoption of the proposed IFC extension in existing procedures. There are also some technical bottlenecks associated with implementing BIM for high-rise land administration. Firstly, the IFC data model includes a large number of physical data elements and some of them, such as plumbing or electrical data elements, are not important in the context of land administration. Therefore, 3D building models in IFC format should be generalized to eliminate unnecessary physical information. Another issue is that initial BIM data provided by architects is the design model, which may differ from the as-built model. The as-built model provides ownership boundaries in the real-world. This requires that the design model should be verified by land surveyor after construction of the building.

5 Conclusions and Future Work

In this article, it was elucidated that 2D building subdivision plans as well as cadastral data models encounter some challenges in managing superimposed and complex ownership properties in high-rise building structures. A BIM-based approach was proposed as a possible candidate to potentially address challenges in management and communication of ownership rights in high-rise buildings. BIM provides highly detailed and valuable physical information; however, legal information is currently not supported and stored in BIM. The current data model of the IFC standard was therefore investigated to decipher an appropriate approach for incorporating legal information into this standard. The proposed extension of the IFC standard demonstrated how legal information could be logically embedded in this standard and the implemented prototype model showcased the potential benefits of BIM for high-rise land administration. Conversely, encapsulating legal information into the IFC standard could potentially support those stakeholders who are already using BIM by providing richer information about ownership and RRR which is fundamental to ongoing management of buildings.

The proposed extension was based on the data elements identified from the literature review. Future work could include further development by incorporating additional data elements required in current practice for high-rise land administration; empirical testing of the prototype by users in terms of its efficiency, usability and reliability; developing a generalization approach to automatically extract required physical information from IFC files; utilizing the Nine-Intersection model, as proposed by Egenhofer and Herring (1990), to model the topological relationships, which are not defined within IFC schema, between building elements and ownership spaces; and evaluation of the proposed extension, particularly by those involved with building subdivision processes as well as experts involved in the development of the IFC standard.

Notes

1 BIMServer can be downloaded from http://bimserver.org/
2 More information about BIMviews can be found at http://bimvie.ws/

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