Harnessing BIM for 3D Digital Management of Stratified Ownership Rights in Buildings

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Key words: Building information model, 3D ownership information, Complex building structures, subdivision plans, 3D digital data environment

SUMMARY

With the growing dominance of high-rise building structures and complex infrastructure in urban areas, land administration systems are facing new challenges for managing ownership rights in complex urban environments. Ownership spaces defined by irregular physical structures inside high-rise buildings may not be effectively communicated via flat and 2D-based representations. Therefore, land administration systems are seeking to adopt 3D digital approaches for managing and representing complex ownership rights.

On the other hand, there has been a significant leap in the development of Building Information Modelling (BIM) approach within the Architecture, Engineering and Construction (AEC) industry. As an integrated and 3D digital information repository, BIM provides many benefits and resource savings in comparison with 2D-based modes of information communication, facilitating collaboration among different AEC actors throughout the development cycle of buildings. BIM models provide a rich amount of 3D spatial and semantic information about buildings; however, information about ownership rights within buildings has not yet been meshed into BIM models.

This paper suggests that a BIM based approach can be used as a possible solution to overcome current challenges of managing ownership rights in high-rise buildings. 3D ownership data elements have been investigated and implemented within a prototype BIM model for a high-rise building in Melbourne. The prototype demonstrates the feasibility of using BIM models for managing complex ownership rights in a 3D digital data environment.

QISA MƏZMUNU

Çoxmərtəbəli tikintilər və şəhər alt quruluşları yaradılması ilə, yer və mülk müdiriyyət etmə sistemləri şəhər mühitində mülkiyyət hüquqlarının idarə olunması üçün yeni çətinliklərlə üzləşdiyi olunur. Çoxmərtəbəli binaların içərisində, mülkiyyət fəzaları əksərən qaydasız fiziki quruluşları ilə müəyyən edilir. Bu fəzalar hərdən səmərəli şəkildə iki ölçülü yanaşmalar vasitəsilə təmsil oluna bilməz. Buna görə, yer və mülk müdiriyyət etmə sistemləri mülkiyyət hüquqlarının idarə və təmsil edilməsi üçün üç ölçülü və rəqəmsal yanaşmalar axtarır.

Başqa tərəfdən, Bina İnformasiya modelləşdirilmək (BİM) yanaşmasi memarlıq, mühəndislik və tikinti sənayesində tanınıb. BİM içində bir ayrılmaz və üç ölçülü rəqəmsal bina məlumat deposu var. İki ölçülü metodarı ilə tutuşdurmada, BİM çox fayda və xərc qənaəti binanın inkişaf prosesiylə təmin edir ve müxtəlif tikinti tərəflərin arasında əməkdaşlıqı asanlaşdırır. BİM modelləri binalar haqqında bir zəngin miqdar məkan və məna məlumatı təmin edir. Ancaq, binalar içərisində mülkiyyət hüquqları barədə məlumat hələ BİM modellərinə daxil edilməyib.

Bu yazı göstərir ki BİM əsaslı yanaşma mülkiyyət hüquqlarının cari çətinlikləri aradan qaldırmaq üçün bir mümkün həlli kimi istifadə edilə bilər. Bu baxımdan, üç ölçülü mülkiyyət məlumat ünsürləri istintaq edilmişdir və Melbourne şəhərində bir çoxmərtəbəli tikinti üçün bir ilkin BİM modelı hazırlanmışdır. Bu model göstərir ki BİM yanaşmasi mülkiyyət hüququnun səmərəli müdiriyyət edilməsi üçün nizamsız binalarda istifadə edilə bilər.

چکیده

با روند روبه رشد آسمان‌خراش‌ها و زیرساخت‌های پیچیده در مناطق شهری، سامانه‌های مدیریت زمین با چالش‌های جدیدی برای مدیریت املاک در محیط های پیچیده شهری روبرو گردیده‌اند. ترسیم فضاهای مالکیت تعریف شده توسط ساختارهای فیزیکی نامنظم در داخل ساختمان‌های بلندمرتبه با استفاده از روش‌های دوبعدی امکان پذیر نمی‌باشد. بنابراین، سامانه‌های مدیریت زمین به دنبال اتخاذ روش‌های سه بعدی و رقومی برای مدیریت و نمایش اطلاعات مالکیت می‌باشند.

از سوی دیگر، جهش قابل توجهی در استفاده از مدل‌های اطلاعات ساختمان (BIM) در حوزه معماری، مهندسی و ساخت و ساز بوجود آمده است. مدل‌های اطلاعات ساختمان به عنوان یک مخزن یکپارچه از اطلاعات رقومی سه بعدی می‌باشند و مزایای زیادی در مقایسه با روش‌های دوبعدی دارند. این مدل‌ها تعامل بین افراد درگیر در توسعه و مدیریت ساختمان‌ها را تسهیل می‌نمایند. مدل‌های اطلاعات ساختمان دربرگیرنده تمام اطلاعات مکانی و معنایی مورد نیاز برای مدیریت و توسعه ساختمان‌ها می‌باشند. این در حالی است که این مدل‌ها حاوی هیچ گونه اطلاعات حقوقی مرتبط با املاک نمی‌باشند.

این مقاله نشان می دهد که یک رویکرد مبتنی بر BIM می تواند به عنوان یک راه حل ممکن برای رفع چالش‌های فعلی در حوزه مدیریت املاک در ساختمان‌های بلند استفاده گردد. بدین منظور، اجزای داده‌ای مرتبط با مدیریت سه‌بعدی املاک بررسی گردیده و در یک مدل نمونه برای یک ساختمان بلند مرتبه واقع در شهر ملبورن پیاده‌سازی شده است. این نمونه نشان می دهد که امکان استفاده از مدل‌های BIM برای مدیریت اطلاعات مالکیت در یک محیط داده‌ی سه بعدی و رقومی وجود دارد.

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1. INTRODUTION

1.1 Research Background

Currently, over half of humanity is distributed in urban areas and it is anticipated that this distribution will reach 70 percent by 2050 (UN, 2012). Urban environments need more high-rise buildings, complex utility networks and infrastructure facilities to accommodate these populations and satisfy their demand for housing, services, water, power, telecommunications as well as transportation. Design and management of complex urban environments in an optimal and collaborative way is crucial for basic urban applications such as disaster management, way finding and navigation, urban planning, facility management, and evacuation. The focus of this paper is on the 3D digital management of land and property ownership rights in high-rise and complex building structures.

Land administration systems are concerned with recording, managing and visualizing spatial information about the tenure, value and use of land (Williamson et al., 2010). Traditionally, these systems mainly utilize 2D plans to map rights, restrictions, and responsibilities (RRRs) associated with a building, a piece of land, or airspace (Kalantari, 2008). As stated in the international standard for land administration, "rights provide formal or informal entitlements to own or do something, restrictions are formal or informal obligations to refrain from doing something, and responsibilities are formal or informal obligations to do something" (ISO19152, 2012).

Ownership rights in high-rise building structures are currently being managed by using 2D paper based or 2D digital plans. In addition, all properties in each high-rise building are registered and represented as only one 2D land parcel in cadastral databases (Kalantari et al., 2008). Given these practices, complex and high-rise buildings (see Figure 1) pose challenges for current 2D-based land administration systems. In order to address these challenges, land administration organizations are supporting research on adopting 3D digital technologies for managing ownership rights in high-rise buildings (Rajabifard et al., 2012). Current research indicates that modelling RRRs in a 3D digital data environment will require both legal and physical entities (Jazayeri et al., 2014). Legal entities are used for modelling various types of ownership rights such as private ownership spaces, common property areas and easements while physical entities are composed of geometric and semantic components.

Figure 1, A complex high-rise structure (Cayan tower in Dubai city)

Over the last decade, there have been significant developments in graphics of computers in terms of rendering 3D models. Consequently, 3D models of buildings and other urban infrastructures have proliferated in different formats and levels of details (Aien et al., 2013; Becker et al., 2013). Among various 3D building models, Building Information Modelling (BIM) is the strongest approach for managing 3D information during the development process of buildings (Krygiel and Nies, 2008). BIM is a shared 3D digital data repository for managing building information in three physical dimensions and facilitates cross-disciplinary collaboration among actors within Architecture, Engineering and Construction (AEC) industry (Eastman et al., 2011). By utilizing a 3D digital and collaborative data environment, BIM provides many cost benefits and resource savings for the AEC industry during design, planning, and construction phases of a building.

Given that legal land administration information about high-rise buildings is mostly derived from the physical aspects of the building, BIM models could potentially offer a feasible solution for the 3D digital management of land and property RRRs. However, current BIM models only include highly detailed physical information. This means that BIM models provide any physical entity being used for modelling built environment; however, there is no legal information in these models and RRRs associated with ownership spaces inside buildings cannot yet be managed in BIM.

1.2 Research Aim

This research therefore aims to enrich BIM models with legal information and use this enrichment to potentially address current challenges in the management of ownership rights in high-rise buildings.

1.3 Scope and Structure

The scope of this research paper is delimited to the management of ownership rights in newly built high-rise buildings which have BIM models. Old buildings without BIM models as well as other types of developments within urban environments are outside of the scope of this research.

In next section, challenges of current land administration practices for managing ownership rights in high-rise buildings are reviewed. In addition, BIM concepts and current BIM literature in land administration are described. The third section is dedicated to elucidating 3D ownership data elements. The fourth section presents the developed prototype BIM model for demonstrating the feasibility of a BIM-based approach for management of ownership rights in a 3D intelligent and digital data environment. This is followed by a discussion on the benefits and technical challenges associated with adoption of BIM models in land administration before the final section of the paper concludes with the main outcomes as well as future research directions.

2. LITERATURE REVIEW

2.1 Challenges of Managing Ownership Rights in High-rise Buildings

Current practices for recording and managing stratified ownership rights are predicated on 2D-based subdivision plans. These plans include floor plans and cross-section views to represent the 3D extent of multi-layered ownership spaces. This mode of communication is efficient for buildings with simple structures; however, there are some challenges for representing ownership spaces inside complex and high-rise building structures (see Figure 2).

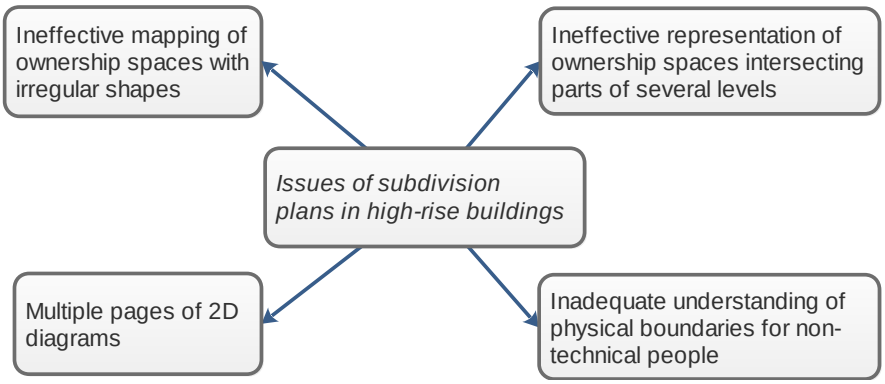

Figure 2, Main issues associated with 2D-based building subdivision plans

One challenge is that the spatial complexity of 3D ownership spaces associated with irregular physical structures inside buildings may not be efficiently mapped via projecting them into horizontal and vertical planes. In addition, complicated textual information, which is used to describe boundaries in subdivision plans, is difficult for people with limited knowledge of land administration to comprehend (Jazayeri et al., 2014). Another issue is that although current 2D-based methods of representation can sometimes be functional, it might be costly for high-rise buildings because a large number of 2D floor plans as well as cross-section diagrams must be produced to fully represent the array of multi-layered ownership spaces (Shojaei et al., 2013;

Shojaei, 2015). Figure 3 shows a plan of building subdivision where the land surveyor produced more than 50 pages of 2D plans to map the legal boundaries of ownership spaces inside a 40-storey tower located in the City of Melbourne (Rajabifard et al., 2014).

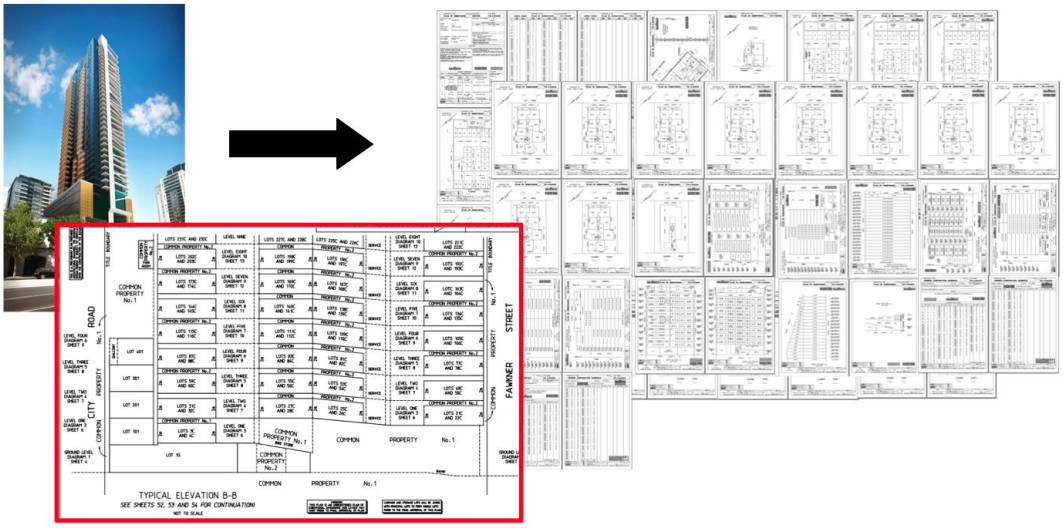

Figure 3, Current practice for subdividing and mapping ownership spaces, in which one cross-section of building is highlighted in red (AAM VEKTA, 2012 in (Rajabifard et al., 2014): Page 5)

Ownership spaces enclosed in one floor of the building is often represented using multiple pages of 2D plans; however, ownership spaces that intersect parts of several levels are difficult to represent in 2D-based subdivision plans. This challenge is much more difficult to overcome in comparison with those previously described. As illustrated in Figure 4, common property areas, such as stairs, are common examples of such ownership spaces.

Figure 4, A common property area passing through three levels

The last challenge is related to ownership boundaries referencing physical building elements. For instance, land surveyors in Victoria State of Australia define physical boundaries in various ways, most commonly by selecting one of three relationships with the physical structure: the interior or

exterior face, or the median of the structure (Land Victoria, 2015). If a person does not have technical knowledge of interpreting these boundary relationships, he/she could easily misunderstand the spatial extent of ownership spaces. Figure 5 shows an example of a cross-section view, in which plan boundaries actually reference interior faces and represents an aggregated perspective of the physical structure of the building used to define the boundary.

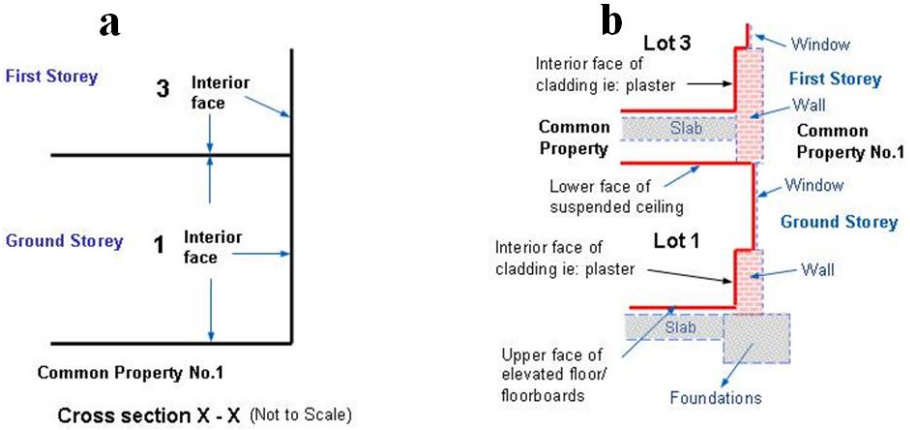

Figure 5 Plan boundaries showing relationship between legal and physical aspects of the building: a) Plan depiction; b) Corresponding building elements (LandVictoria, 2015)

2.2 BIM

The acronym BIM is used in two contexts, namely product or process. As a product (Building Information Model), it is considered as a three dimensional digital representation of physical (or spatial) as well as functional (or semantic) information about elements of a facility from its conception to its destruction (NBIMS, 2012). As a process (Building Information Modelling), it is used to create, manage, derive and share BIM products among different stakeholders involved in various phases of construction process in order to facilitate collaboration and communication between them (Eastman et al., 2011) (see Figure 6).

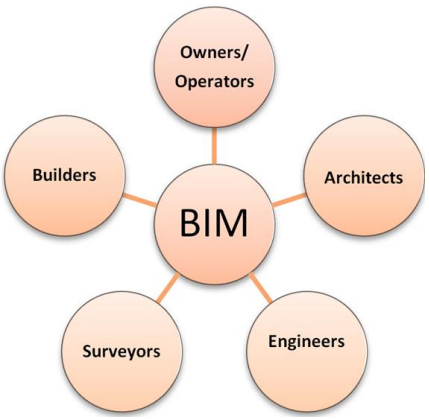

Figure 6, Different stakeholders involved in BIM, adapted from (Ong, 2012)

The main features of BIM are an object oriented structure, information richness, spatially related, open data exchange standard and extensibility (Isikdag et al., 2007). Despite improving productivity within the AEC industry, there are some technical and institutional challenges associated with the adoption of BIM. The most important technical challenge for using BIM models is the interoperability issue. This issue stems from the fact that each BIM platform has its own data format for storing BIM models. Consequently, the BuildingSMART organization has developed Industry Foundation Classes (IFC) standard to facilitate interoperability over the development cycle of a building (ISO16739, 2013). In this research, the IFC standard is used for exchanging BIM models between two BIM platforms.

2.3 BIM research in urban land administration

Incorporation of BIM models into the geospatial domain leads to integrated indoor/outdoor urban management systems (Isikdag et al., 2011; Isikdag and Zlatanova, 2009). Land administration systems in urban areas can therefore leverage BIM to manage various rights associated with ownership spaces in multi-storey buildings in a digital environment. In this section, recent studies researching BIM in land administration domain are reviewed to highlight the difference between these studies and the research presented in this paper.

The first researchers, who investigated the use of BIM in land administration, were Clemen and Gründig (2006). They indicated that the IFC standard can be enriched with different processed surveying measurements and observations for indoor cadastre purposes. However, they did not implement any BIM model enriched with cadastral information. More recently, El-Mekawy and Östman (2012, 2015) introduced the extension of Unified Building Models (UBM) with four types of boundaries to manage various ownership rights for a hospital building in Sweden. These boundaries are “Building Elements Surfaces”, “Digging Surfaces”, “Protecting Area Surfaces”, and “Real Estate Boundary Surfaces”. UBM is reference ontology for bi-directional data exchange between IFC and CityGML standard (El-Mekawy, 2010). However, the enriched UBM does not model information about interest holders and legal documents. El-Mekawy et al (2014) argued that enriching BIM with those four (UBM) extended boundaries could result in improving the interaction between BIM and 3D property domain but they did not present a BIM model enriched with 3D property information. Finally, Isikdag et al (2014) investigated connecting legal data models with 3D physical data models such as IFC, arguing that this could potentially facilitate current practices for valuating properties in various countries.

Although various levels of harnessing BIM for supporting land administration systems have been researched in above studies, enrichment of BIM with comprehensive 3D ownership data elements used in current building subdivision practices has not yet been investigated.

3. 3D OWNERSHIP DATA ELEMENTS IN HIGH-RISE BUILDINGS

In order to identify 3D ownership data elements, the current building subdivision process was investigated through a placement in a Victorian surveying company. As indicated in Figure 7, ownership data elements in high-rise structures can be classified into two main categories: 3D legal objects and 3D physical objects.

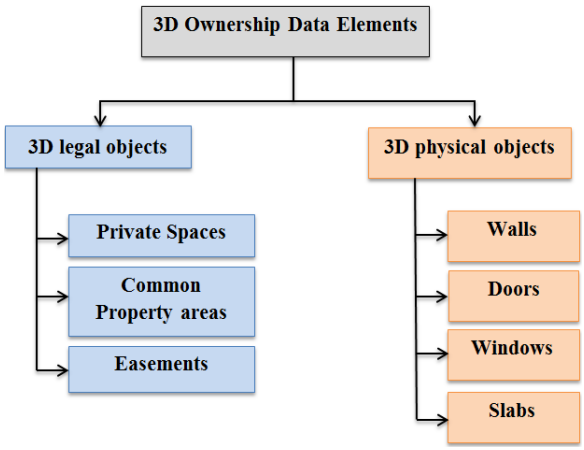

Figure 7, Main ownership data elements in high-rise structures

3.1 3D legal objects

There are three types of 3D legal objects which define the spatial extent of ownership rights in high-rise buildings, namely private ownership spaces, common properties and easements. Private spaces can comprise two parts: apartment unit and accessory lot. There are two types of accessory lots: car parks and/or storage areas. Figure 8 represents an example of private spaces in floor plan views.

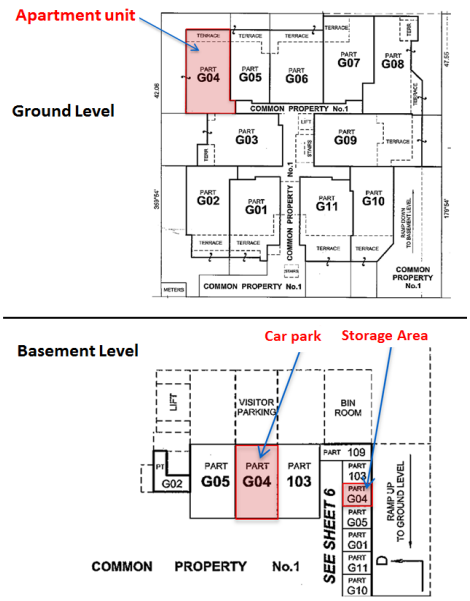

Figure 8, Private ownership spaces (Reeds Consulting, 2015)

The important attributes for private ownership spaces were then identified and are provided in Table 1.

Table 1, Attributes of private spaces

Attribute	Data Type	Description
Lot Name	Text	The name given to each private ownership space
Lot Liability	Integer number	The proportion of the administrative and general expenses that each private owner is obliged to pay.
Lot Entitlement	Integer number	The share of interest that each private owner has in the common property area
Owner Name	Text	The name of the private owner
Owner Share	Integer number	The share of ownership
Owner Type	Enumeration	The enumeration values are Person, Group, Organization, Association, Tribe and Family
Legal Object Unit	Enumeration	The enumeration values are Administrative, Single, Multipart, and Part
Legal Object State	Enumeration	The enumeration values are Created, Affected, Extinguished, and Existing
Land Use	Enumeration	The enumeration values are Residential, Commercial, Mixed Use
Title Folio Number	Integer number	The folio number of the title for the private ownership space
Title Volume Number	Integer number	The volume number of the title for the private ownership space
Volume of Parent Title	Integer number	The number of the parent title for the private ownership space
Creation Date of Title	Time	The date and time when the title for private ownership space is issued

Subdivision plans define common properties as the areas which are not included in private ownership spaces. All, or specific groups, of private owners jointly own and use common properties through their membership in an Owners Corporation. Owners Corporations are the responsible body for managing common properties. A part of the common property area for one floor of a building is

highlighted in Figure 9. The important attributes of common properties were identified and are represented in Table 2.

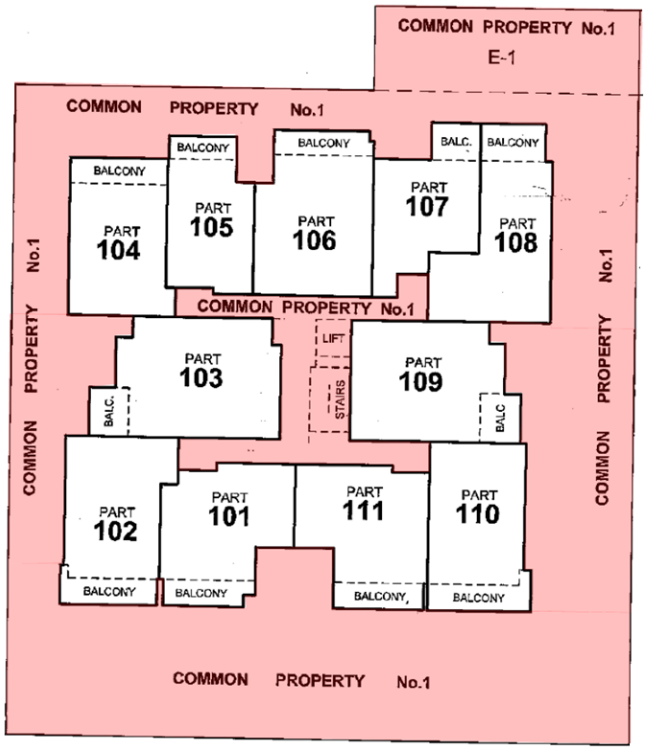

Figure 9, A part of common property area highlighted in red (Reeds Consulting, 2015)

Table 2, Attributes of common property areas

Attribute	Data Type	Description
CP Name	Text	The name of the common property
CP Type	Enumeration	There are two types of common property: Limited and Unlimited
OC Name	Text	The name of the owners corporation
OC Type	Enumeration	There are two types of owners corporation: Limited and Unlimited
Legal Object Unit	Enumeration	The enumeration values are Single, Multipart and Part
Legal Object State	Enumeration	The enumeration values are Created, Affected, Extinguished, and Existing

Easements represent legal spaces which provide benefits or pose restrictions on the initial land parcel that the building has been developed on. It is usually defined as volumetric spaces

surrounding utility networks, such as pipelines or cables, held by service providers. Figure 10 depicts part of a complex multi-storey development, in which one easement is highlighted. The important attributes of easements were identified and are explained in Table 3.

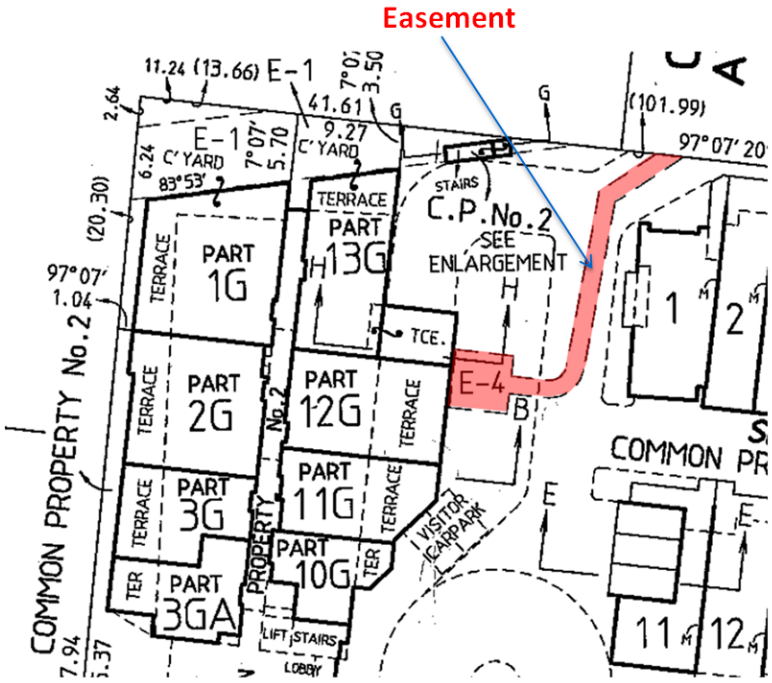

Figure 10, An easement object in a complex building development (Reeds Consulting, 2015)

Table 3, Attributes of easement objects

Attribute	Data Type	Description
Easement Reference	Text	The name of the easement
Purpose	Enumeration	Easements can be utilized for a variety of purposes. Examples are Drainage, Power line, Sewerage, Floodway, and Wetland
Land Benefited	Text	Lots benefiting from the easement
Easement Owner	Text	The name of the authority owning the easement
Legal Object Unit	Enumeration	The enumeration values are Single, Multipart and Part
Legal Object State	Enumeration	The enumeration values are Created, Affected, Extinguished, and Existing

3.2 3D physical objects

3D legal objects themselves cannot effectively communicate various types of boundaries associated with physical structures. Therefore, 3D physical objects can be utilized as auxiliary components to facilitate understanding of such boundaries for non-specialists. The most widely used building elements for representing physical boundaries are walls, doors, windows, ceiling and floor slabs (see Figure 11). As mentioned in the introduction, BIM models include comprehensive data elements for modelling both semantic and spatial dimensions of physical building elements. Only two ownership attributes, which are detailed in Table 4, are appended to physical objects.

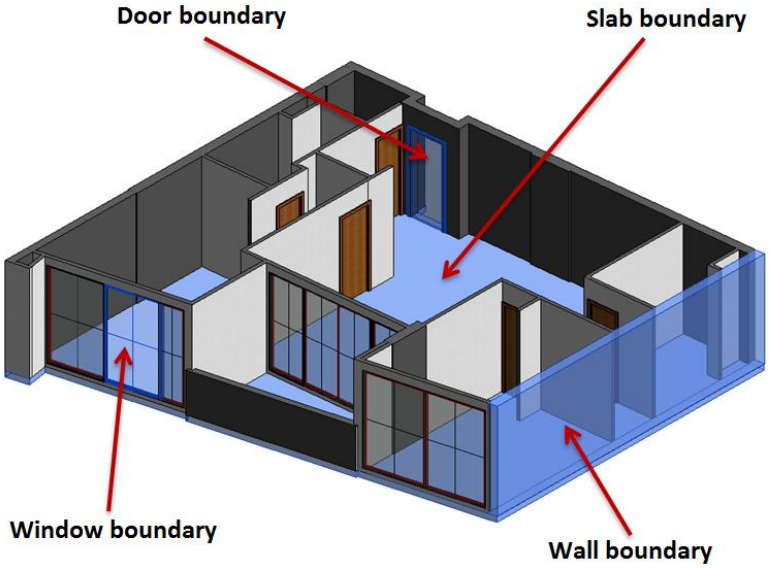

Figure 11, Physical boundaries of an ownership space

Table 4, Ownership attributes incorporated into physical building elements

Attribute	Data Type	Description
Boundary position	Enumeration	The boundary can be positioned in three ways: interior face, exterior face or median of the physical structure
Corresponding ownership spaces	Text	This indicates which ownership spaces are adjacent to each other via the physical structure

4. DEVELOPMENT OF PROTOTYPE BIM MODEL

In order to demonstrate the feasibility of using BIM for 3D digital management of ownership rights, a prototype BIM model for four levels of a high-rise development located in Melbourne has been developed. The process for modelling and visualizing the prototype model is depicted in Figure 12. The process starts from constructing different 3D physical objects, namely interior walls, exterior walls, sliding doors, single-flush doors, awning windows, fixed windows, stairs and slabs. Both

geometric and semantic information about these physical elements have been developed in the BIM model. Two types of ownership spaces, including private spaces and common property areas, are then created through utilizing the "room" capability in Revit. In the next stage, both private and common legal objects are enriched with attributes provided in Tables 1 and 2. Since Revit does not show legal objects in its 3D view, the prototype model is then exported in IFC format and imported into Solibri Model Viewer which provides 3D visualization of ownership spaces.

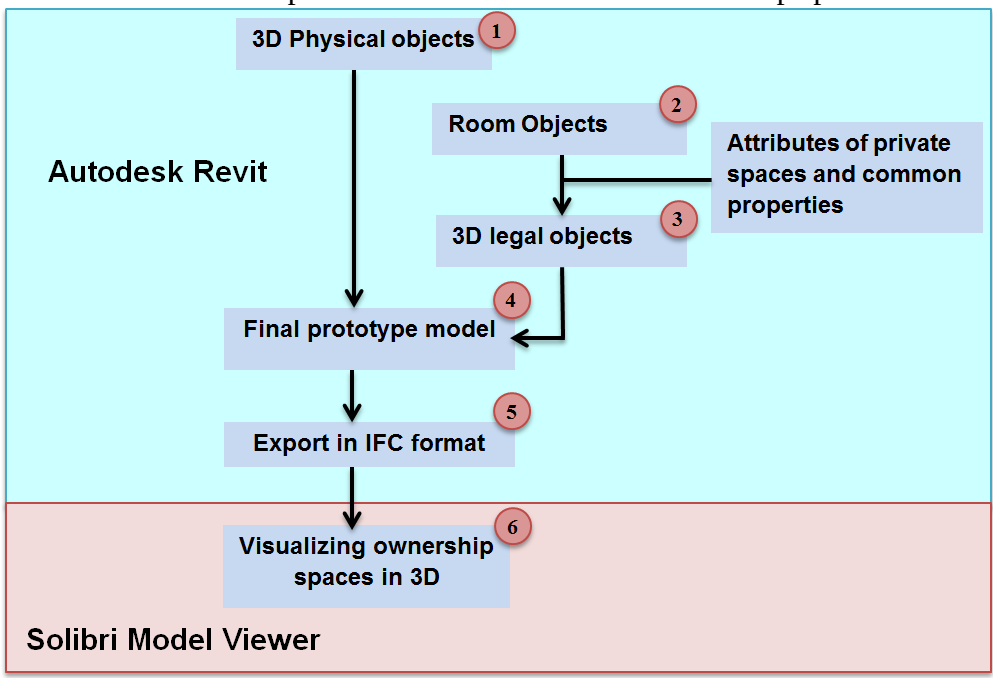

Figure 12, Development process of the prototype BIM model

Figure 13 shows the BIM model with only physical objects. In this Figure, the ownership attributes of a physical boundary are highlighted in red.

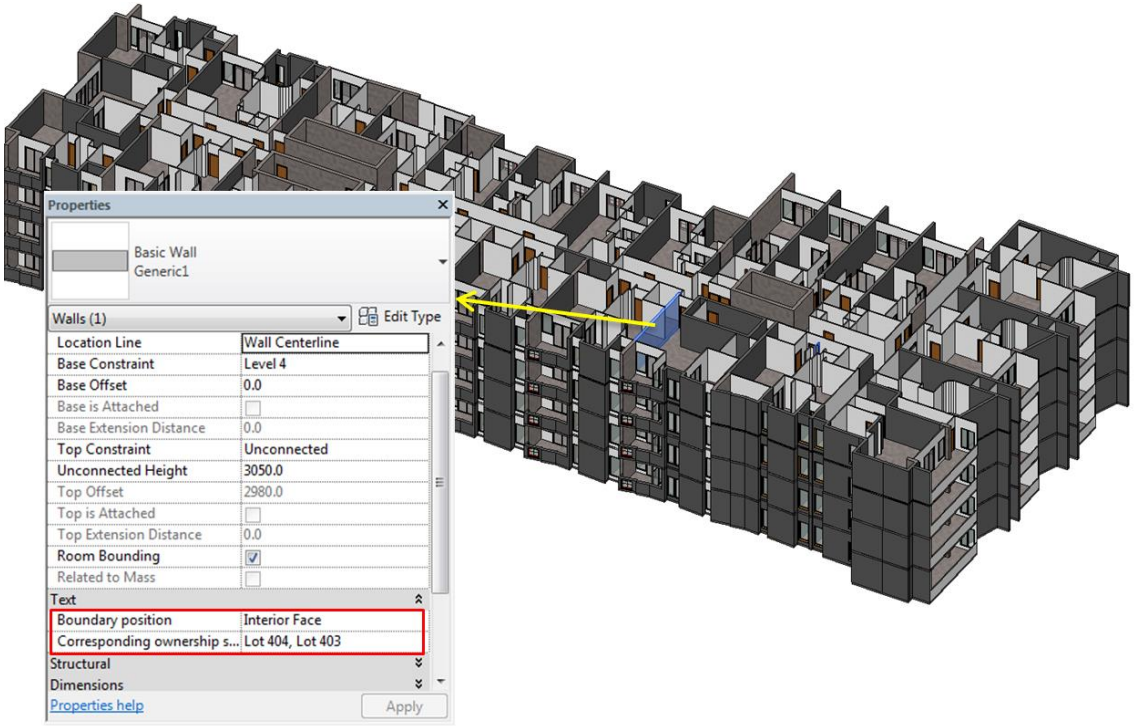

Figure 13, 3D physical objects in the developed BIM model

Examples of both private ownership spaces and common property areas are represented in Figures 14 and 15, respectively.

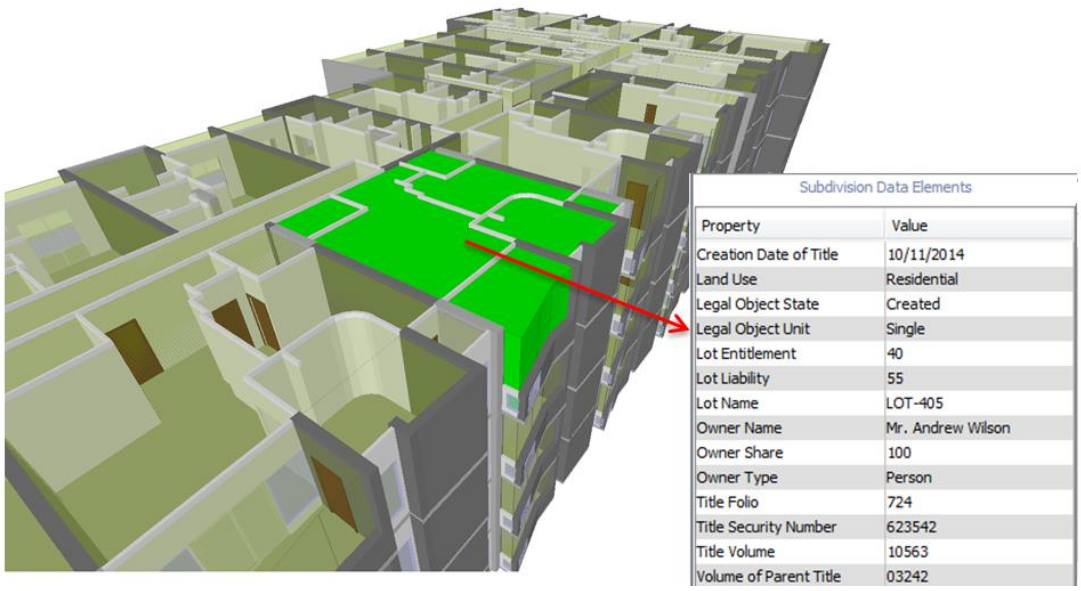

Figure 14, An example of private ownership spaces in BIM environment

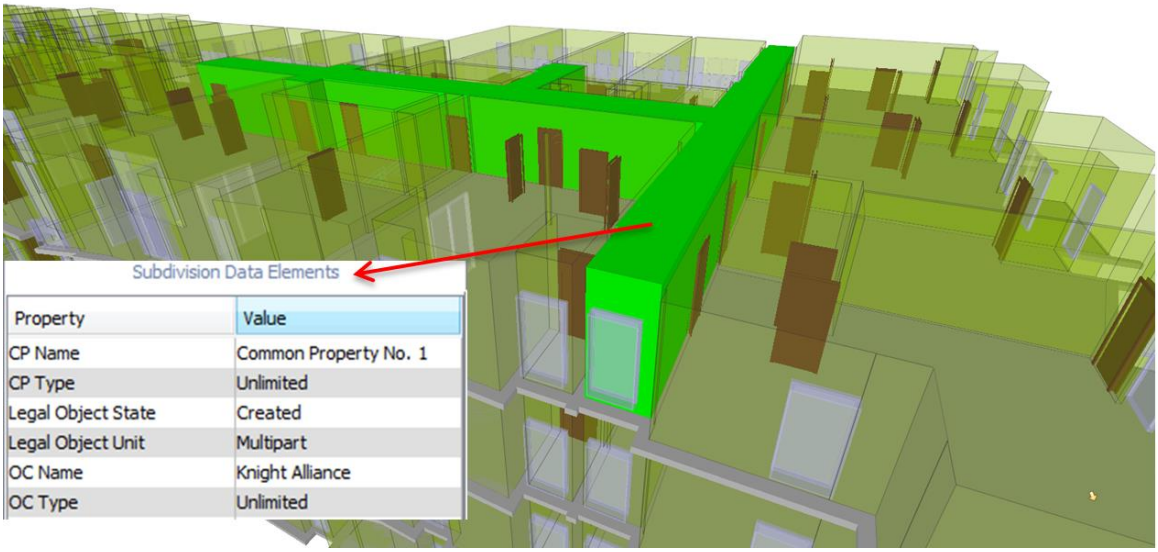

Figure 15, An example of common properties in BIM environment

5. DISCUSSION

The developed prototype model highlights significant benefits that BIM could potentially provide for managing ownership rights in high-rise buildings. One benefit would be enhancing visualization of the physical manifestation of legal boundaries associated with complex and stratified ownership spaces since representation of only legal spaces cannot unambiguously communicate those boundaries. Physical building elements inside the BIM environment can facilitate understanding of ownership boundaries and it is easy to specify whether the boundary is interior, median or exterior. This can provide a clear representation of the spatial extent of ownership spaces. Another benefit would be computing volume of ownership spaces within BIM environment and utilizing it for valuation and taxation purposes.

Additionally, enriching BIM with information about ownership rights can also support BIM domain in better management of the urban built environment. For instance, entitlements and liabilities of ownership spaces play a fundamental role throughout the lifecycle of building, especially in the ongoing management of common property areas. The BIM enrichment proposed in this paper would provide an integrated 3D digital data environment encompassing both legal and physical information. Such a data environment would facilitate collaboration between the land administration industry and the AEC and facilities management industries.

Although the proposed approach was a good trial in investigating the feasibility of BIM for land administration systems, there are some challenges in fully implementing BIM for digital management of stratified ownership rights. Firstly, BIM models usually include abundant physical information, some of which are not necessary in the context of managing ownership spaces.

Therefore, the generalization of BIM models is required to remove unessential building elements. This generalization could also result in lowering the data volume of BIM models and increase visualization performance. Another issue is that architects provide land surveyors with the design model of the building which sometimes may not be coincident with the as-built model of the building. The realization of physical boundaries is predicated on the as-built model. Hence, land surveyors will likely need to verify conformance of the design model to the as-built one after construction of the building.

6. CONCLUSIONS AND FUTURE WORK

This paper emphasized that current 2D-based subdivision approaches faces some challenges in managing multi-layered ownership RRRs in high-rise buildings. A BIM-based approach was proposed as a potential solution for overcoming these challenges. There is a rich amount of physical information inside BIM models; however, ownership data elements are not recorded in BIM models. Hence, 3D ownership data elements were identified based on current building subdivision practices and a prototype model was then developed and enriched with the identified ownership data elements. The implemented model highlighted the potential benefits of BIM for managing stratified ownership rights. Additionally, enriching BIM models with ownership information would potentially contribute on the performance of these models in better management of facilities throughout the lifecycle of buildings.
Future research directions could be evaluation of the prototype model by experts in three aspects, namely efficiency, usability and reliability; and development of a generalization algorithm to automatically retrieve essential physical building elements from BIM models.

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