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RESEARCH ARTICLE

Applying BIM to support dispute avoidance in managing multi-owned buildings☆

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Abstract

With the growth of high-density living, disputes experienced by residents in multi-owned buildings (MOBs) have become an ongoing challenge in urban areas. A significant number of the disputations have found their root cause in the issues concerning improper use and management of MOBs by residents. It stems from their inaccurate understanding of ownership rights that are inherently 3D but using 2D cadastral survey plans, authoritative documents of ownership. This research explores the ability of building information modeling (BIM) to address required information for improving the perception of ownership rights that affect resident behaviors in managing MOBs. An open data model of BIM is extended to accommodate the necessary information for preventing resident misbehaviors that led to dispute cases in Victoria state, Australia. In this study, we implement BIM data of an MOB where a real dispute happened to demonstrate the validity of the enriched data model on the information delivery and an enhanced understanding of ownership rights. It is confirmed that the use of BIM facilitates the alleviation of the misbehaviors by informing residents with accurate communication of ownership rights and could support the avoidance of disputes in MOBs.

Keywords: BIM; resident behavior; dispute avoidance; IFC; multi-owned building; 3D ownership right

1. Introduction

As the population residing in multi-owned buildings (MOBs) grows, high-density living attracts an increasing incidence of disputes among residents (owners and occupiers) (Blandy, Dupuis, & Dixon, 2010; Dredge & Coiacetto, 2011). The critical matters that lead to disputes within MOBs include residents' inappropriate use and management of dwellings and common areas (Ho, 2014). Although the legal basis of MOBs varies among countries, the arrangement of ownership rights acts as a management mechanism for assets and resident behaviors (Easthope, Randolph, & Judd, 2012). It means that the harmonious living in MOBs requires the residents to be aware of how to behave in MOBs peacefully according to their ownership. Despite more than 60 years of history for adoption, most residents still tend to be unaccustomed toward the living style within MOBs under their legal rights and obligations (Easthope et al., 2014).

Ownership of MOBs generally takes a composite form that combines individual ownership of a lot (units or flats) and co-ownership of the common properties (CPs) that are owned and managed by groups of all or specific lot owners (Çağdaş et al., 2018). Unlike detached houses, the ownership rights, responsibilities, and restrictions (RRRs) delimit who owns the lots or CPs and who is responsible for managing which parts of MOBs. It wholly determines the authority for using each part of MOB along with the weights of the vote held by each owner for making collective decisions regarding the CP management. As highlighted by Cradduck (2013), a clear interpretation of ownership RRRs, which is an artifact of knowledge for MOB residents, potentially prevents behavioral issues causing the disputes, such

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as over-exploitative use of CP and apathy toward management of their properties.

Currently, understanding of proper behaviors within legal limits from ownership has been challenged by residents in MOBs (Goodman & Douglas, 2008). In jurisdictions using the cadastral plans for land registration, the 2D-based plans determine the dimension and arrangement of ownership RRRs, which are 3D volumetric, invisible, and multi-layered spaces. (Sherry, 2009; Lemmen, Van Oosterom, Thompson, Hespanha, & Uitermark, 2010). The current practice relies on (i) the 2D projection to graphically represent ownership boundaries and (ii) textual description to clarify RRRs. This method of abstraction shows insufficient flexibility and requires numerous pages of the 2D floor and section diagrams in recording the vertical and horizontal extent of ownership RRRs in MOBs (Stoter, Van Oosterom, & Ploeger, 2012). It imposed a substantial amount of time and load to understand the full picture of ownership over the lots and CPs by overlapping the 2D documents. In this context, the accurate interpretation of the ownership RRRs by the residents outside of the surveying profession is highly unlikely (Rajabifard et al., 2014). Resident misbehaviors stemming from the ambiguous interpretation of their ownership using the 2D plans have exacerbated neighborly disputation (Dupuis & Dixon, 2010; Douglas, Leshinsky, & Condliffe, 2016).

Over the last decades, various research has investigated on 3D data models to respond to the limitations of 2D-based cadastral plans in representing and communicating the complex geometric ownership RRRs (Janečka & Karki, 2016). Among the 3D models, building information modeling (BIM) has been considered as a feasible approach to manage information regarding ownership of MOBs (Atazadeh, Kalantari, Rajabifard, & Ho, 2017a). BIM is a shared knowledge source for the building, including every piece of geometrical, functional, and semantic information (NBIMS, 2015). It is widely applied to facility management as an information repository for supporting asset management practices throughout the building lifecycle (Becerik-Gerber, Jazizadeh, Li, & Calis, 2011). BIM has a high potential to digitalize, visualize, and communicate ownership information, including the spatial dimension of ownership RRRs and associated authoritative annotation in cadastral plans on top of the layout of building elements in architectural plans.

The aim of this research is to explore the ability of BIM to address information required for improving the perception of ownership RRRs among the MOB residents that potentially prevents disputes in using and managing their properties. This research extends the IFC data structure, which is an open standard of BIM data exchange model, to accommodate the identified information in the BIM environment (ISO16739, 2013). The IFC model for an MOB where a dispute happened is implemented to evaluate the validity of the extended data structure on alleviating resident misbehaviors causing disputes by increasing awareness of ownership RRRs. It proceeds in the context of Victoria, Australia, as one of the urbanized jurisdictions in the world.

This paper begins with an overview of the current state of ownership awareness impacting on disputes on using and managing MOB, and the application of BIM to address ownership information (Section 2). Section 3 analyzes 62 dispute cases in MOBs that were applied to the tribunal in Victoria to derive the types and causes of resident misbehaviors regarding the use and management of MOBs. Section 4 identifies the information necessary to mitigate those causes and extends the IFC schema to accommodate it. The IFC model of an MOB where a real dispute occurred in Victoria is implemented in Section 5, according to the extended schema. Section 6 compares the IFC model against 2D cadastral plans of the MOB to assess its utility in preventing resident misbehaviors that cause the dispute. This paper is concluded with a summary of contributions and future research.

2. Understanding of MOB Ownership Obligations and Applications of BIM

2.1 Ownership awareness and disputes in MOBs

Living in MOBs differs from one in the detached housing due to their physical and ownership features, such as closer proximity, shared interest over CPs, and self-governing mechanism (Johnston & Reid, 2013). In this inevitable higher social density in MOBs, varying interests of residents are in conflict with each other and are likely to cause disputes. Many of the interest-based conflicts are caused by the complex relationships between individual ownership and collective ownership (Zhu, 2015; Easthope & Randolph, 2018). More complex ownership arrangements created by the growing size and mix-used MOBs have escalated the likelihood of the conflicts among residents. Many studies demonstrated that disputes tend to arise in CPs, in which communal interests of different stakeholders are intertwined (Easthope & Judd, 2010; Leshinsky, Condliffe, Taylor, & Goodman, 2012; Douglas & Leshinsky, 2017).

Existing research provides segmented pictures of how residents' inaccurate understanding of the RRRs affects the conflict incidence that might lead to disputes. Goodman and Douglas (2008) ascertained that the unclear awareness of ownership RRRs results in management challenges, such as residents' exploitive use of CPs, and apathy and negligence in CP management. Easthope and Randolph (2018) addressed that limited comprehension creates the unrealistic expectation of their responsibility for managing CPs and their power to use and enjoy individual and common properties in MOBs. In addition to this, Amole (2009) highlighted that it generates the gap between residents' aspired needs and experience that determines the degree of satisfaction they had in MOBs. Cradduck (2013) explained that dissatisfaction from the gap raises unacceptable behaviors against their ownership to fulfill the needs, and it causes a nuisance to the neighbor, using issues raised by Easthope et al. (2012). At this moment, the conflict of interest between an individual and affected neighbors is created, according to Ho and Gao (2013) and Gao and Ho (2016). It means that MOB communities (residents and OCs) fail to achieve collective actions that require the effort of all residents to achieve collective and non-excludable goods and might have disputes regarding the interest-related issue.

The abovementioned investigations showed consensus about the role and impact of residents' interpretation of ownership RRRs on dispute incidence in MOBs. It was highlighted that an accurate understanding of ownership in MOBs is necessary to be enhanced for preventing the conflicts potentially resulting in protracted disputes. However, little attention has been paid to the practical approaches or methods to improve the erroneous awareness of the MOB residents for avoiding disputes in advance.

2.2 Challenges in understanding of ownership obligations for MOB management

MOB management is about (i) making collective decisions on how to use and manage MOBs, (ii) monitoring the performance of MOBs, and (iii) enforcing the decided rules against the use of MOBs (Gao, 2015; Johnston & Too, 2015). The mechanism of using and managing MOBs is outlined by the partition of ownership spaces (lots and CPs), the shared co-ownership of CPs, and tiers of owners' groups in the cadastral plans. Ownership spaces indicate pieces of land and properties separately owned by individuals or legal entities. The understanding of RRRs granted to ownership spaces has profound impacts on dispute avoidance by reducing the potential conflicts in MOBs. Although legislation and the plan have all information on the ownership, the correct interpretation and use of these plans for MOB management are highly unlikely to the residents (Douglas, Leshinsky, & Condliffe, 2016).

The literature around MOB use and management has been acknowledged as limited and fragmented; nonetheless, there appears to be a substantial barrier for residents to understand ownership RRRs. Blandy et al. (2010) and Yip (2016) found that the legislation was generally not objective, and legalistic jargon causes confusion and ambiguous interpretation that end with different perceptions of ownership by residents. Christensen and Wallace (2006) discovered that owners' lack of understanding of the tiered owner group and their obligations to manage each CP plays a primary role in the conflict occurrence in complex MOBs. Johnston and Reid (2013) emphasized that the tiered structure of owner groups and the intricately grouped CPs intensifies the confused awareness regarding private lot ownership and collective CP ownership; it detracts from the functionality and viability of MOBs. Christudason (2004) explored the common misconceptions among MOB residents and building managers regarding the meaning and composition of CPs and explained how it drove the disputes in Singapore. Ho (2014) ascertained that ownership boundaries are a significant area that was not understood by MOB residents, particularly the demarcation between the lots and CPs. This point is in line with the founding of Easthope and Randolph (2009) that considerable residents face the difficulty in determining the distinction between the lots and CPs from the boundaries in the cadastral plans.

Available research identified that MOB management involves different stakeholders who have different interests and ownership, but many of them are unaware of the detail of their RRRs. In MOBs, the understandable information about the RRRs is fundamental to avoid conflict and disputes on managing MOBs. As noted by Leshinsky et al. (2012), the information tool regarding ownership RRRs in MOBs could widen the understanding of MOB living and provide knowledge and practical tips on how to deal with issues leading to disputes. However, there is a dearth of research that explores vital information across residents for improving their awareness of the RRRs together with the technical approach to offering it effectively.

2.3 BIM to manage ownership obligations in MOBs

The disapproval has mounted against the current 2D-based practice of recording 3D ownership RRRs of MOBs (Isikdag, Horhammer, Zlatanova, Kathmann, & Van Oosterom, 2014). It has been shown how the abstracted 2D projection of 3D RRRs is likely to reach different concepts over the same set of diagrams in the cadastral plans. Notably, the traditional method is not able to reflect full aspects of geospatial information about the ownership in cases of MOBs with intricate building structures and stratified RRRs. To overcome the visualization and communication challenges, the needs for 3D documentation of ownership spaces and properties have arisen by many studies (Marcin, 2012; Shojaei, Kalantari, Bishop, Rajabifard, & Aien, 2013; Paasch et al., 2016; Dimopoulou et al., 2018).

As one of the 3D representation approach for facilities, the potential of BIM to accommodate ownership RRRs of MOBs has been discussed in various investigations. Barton, Marchant, Mitchell, Plume, and Rickwood (2010) enriched IFC to manage indoor and outdoor ownership data of land and buildings, focusing on defining ownership spaces; however, ownership boundaries were not accommodated into IFC. Oldfield, van Oosterom, Beetz, and Krijnen (2017) examined the extension of the IFC data structure to incorporate the information of 3D spatial ownership RRRs, as input data for the land registry in the Netherlands. Clemen and Gründig (2006) highlighted the potential of IFC to manage information about ownership of indoor properties. The authors explored the geometric expression of IFC and identified a set of IFC entities necessary for representing ownership spaces, such as nodes and edges for surveying measurement. El-Mekawy, Paasch, and Paulsson (2014) investigated the usage of IFC for addressing 3D ownership information in the Swedish context. The proposed IFC extension mainly addresses the visualization of boundaries required for defining RRRs without semantic data. Atazadeh, Kalantari, Rajabifard, Ho, and Champion (2017b) proposed an IFC extension capable of accommodating the 3D ownership spaces of MOBs to provide an unambiguous representation of ownership for the land registry.

Most studies focus on extending the IFC data structure for 3D representation of ownership RRRs from land administration purposes. There has been little effort directed to the required information for enhancing residents' understanding of their ownership and facilitating the harmonious use and management of MOBs. Based on the identified flexible expandability, it is considered that IFC has the potential to be used as an information source for geometric and semantic aspects of 3D RRRs in MOBs for mitigating misbehaviors escalating to disputes. In the next section, actual dispute cases among MOB communities in Victoria are analyzed to grasp types and causes of the resident misbehaviors.

3. Issues in Use and Management of MOBs in Victoria

3.1 Formation of ownership in MOBs in Victoria

In Victoria, the *plan of subdivision* defines the ownership RRRs within MOBs, as a cadastral plan. The plan uses the 2D-based method to map the dimension of 3D ownership spaces onto floor and section plans (Land Use Victoria, 2015). It also provides the textual notation of RRRs, describing the boundary location and the composition of CPs, while using the schedule to delineate the co-ownership share in each CP held by each lot and the tiered structure of the owner groups. The group of owners is named *owners corporation* (OC).

For mixed-use complex MOBs, it is common that there are multiple separate CPs with multiple OCs. The tiered structure of OCs and CPs provides a fair approach to distribute the responsibilities for managing CPs, based on real usage (Leshinsky & Libbis, 2008). The CP solely used and managed by the specific OC is referred to as *limited CP.* The OC, called *limited OC,* has exclusive benefits, uses, and responsibilities toward respective limited CP. On the other hand, all the parts of CPs excluding the limited CPs are named *unlimited CP*; it provides common services for all lot owners in MOBs. *Unlimited OC* consisting of all the owners is designed to use and manage the unlimited CP with holding ownership of both unlimited and limited CPs. This ownership allows the unlimited OC to possess unlimited power and responsibilities for managing MOBs (Government of Victoria, 1988). For instance, one lot in Tower A is a member of OC No. 3, as well as OC No. 1 (see Fig. 1). This lot does not have any benefit from CP No. 4 located in Tower B as a user, but it has an interest in it as a communal owner in OC No. 1. It means that the lot owner is not involved in decision-making about managing CP No. 4, but have vote power on general governance issues about this CP.

The ownership boundary acts as a mechanism for defining RRRs; it draws the full spatial extent of all ownership spaces and their layout throughout MOBs. Indicating the boundary location mainly relies on faces (interior, exterior, median, or other) of building structures. The structures (wall, door, window, ceiling, and floor) used as references for boundaries are called boundary structures. As illustrated in Fig. 2, the ownership space of Lot 1 excludes the volume of internal and external walls when the boundary location of all walls surrounding the lot is referenced as the interior face.

3.2 Causes of resident misbehaviors in MOB disputes

The 62 dispute cases applied to the tribunal in Victoria from 2016 to 2018 have been analyzed to identify the types and causes of misbehaviors that touched off disputation in using and managing MOBs. As represented in Table 1, eight misbehaviors of MOB communities are derived from the disputes and linked to three types of disputes: (i) CP management regarding maintenance and repair of CPs, (ii) lot management regarding RRRs in managing the lots, and (iii) CP use regarding inappropriate use of CPs by residents for the enjoyment of their lots. The eleven causes of the misbehaviors are derived from the published finding of the tribunal.

As the most important cause, the failure to correctly perceive the extent of ownership, which stems from an *incorrect understanding of boundary location, ownership of building structures, and distinction between CPs*, impacted all misbehaviors in three types of disputes. Identifying the exact boundary location that lies along or within a structure requires the inference from 2D isometric layout and notation in the plans. It imposes challenges for MOB communities in the reading subdivision plan to determine the horizontal and vertical extent of ownership spaces, the responsibility for building structures, and what constitutes each CP. All eight misbehaviors began from the inaccurate interpretation of ownership extent based on the guess that obstructs to reach common consent in managing and using MOBs among the communities.

For the OCs, *misconception in co-ownership of CPs* and *confusion in ownership RRRs of multiple OCs* drive the controversy over the management authority of CPs. In the subdivision plans, there is no clear description or notation regarding management responsibilities for each part of CP under the multi-tiered OC structure. Particularly, it shows the limitation in representing ownership RRRs of OCs over managing CPs. The confusion in which OC is entitled to use and manage specific CPs led to the following misbehaviors: (i) imputation of management responsibility for CPs, (ii) poor management of CPs, and (iii) refusal to pay levies for repairing CPs. These behaviors are exacerbated by *disagreement in management levels of CPs* among each OC that determines to what extent CPs need to be managed. A lack of consensus in this matter results in conflicts concerning management costs and activities.

For lot owners, their *misunderstanding of co-ownership share* and *difficulty in identifying beneficiaries from CPs* trigger avoidance of levy payment. In MOBs, all lot owners are obliged to pay for upkeeping CPs that they benefit from, in compliance with their co-ownership share in the plan. This share is defined as lot liability, which is the owner's proportion of expenses for governing OC. In most cases, however, residents refuse their financial obligations since they are not sufficiently aware of their membership and liability regarding OCs and the CPs providing benefits, functions, and services to their lots.

A *vague awareness of OC rules*, together with the ownership extent, provokes improper improvement of the lots and arbitrary use or change of CP by residents. The OC rule in each MOB is a set of rules to regulate the behaviors of residents and visitors. The misunderstanding of these rules has raised inappropriate enjoyment of the lots and CPs that damaged other lots or CPs or encroached CPs. Similarly, the *ambiguity in understanding relevant legislation* leaves some room for various interpretations of using the lots. For instance, the residents' confusion about the power upon OCs guaranteed by Owners Corporations Act 2006 disturbs the management of CPs that are only accessible from the lots by

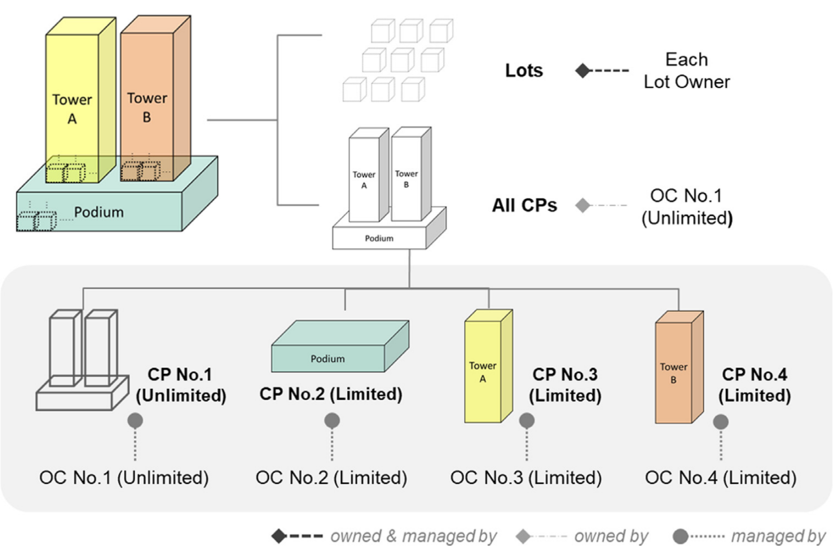

Figure 1: Example of managing authority in an MOB with multiple OCs.

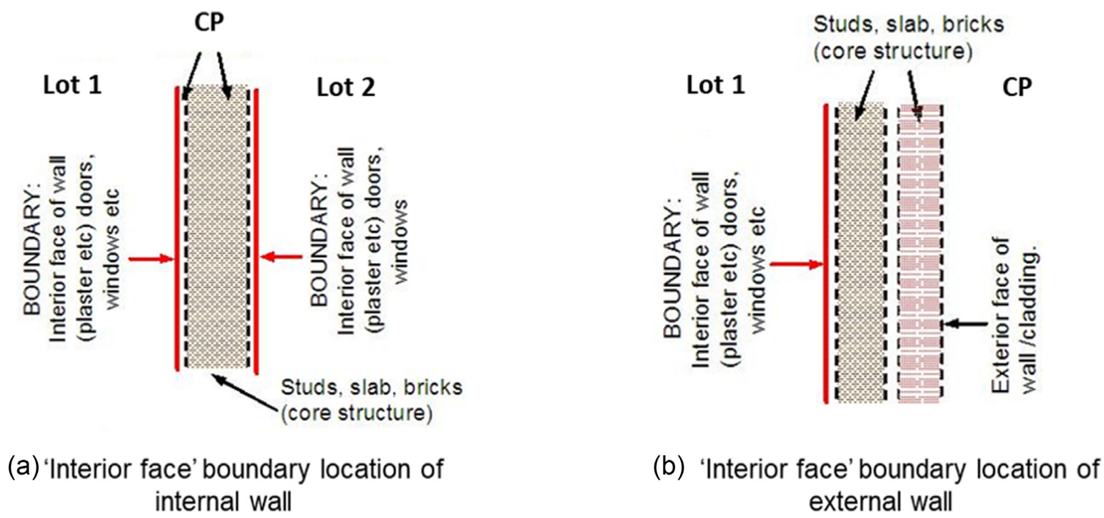

Figure 2: Boundary location of (a) internal wall between two lots and (b) external wall between the lot and CP under the interior boundary location, adopted from Land Use Victoria (2015).

Table 1: Misbehaviors in using and managing MOB and their causes from 62 disputes in Victoria.

Dispute type	No. of cases	Misbehavior		Main cause
		Actor	Description	
CP management	34	OC	Imputation of responsibility for managing CPs	■ Diverse interpretations of boundary location
		OC	Disturbance to CP management	■ Incorrect depiction of boundaries in the plan
		Owner, OC	Refusal to pay levies for upkeeping CPs	■ Confusion in ownership of building structure
		OC	Speculation over necessity for implied easement over CPs	■ Unclear distinction between CPs
				■ Misconception in co-ownership of CPs
CP use	17	Owner, Occupier	Invalid use of CPs	■ Confusion in ownership RRRs of multiple OCs
		Owner	Arbitrary change of CPs	■ Disagreement in the level of CP maintenance
				■ Misunderstanding of co-ownership share
Lot management	11	Owner, OC	Damage from other ownership spaces	■ Difficulty in identifying beneficiaries from CPs
		Owner, Occupier	Lot improvement encroaching CPs	■ Vague awareness with OC rules
				■ Ambiguity in understanding relevant legislation

refusing OC's access. The misconception of Subdivision Act 1988 resulted in the arbitrary inference concerning the necessity for an implied easement.

The discussed causes show a direct connection between the limitation of 2D representation in MOB subdivision practice and the inaccurate understanding of ownership RRRs in MOBs. The subdivision plan does not depict the actual location of the boundary within MOBs, but provides the indications thereof, using diagram and notation (see Fig. 3). Without the elevation diagram and detailed notation, it takes the vertical projection approach for the horizontal boundaries of void spaces (e.g. air space in the balcony) to delimit the vertical extent of ownership. In addition, only the brief notation is provided for defining the boundary type and components of CPs. In this circumstance, the MOB communities outside of surveying have faced difficulties in capturing and knitting the full range of 3D RRRs from the information in three different layers—2D diagrams, notation, and the schedules of lot liability. It is more challenging for residents in structurally complicated large MOBs, where ownership spaces are with the unique-shaped complex layout or spanning several floors. It implies the necessity of 3D representation to accommodate those layers for improving their perception of ownership RRRs. BIM enables to provide the information repository of ownership that integrates all of the geometric and semantic information of facilities (Eastman, Teicholz, Sacks, & Liston, 2011).

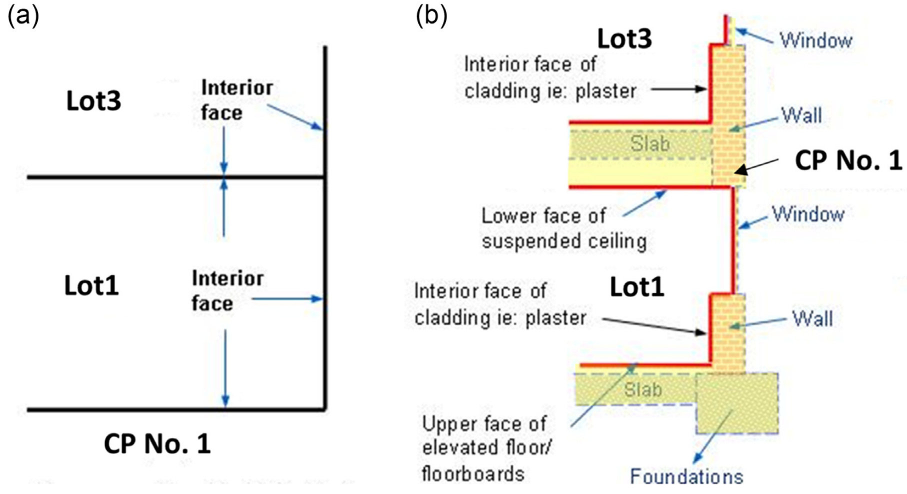

Figure 3: Comparison of (a) a depiction of the subdivision plan with (b) actual location of ownership boundary (example of the interior boundary), adopted from Land Use Victoria (2015).

Table 2: Information requirements for resolving causes of the misbehaviors in using and managing MOBs.

Cause of misbehavior	Required information	Data element
Diverse interpretations of boundary location	3D ownership boundary layout	Ownership boundary Boundary type Boundary location Building element
Confusion in ownership of building structure Unclear distinction between CPs	Extent of ownership RRRs	Building element owner Legal zone Legal space Zone name
Misconception in role of co-ownership share Misconception in co-ownership of CPs	Co-ownership share of lots	Lot liability Affiliated OC
Confusion in ownership RRRs of multiple OCs Ambiguity in understanding relevant legislation	Ownership RRRs of OCs	CP type OC with ownership Management OC
Difficulty in identifying beneficiaries from CPs	Beneficiaries from CPs	Benefiting CP Usage type
Disagreement in the level of maintenance	Management level	Performance

4. IFC Extension for Avoiding Improper Behaviors in Managing MOBs

4.1 Information requirements

The essential information required for preventing misbehaviors has been investigated based on the identified causes. The information is embedded into the BIM data environment to enhance the awareness of the controversial issues in the misbehaviors. It can provide a base for making correct decisions in using and managing MOBs according to ownership RRRs. To address common and generic information across MOBs, the causes relevant to OC rules and surveyor's mistakes are not considered in this paper. As represented in Table 2, the information requirements are derived, and data elements to address them are defined.

The 3D ownership boundary layout is required to disambiguate the real boundary location within MOBs. For this, the data about *ownership boundary* are necessary to represent the geometry for boundary position. It needs to be expressed visually together with its type, location, and the referenced building structure. There are two *boundary types*, fixed and structural (Atazadeh et al., 2017b). The fixed boundary is described based on the surveying measurement, while the structural one is defined by referencing boundary structures. *Boundary location* is only for the structural boundary; it indicates surfaces of the structures used as ownership boundaries. It has four location types, interior, median, exterior, and other. The aggregate of *building elements* represents the physical form of the MOB, along with the geometry of boundary structures and other elements lying on boundaries where disputes frequently happen. It contains walls, floors, ceilings, roofs, doors, windows, and foundation, and utility services.

The information concerning the extent of ownership RRRs, which is outlined by the boundary layout, delimits the dimension of all ownership spaces. It enables MOB communities to easily distinguish the extent of each CP as well as ownership of building structure. As ultimate objects of possession, the ownership spaces for the lots and CPs comprising multiple partial spaces are defined with zone concept (*legal zone*). The single or multiple spatial parts of the legal zone that spread out across MOBs are named the *legal spaces*. For instance, the spaces for bedroom, balcony, storage, or car park comprise the zone for the lot, while corridor, stair, lift, or service rooms are parts of the CP

Table 3: Data elements representing information requirement for preventing misbehaviors in using and managing MOBs.

Representation type	Data element	Explanation	Lot	CP
Geometric data	Ownership boundary	Graphical objects representing boundary location	✓	✓
	Building element	Boundary structures and building elements lying on boundaries where disputes frequently occurred	✓	✓
	Legal zone	Geometric dimension of ownership zone (lot, CP) delimited by ownership boundary	✓	✓
	Legal space	Partial space comprising the legal zone	✓	✓
Semantic data	Boundary type	Two types of boundaries (fixed, structural)	✓	✓
	Boundary location	Face of the boundary structure where the boundaries are located (interior, median, exterior, other)	✓	✓
	Building element owner	Owner of each building element, such as OC (for interior boundary), shared (for median boundary), and lot (for exterior boundary)	✓	✓
	Zone name	Name of legal zone defined in the subdivision plan	✓	✓
	Zone type	Two types of legal zone (lot, CP)	✓	✓
	Lot liability	Share of expenses for CP management allocated to each lot	✓	
	OC membership	Name of OC to which each lot zone belongs	✓	
	CP type	Two types of CP zone (unlimited, limited)		✓
	OC with ownership	OC holding ownership of each CP		✓
	Management OC	OC entitled to use and manage each CP		✓
	Benefiting CP	CPs where the lot can be benefited	✓	
	Usage type	Two types of the lot usage (residential, commercial)	✓	
	Performance	Targeted performance level of legal spaces of CPs achieved by MOB management		✓

zone. Apart from it, *name* and *ownership data* that are assigned to every legal zone and boundary structure could minimize human intervention in the interpretation of ownership over them.

To prevent lot owners' misconception regarding responsibility for managing CPs, the co-ownership share of lots needs to be delivered intuitively. Instead of using a schedule, a direct connection of *lot liability* and *affiliated OC* to each lot zone can provide corresponding responsibility only related to the individual lots. Those data elements describe the lot owners' membership of multiple OCs and their financial burden derived from the membership, respectively.

The ownership RRRs of OCs, which address the information regarding OC governance, can facilitate the comprehension of the CP management mechanism based on the OC structure and membership. This information can support resolving the confusion among OCs in their management scope by providing a clear description regarding their RRRs over specific CPs throughout MOBs. For this, the following data elements are required: *CP types* (unlimited or limited), *OC with ownership* (possessor), and *management OC* (managing body). It differentiates the OC with responsibilities for CP upkeep and the OC holding power of decision-making that generally require the understanding of statements in Owners Corporations Act.

The data elements regarding beneficiaries from CPs (*benefiting CP*) and targeted management levels (*performance*) provide supportive information for reaching the consensus for CP management practices. The former represents a list of CPs that provides shared services to the lots explicitly; it clarifies the party financially responsible for managing part of CPs when the benefits to the lot owners from works on the CP are not equal. It is aligned with the benefit principle – the owner of the lot that benefits more should pay more. The latter shows the goals of CP management, and it can promote the appropriate decision-making on the management and better management activities of OC. In addition, *usage type* (residential or commercial) for the lots demonstrates whether the lot is well grouped into the OCs and fairly shares the responsibility for CP management with other lots holding similar interests.

As represented in Table 3, the mentioned data elements can be classified into geometric and semantic types, according to the way of representation. The data elements relevant to the ownership boundaries, building elements, legal zones, and legal spaces are defined as the geometric data indicating volumetric and graphical objects. The remains are represented as semantic data for legal zones or building elements.

4.2 Extension of IFC data structure

The identified data elements are translated into IFC entities, properties, and relationships. Although the latest version of IFC has been released, this research focuses on IFC 2×3, regarded as the most supportive and stable format used in the current practice. The extension is conducted in the way of (i) mapping the geometric data into existing IFC entities and then (ii) defining semantic data as attributes or properties of the corresponding geometric data (see Table 4). For the information unsupported by IFC, this research adds new properties to IFC schema to accommodate it.

As illustrated in Fig. 4, the legal zones and spaces are described as IfcZone and IfcSpace, respectively. IfcRelAssignsToGroup defines the relationship between one zone and its constituent spaces. The ownership boundaries of the zone are represented as the aggregated boundaries of partial spaces. The geometry of the ownership boundary is expressed as IfcConnectionSurfaceGeometry, and it is linked to IfcSpace by IfcRelspaceBoundary. For the fixed boundary, IfcRelspaceBoundary references IfcVirtualElement as RelatedBuildingElement to indicate the placement of surveying measurements that exist non-physically. It has "virtual" as a value of PhysicalOrVirtualBoundary indicating the boundary type. For the structural boundary, subclasses of IfcBuildingElement are referenced by IfcRelspaceBoundary, with the value of "physical" for

Table 4: IFC definition of the identified geometric and semantic data for preventing misbehaviors in MOBs.

	Data element	IFC entities	Attribute	Property	
				Property set	Property name
Geometric data	Legal zone	IfcZone	-	-	-
	Legal space	IfcSpace	-	-	-
	Ownership boundary	IfcConnection SurfaceGeometry IfcVirtualElement	-	-	-
	Building element	Subclass of IfcBuildingElement	-	-	-
		Subclass of IfcDistributionElement	-	-	-
Semantic data	Boundary type	IfcRelSpace Boundary	PhysicalOrVirtual Boundary	-	-
	Structural boundary	Subclass of IfcBuildingElement	-	Pset_BE Ownership	Structural boundary
	Boundary location	Subclass of IfcBuildingElement	-		Boundary location
	Building element owner	Subclass of IfcBuildingElement	-		Owner
	Zone name	IfcZone	Name	-	-
	Zone type	IfcZone	ObjectType	-	-
	Usage type	IfcZone	-	Pset_Lot Ownership	Usage type
	OC membership	IfcZone	-		OC membership
	Lot liability	IfcZone	-		Lot liability
	Benefiting CP	IfcZone	-		Benefiting CP
	CP type	IfcZone	-	Pset_CP Ownership	CP type
	OC with ownership	IfcZone	-		OC with ownership
	Management OC	IfcZone	-		Management OC
	Performance	IfcSpace	-		Performance

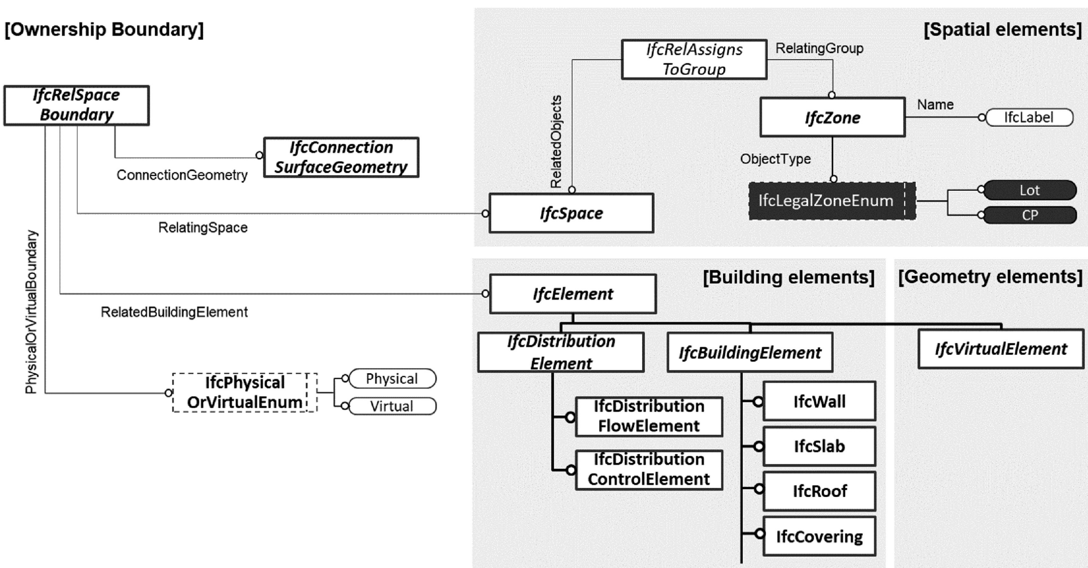

Figure 4: Relevant entities for expressing geometric data in IFC data structure.

PhysicalOrVirtualBoundary. Boundary structure and other structural elements are described as subclasses of IfcBuildingElement, such as IfcWall and IfcSlab, while subclasses of IfcDistributionElement represent utility services.

The location of the structural boundary is set as a property of a newly defined property set for subclasses of IfcBuildingElement indicating boundary structures. This property set is denominated as Pset_BEOwnership; it contains two more properties about the owners of building elements and whether the building element is the boundary structure or not. IfcRelDefinesByProperties creates a connection between Pset_BEOwnership and the corresponding the IFC entity. For instance, IfcWall for a boundary wall delimiting the extent of the lot is defined as RelatedObjects of IfcRelDefinesByProperties whose RelatingPropertyDefinition is an IfcPropertySet with Pset_BEOwnership (see Fig. 5). This property set has values regarding the structural boundary, boundary location, and building element owner that are set as ”true,” ”interior,” and ”OC,” respectively. The

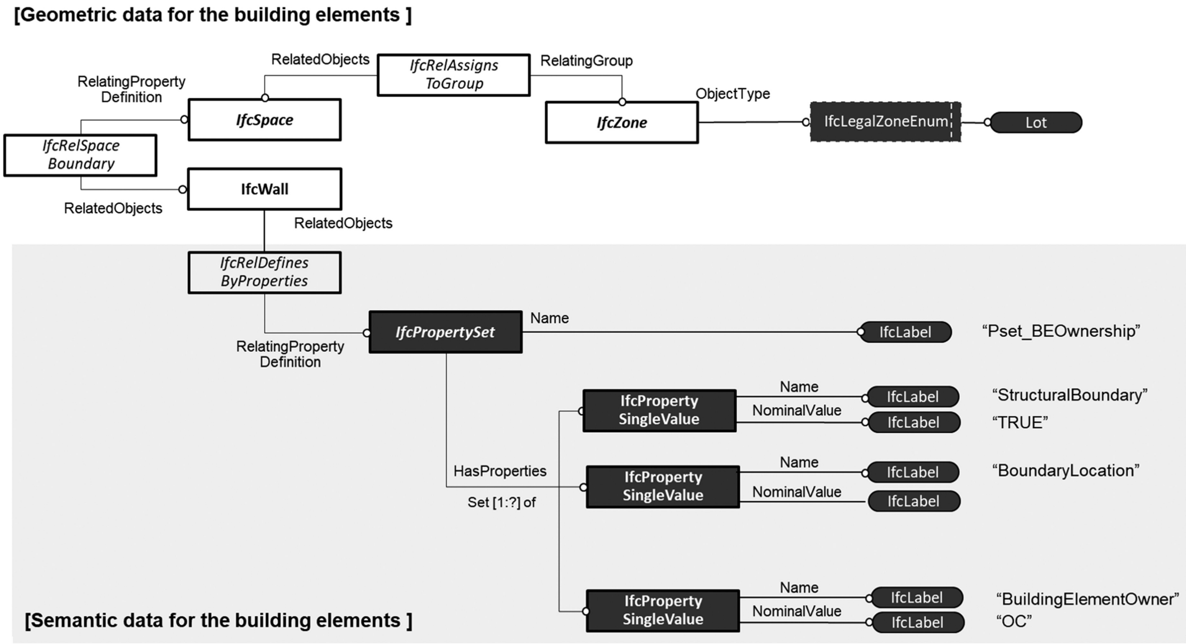

Figure 5: Geometric and semantic data for a boundary wall delimiting the lot in IFC data structure.

relationship between building elements and legal zone is expressed by IfcRelSpaceBoundary and IfcRelAssignsToGroup.

The semantic data of legal zones are also described in IFC schema using attributes and the property set. The name and ownership zone type (lot or CP) are defined as attributes of IfcZone (see Fig. 6). The enumeration to define the zone type is suggested as IfcLegalZoneEnum consisting of two values, lot and CP. The property set for addressing four data elements of the lot legal zone is captured in Pset_LotOwnership. It comprises usage type, OC membership, lot liability, and benefiting CP. For instance, one residential lot with memberships of two OCs is expressed as IfcZone in Fig. 6. IfcRelDefinesByProperties assigns its ownership information addressed in Pset_LotOwnership. Similarly, Pset_CPOwnership is suggested to incorporate the four data elements for CP, such as CP type, OC with ownership, management OC, and performance.

5. Implementation

To assess the practicability of the proposed IFC extension, an IFC model for a real MOB, in which the dispute case happened in Victoria, has been created. This dispute case is categorized into the CP management type—*Bourne v Lorkin* (Owners Corporations) [2017] VCAT 2140 (20 December 2017). The MOB is located in Melbourne and consists of four lots, two CPs (unlimited and limited) with two OCs (unlimited and limited). The fixed boundaries and structural boundary (median type) are used to delimit ownership RRRs within the MOB. Despite its less complexity of the structural layout, this MOB is selected for the case study since three types of misbehaviors happened and led to conflicts among its residents. This case allows validating the potential of the enriched IFC data structure for delivering the required information of ownership RRRs to preventing the misbehaviors under different scenarios.

Using Autodesk Revit 2018, the geometric data about the 3D layout of building elements (walls, floors, ceilings, windows, and doors) were created based on the 2D architectural plan. Due to the limitation in data collection, utility services were not considered in this paper. According to the subdivision plan, the six ownership spaces were defined as legal zones and spaces. *Space separator* was used to define the vertical and horizontal boundaries of the constituent spaces on top of the building elements, including boundary structures. The spaces, such as rooms in the lots, parking spaces, storage, stair, corridor, and entrance, are grouped into four lot zones and two CP zones. The semantic data were input into boundary structures and legal zones by using the *Project Parameters* in Revit. Three properties in the Pset_BEOwnership were defined in every boundary structure in the subdivision plan. In the same way, each property in the Pset_LotOwnership and the Pset_CPOwnership was added to legal zones. In addition, the six legal zones were enriched with two attributes regarding their name and types.

After developing all data elements in BIM data, the IFC model for the MOB exported with its fully populated ownership RRRs information on top of 3D visualization. In accordance with the suggested IFC extension, all properties in BIM data were grouped into three property sets of the IFC model. Solibri Model Viewer was used to navigate the IFC model of the MOB, as shown in Fig. 7.

6. Discussion

There have been a significant number of disputes in MOBs that were caused by improper behaviors of residents in using and managing MOBs. The misbehaviors have been incurred by the imprecise interpretation of ownership RRRs based on the 2D-based cadastral plans. To address this problem, this research aims to examine the capability of BIM to visualize and communicate the required information for improving the understanding of ownership in MOBs. Here, the validity of BIM utilization is assessed by comparing the communicated information for alleviating the misbehaviors in the case-study dispute from the implemented IFC model and the subdivision plan of the MOB.

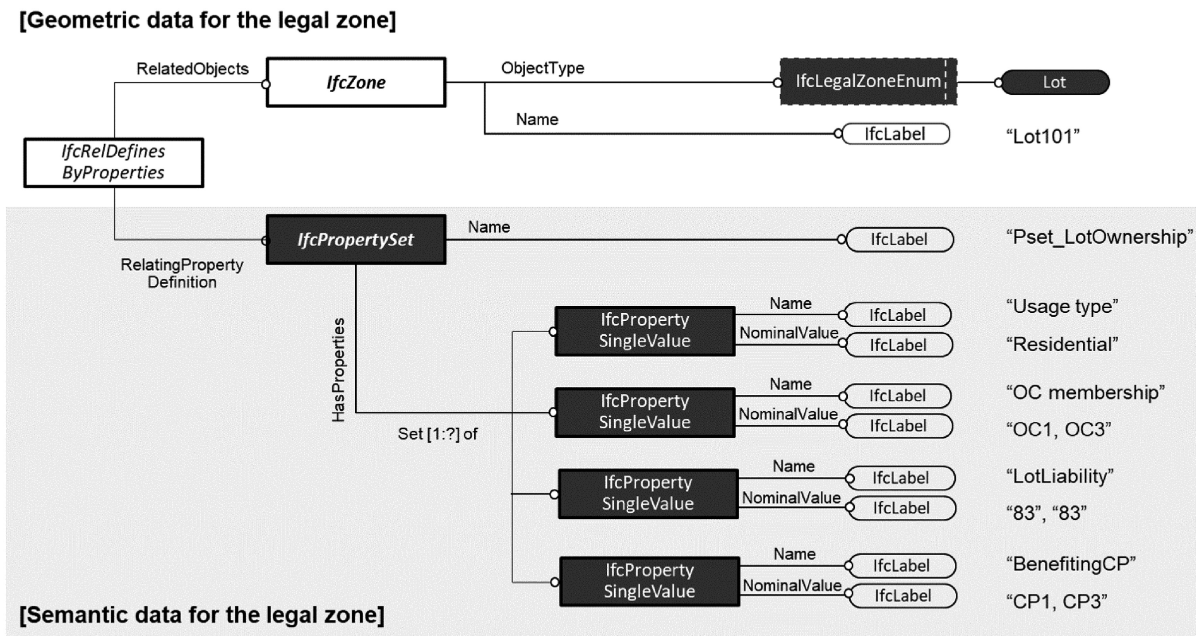

Figure 6: Semantic data for defining ownership RRRs of the lot in IFC data structure.

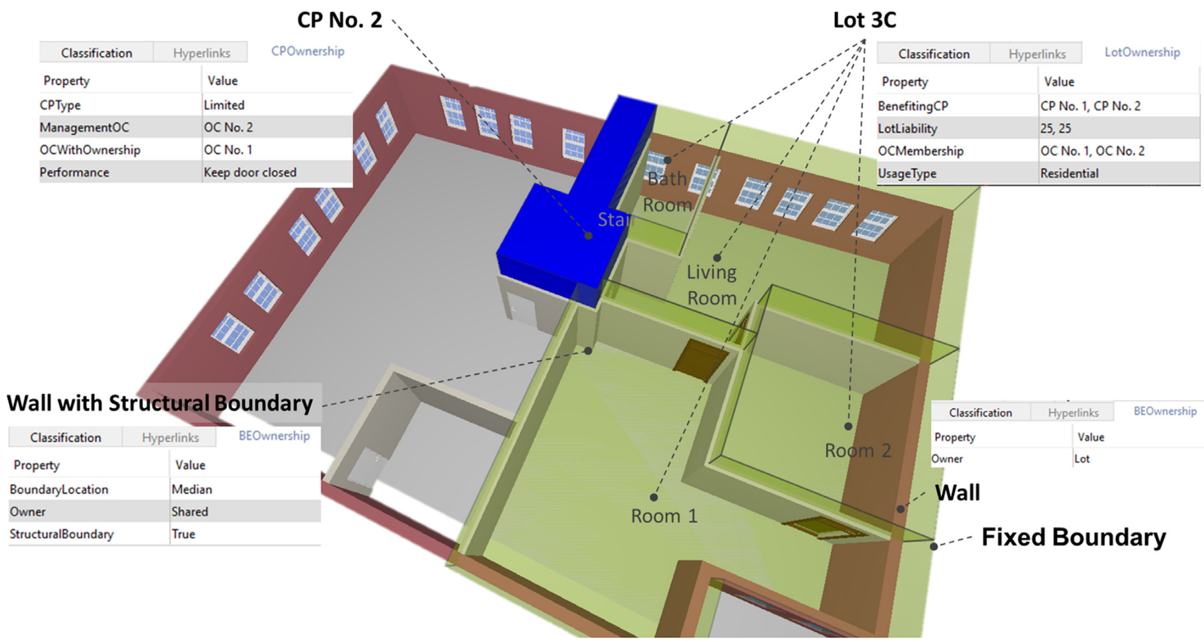

Figure 7: IFC representation of the MOB with geometric and semantic data (first floor).

All data elements to address the controversial issues in the misbehaviors regarding ownership RRRs are accommodated into the BIM environment with the help of the extended IFC data structure. IFC entities for spatial, building, and geometry elements with attributes and properties provide a holistic view of the ownership RRRs, which are currently defined at three different layers in the subdivision plan—plan diagrams, notations, and schedules (see Fig. 8a). For instance, all information to understand the ownership of lot 4D (including ownership RRRs extent, OC governance, and management data) is mapped to its spatial form limited by fixed and structural boundaries (see Fig. 8b). The linkage between 3D geometry and semantic data in IFC enables to flexibly represent the complicated arrangement of legal zones with ownership RRRs. The various solid modeling methods for the shape representation in the IFC schema, such as B-rep, CSG, and swept solid, support the generation of valid 3D ownership spaces in the plan. It could facilitate the creation of complicated ownership spaces with odd shapes or spanning several floors in MOBs.

The dispute case discussed in the previous section was developed by three resident misbehaviors. The two parties asserted the other's breach of ownership, namely applicants (owners of

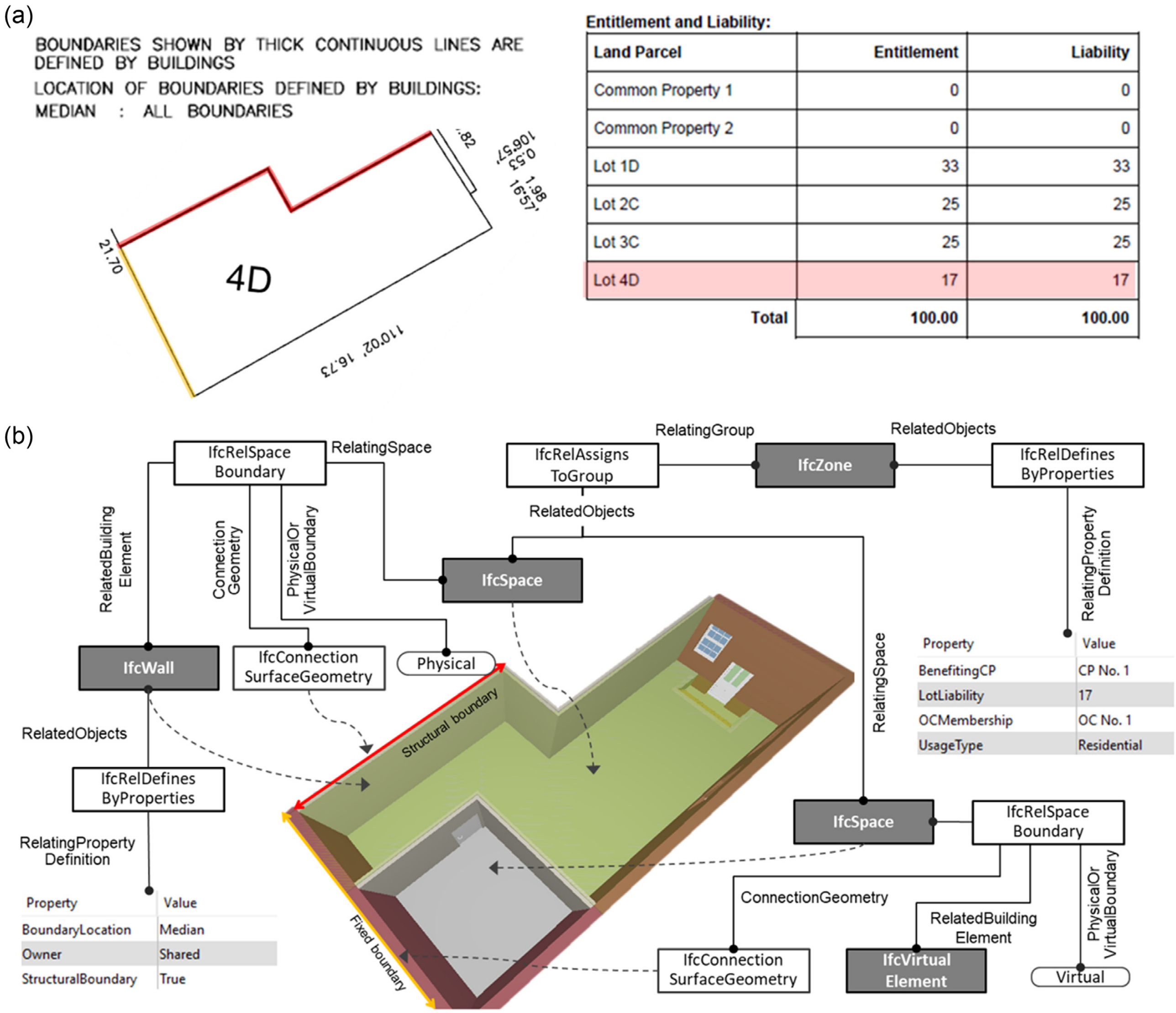

Figure 8: Required information for delimiting the lot ownership space in (a) subdivision plan and (b) IFC model.

lot 1D and 4D) and respondents (owners of lot 2C and 3C). The respondents alleged that applicants arbitrarily changed exterior walls and windows to install air conditioning (AC) and security screens. The applicants claimed that respondents inappropriately occupied storage and improperly denied an implied easement over the roof to install TV aerial.

- Arbitrary change of CP: With surveying coordinates and isometric diagrams in the plan (see Figs 9a and 10a), both parties reached different interpretations of the location of the fixed boundaries. The respondents asserted that the exterior walls and windows where applicants installed AC unit and screen are part of CP No. 1, while the applicants believed that they possessed the parts. According to the coordinates, the fixed boundaries are located on the external surface of the building elements; it means that these parts belong to the applicants. Despite the ownership, the installation of volumetric objects (AC unit) on the wall breaches the ownership RRRs since air space of the CP is directly adjacent to the boundaries of the lots; it encroaches CPs. Navigating the IFC model allows applicants to perceive the circumstance that they only can install the screen but need approval from OC to install the device (see Figs 9b and 10b).
- Invalid use of CPs: In CP No. 1, all applicants have just as much right to use it as having the respondents. However, implicit notations in the plan regarding the ownership rights to use any CPs drew the improper conclusion of the respondents—exclusive use of the storeroom (see Fig. 11a). In contrast, the accurate dimension and location of storage with clear indications of the owner, manager, and required performance are delineated in the extended IFC model (see Fig. 11b). Using this model, both parties can intuitively understand their ownership interests on using and managing each CP.
- Speculation over the necessity for an implied easement over CPs: TV transmission is an essential service for all the lots; so, an implied easement of passage over all parts of MOBs to install TV aerial exists when there is no other feasible way of provision. Using the subdivision plan with no elevation diagram, the respondents showed a limited conceptualization of the vertical extent of ownership RRRs. As illustrated in Fig. 12a, the section diagram without any legend is hard to

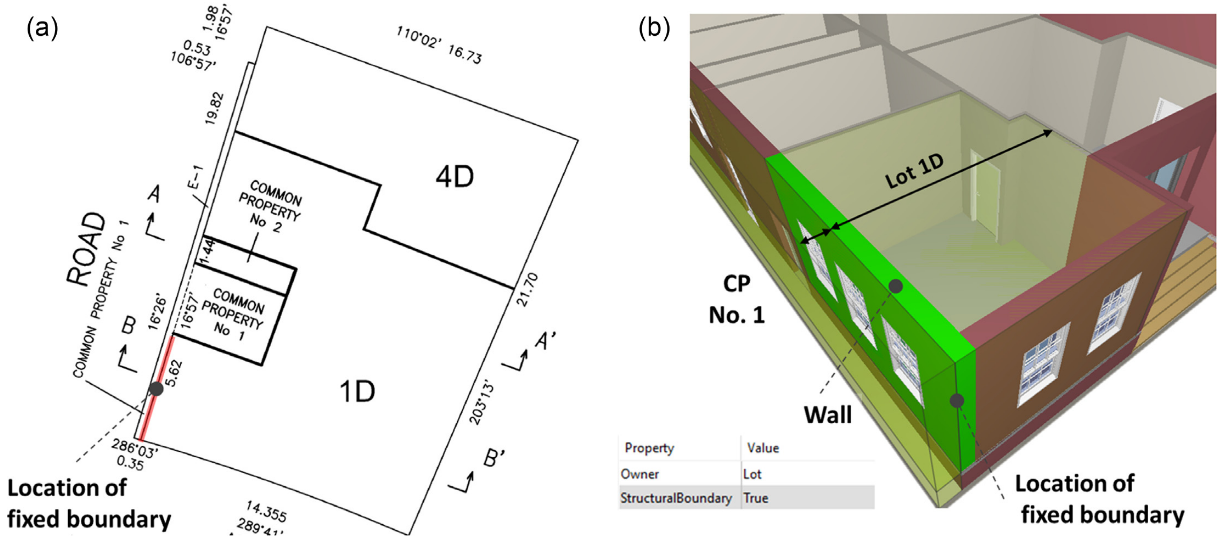

Figure 9: Required information for delimiting ownership over the wall in (a) subdivision plan and (b) IFC model

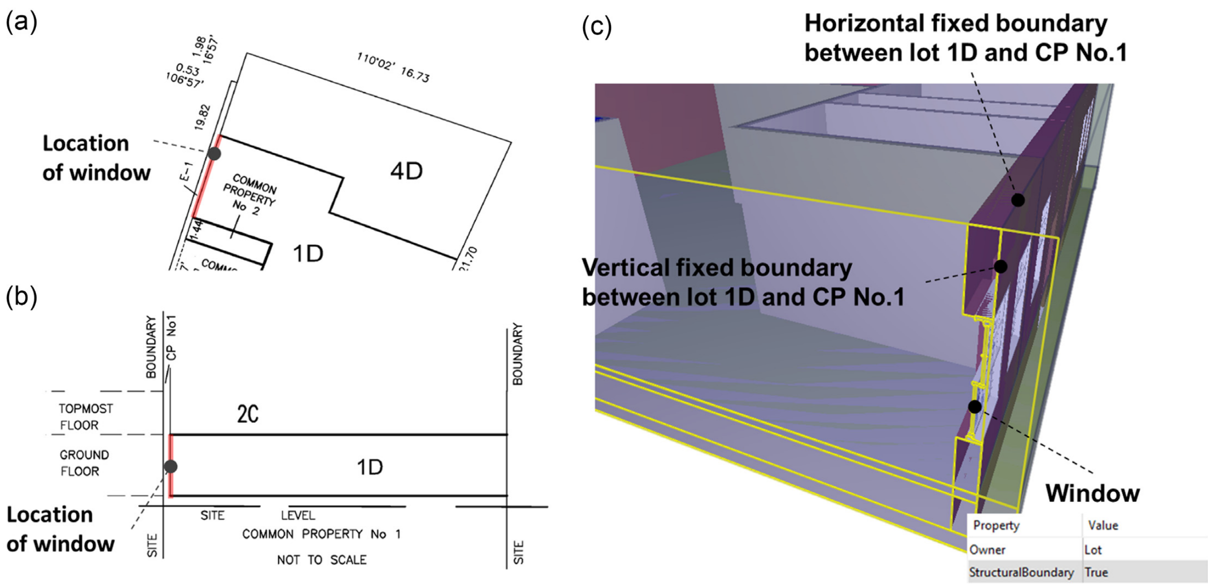

Figure 10: Required information for delimiting ownership over the window in (a) subdivision plan and (b) IFC model.

interpret the boundary location and the ownership over horizontal building structures, such as the roof. Poor perception of the overall layout of ownership RRRs led to a misjudgment on the existence of alternative means of service provision; it resulted in the respondent denial for the easement. The necessity of the easement is clearly communicated in 3D visualization of the IFC that can provide dynamic and interactive views of all legal zones, as represented in Fig. 12b.

The above misbehaviors have their roots in the wrong decisions based on the misconception regarding ownership RRRs in MOBs. The comparison demonstrated that the implemented IFC model could deliver the information that influences the formation of the accurate perception of ownership. Using 2D subdivision plans, the interpretation and utilization of ownership information relied on individual expertise and ability. However, the BIM environment enables the MOB residents to interact with a full image of the 3D extent of RRRs intuitively. The 3D visualization provides the explicit conceptualization of ownership boundaries and RRRs on top of physical MOB form that is represented in the virtual world with the real locations. In addition, its digitalized representation allows the interactive experience of exploring the various views of ownership by navigating, querying, and analyzing the information in BIM data. With these features, BIM could remove the ambiguities in identifying RRRs associated with using and managing MOBs and facilitate the understanding of ownership that is a prerequisite for preventing the misbehaviors causing disputes.

Despite the benefits, several limitations of the use of BIM for mitigating resident misbehaviors were also identified. As discussed above, the majority of the OC communities are not experts in surveying and architecture. It infers that a platform, in which the communities easily use, search, query, and analyze the ownership information in the IFC model, is necessary to

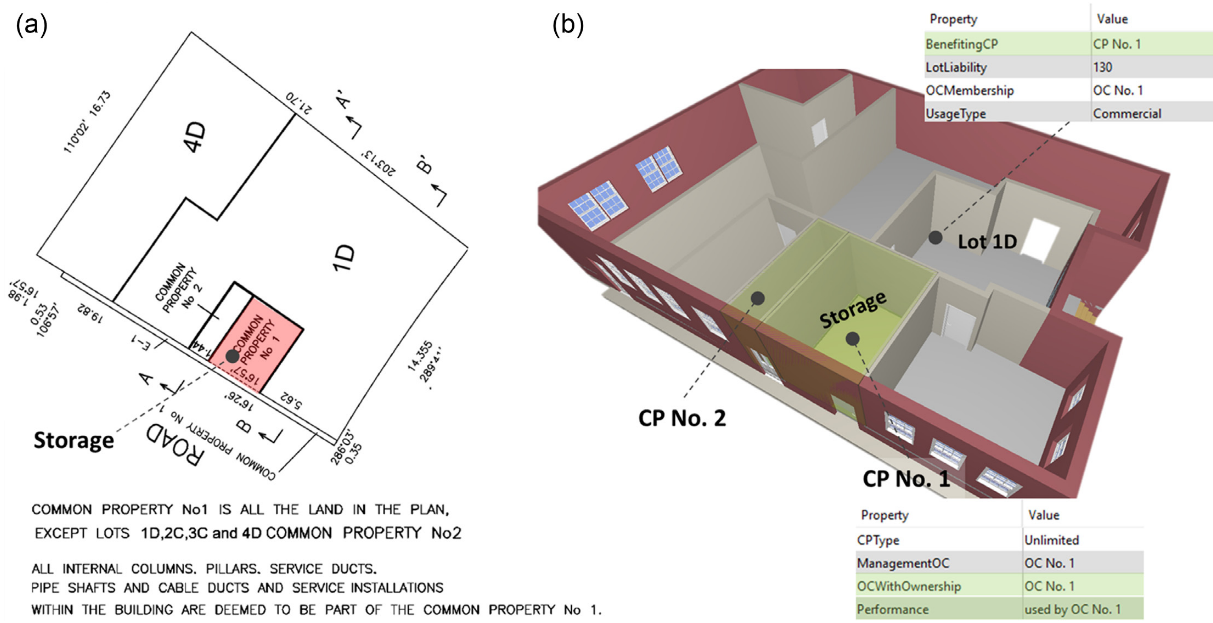

Figure 11: Required information for indicating ownership right to use storage in (a) subdivision plan and (b) IFC model.

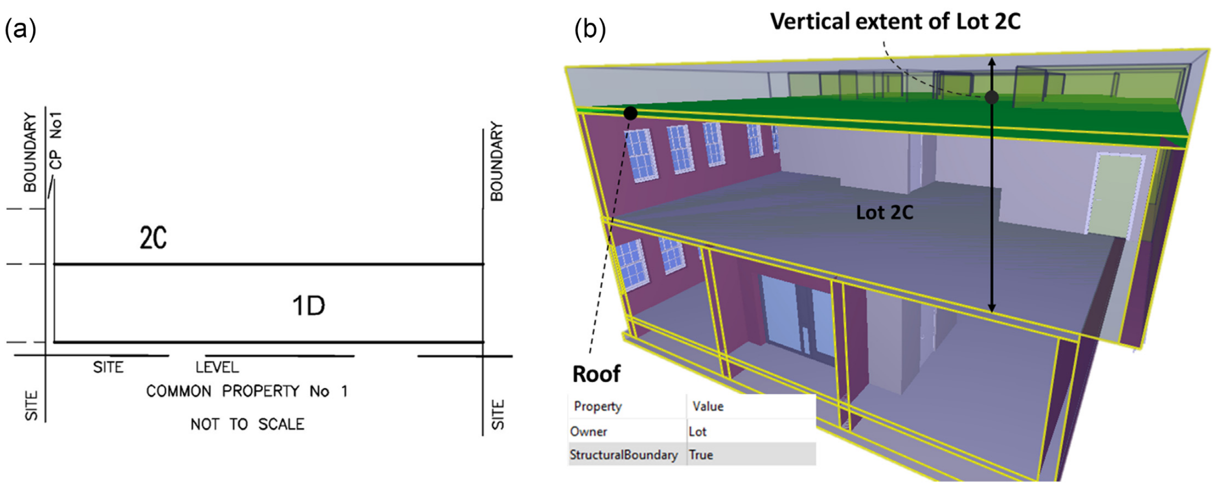

Figure 12: Required information regarding the existence of an easement in the roof in (a) subdivision plan and (b) IFC model.

improve their understanding as well as to remove confusion. This platform would generate reliable insight for using and managing MOBs and the mediation of conflict among residents, as a decision support system in MOBs. Secondly, the subject of creating and managing BIM data is not addressed in this study. In Victoria, information regarding the ownership RRRs and physical structures of MOBs are defined by surveyors and architects, respectively; however, surveyors prepare the plan of subdivision based on architectural drawings. Given the current situation, the integration of ownership and physical aspects of MOB information under the responsibility of surveyors is considered as appropriate. The detailed mechanism of the integration, on both data and process levels, needs to be investigated in a further study. Lastly, this research only focused on the disputes in MOBs from the management perspective. According to Christensen and Wallace (2006), many causes of the disputations lie in poor management stemming from the inappropriate ownership, and organizational and physical design features. It indicates that a significant number of disputes can be avoided if appropriate features had been employed. In this context, it is essential to investigate the correlation between ownership and physical design features and dispute incidence fundamentally.

7. Conclusion

The rising tide of disputes regarding the use and management of MOBs has affected harmonious communal living in urban areas. This trend has been exacerbated by the inappropriate behavior of residents, stemming from the inaccurate understanding of 3D ownership RRRs in MOBs that is solely interpreted by using 2D subdivision plans. To respond to the disputes proactively, this research paid attention to the alleviation of the resident misbehaviors in using and managing MOBs. In this context, the feasibility of the use of BIM was explored, focusing on removing ambiguity in ownership awareness among residents by delivering easily understandable 3D representation of ownership RRRs overlaid on the physical form of MOBs.

From 62 dispute cases in Victoria, typical misbehaviors raising the disputes and their leading causes were identified. The IFC data structure was enriched with critical information regarding ownership RRRs for resolving the causes. Its practicability was assessed by implementing the IFC model of MOBs that experienced real dispute in Victoria. Using the IFC model, the validity of the use of BIM was discussed by comparing its communicated information for alleviating the misbehaviors in the dispute with subdivision plans. The results demonstrate that the BIM environment can facilitate intuitive and accurate interpretation of ownership and support misbehavior prevention, as a 3D digitalized foundation for representing and navigating the 3D range of ownership RRRs.

Future work will focus on exploring the limitations of the suggested approach addressed in the discussion. More importantly, the development of an IFC-based platform for managing information regarding RRRs will be carried out to support MOB management practices effectively, considering the information integration process. In parallel, the correlation between ownership and physical forms of MOBs and dispute incidence will be identified to provide the foundation for addressing disputes proactively at design stages.

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Conflict of interest statement

None declared.

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