Building Information Modelling for Urban Land Administration

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For my parents
Abstract

Over the last decades, rapid urbanization has resulted in unprecedented pressure on development and use of land in cities around the world, proliferating multi-storey buildings as well as other urban infrastructure facilities. This means that urban built environments are becoming more and more spatially complex. Urban land administration mainly refers to the information and processes required for recording and managing legal interests in multi-storey building developments, in which a community of owners hold their distinct private, communal, and public legal interests. In multi-storey building developments, the spatial extent of legal interests is often outlined as three-dimensional (3D), invisible, multi-layered and complex volumetric spaces.

Currently, urban land administration practices mainly rely on 2D-based analogue subdivision plans to define boundaries of legal interests. These plans are recognized as posing a range of challenges in terms of communicating and managing the spatial complexity associated with various legal interests defined inside and around multi-storey buildings. In response to these challenges, 3D digital models are being investigated as a potential approach for managing complex, vertically stratified legal arrangements.

In this research, the feasibility of a widely used 3D modelling approach in the architecture and construction industry – Building Information Modelling (BIM) – was investigated for the 3D digital management of legal interests in multi-storey building developments. BIM provides a common and 3D digital data sharing space, underpinning a reliable basis for facilitating collaboration and decision making over the lifecycle of buildings. However, legal attributes and spatial structure of legal arrangements inside and around buildings are yet to be accommodated within the BIM data environment.

Therefore, a range of data elements required for managing legal information has been elicited by investigating current practices pertaining to subdivision of legal interests within multi-storey building developments in Victoria, Australia. An open data model in the BIM domain – Industry Foundation Classes (IFC) – was extended with these legal data elements and a prototype BIM model for a multi-story building development was
implemented to demonstrate the viability of the extended IFC data model for 3D digital management and visualization of data related to complex legal arrangements.

To validate the extended IFC data model, three assessments were conducted. In the first assessment, land administration experts and IFC specialists reviewed the extended data model in terms of its information completeness and logical validity. In the second assessment, the prototype BIM model was compared with its 2D plan version, and benefits and obstacles of using a BIM-driven approach for urban land administration were discussed. Final assessment includes the comparison between the prototype BIM model, which is an integrated legal and physical model, and its purely legal and purely physical models using some objective metrics. These metrics include number of objects and geometry batches, visualization speed in terms of frame rate, query time, modelling the spatial structure of legal interests, modelling legal boundaries, and visual communication of legal boundaries.
Declaration

This is to certify that:

- The thesis comprises only my original work towards the PhD except where indicated in the Preface.
- Due acknowledgement has been made in the text to all other material used.
- The thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

____________________________

Behnam Atazadeh
Melbourne, May 2017
Preface

The following is a list of publications that has been produced as part of this thesis:

i. Journal articles


ii. Peer-reviewed conference papers


iii. Articles in professional magazines


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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>2D</td>
<td>Two Dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
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<tr>
<td>ADE</td>
<td>Application Domain Extension</td>
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<tr>
<td>AEC</td>
<td>Architecture, Engineering, and Construction</td>
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<tr>
<td>B-Rep</td>
<td>Boundary Representation</td>
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<tr>
<td>BIM</td>
<td>Building Information Modelling (or Model)</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
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<td>CoM</td>
<td>City of Melbourne</td>
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<td>CAD</td>
<td>Computer Aided Design</td>
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<td>CSG</td>
<td>Constructive Solid Geometry</td>
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<td>XML</td>
<td>eXtensible Markup Language</td>
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<tr>
<td>IFC</td>
<td>Industry Foundation Classes</td>
</tr>
<tr>
<td>FIG</td>
<td>International Federation of Surveyors (Fédération Internationale des Géomètres)</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standard Organisation</td>
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<tr>
<td>KML</td>
<td>Keyhole Markup Language</td>
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<tr>
<td>LADM</td>
<td>Land Administration Domain Model</td>
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<tr>
<td>LoD</td>
<td>Level of Detail</td>
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<td>MLSM</td>
<td>Multi-Layered Space Model</td>
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<tr>
<td>NRG</td>
<td>Node-Relation Graph</td>
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<td>OGC</td>
<td>Open Geospatial Consortium</td>
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<td>RRR</td>
<td>Rights, Restrictions, and Responsibilities</td>
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<td>SSM</td>
<td>Structured Space Model</td>
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<td>UBM</td>
<td>Unified Building Models</td>
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<td>VRML</td>
<td>Virtual Reality Modelling Language</td>
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<td>OWL</td>
<td>Web Ontology Language</td>
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CHAPTER 1

INTRODUCTION
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1 Introduction

1.1 Research Background and Motivation

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 maps and subdivision plans to manage the spatial dimension of rights, restrictions, and responsibilities (RRR) associated with a piece of land, building or property. As stated in Enemark (2009), “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 registering RRR information. 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 2008), US Cadastral Data Content Standard for the National Spatial Data Infrastructure (FGDC 2008), ePlan model (ICSM 2010), and ISO 19152-LADM (ISO19152 2012a). The differences between these cadastral data models mainly stem from the fact that each jurisdiction has its distinct requirements and expectations for managing RRR information and, therefore, implement these models variably. However, most cadastral data models have one thing in common: they rely on two-dimensional (2D) land parcels as the basis for recording and communicating RRR information (Aien 2013).

Over the last decades, urbanization process has resulted in unprecedented pressure on development and use of land in cities around the world, proliferating multi-storey buildings as well as other urban infrastructure facilities. Consequently, urban built environments are becoming more and more spatially complex. “Urban land administration” mainly refers to processes and information required for recording and managing RRR information about multi-storey building developments, in which a community of owners hold their distinct private, communal, and public legal interests (Ho 2014). In multi-storey building developments, the spatial extent of legal interests is often outlined as three-dimensional (3D), invisible, multi-layered and complex
Building Information Modelling for Urban Land Administration

volumetric spaces (Stoter and van Oosterom 2006). Land administration systems traditionally utilize 2D-based cadastral maps and subdivision plans to manage both spatial and semantic information associated with 3D RRR spaces (Kalantari et al. 2008). These 2D-based systems face challenges in terms of recording, storing and communicating the spatial complexity of 3D RRR spaces in multi-storey building developments. These challenges are very well-known in literature (Karabin 2012, Stoter et al. 2012, 2013, Aien et al. 2013, Shojaei et al. 2013, Ho 2014, Rajabifard et al. 2014); however, a condensed list of them is (Ho 2014):

- 3D RRR spaces associated with oddly shaped and complex structural elements may not be effectively represented by projecting them into floor plans and cross-section views.
- Multiple pages of 2D plans are required to communicate the spatial extent of all 3D RRR spaces within a high-rise development. Such large number of 2D plans imposes a considerable amount of cognitive load on non-specialists to understand the delimitation of 3D RRR spaces.
- 2D parcel-based cadastral data models cannot sufficiently map and visualize complex 3D RRR spaces.
- Representation of a 3D RRR space spanning several floors is a very arduous task by using 2D plans.
- Stakeholders with limited background in land administration sometimes misunderstand spatial extent of 3D RRR spaces with boundaries referencing different faces (interior, median, and exterior) of physical structures such as walls, slabs or doors.

In response to the above challenges, land administration agencies are now supporting research on three-dimensional (3D) digital management of land and property information in urban built environments. 3D digital management of land and property information in an urban built environment requires two main dimensions, namely legal and physical information. Legal information refers to legal attributes, legal boundaries, common properties and easements. Legal information is a prerequisite for managing RRR information in the development process of built assets and is associated with the concept of legal spaces which include invisible cadastral objects (Bittner and Smith
Physical information includes geometric and semantic components. Geometric information refers to the shape and geometrical aspects of physical elements such as precise surveying data, coordinate systems, and measurements. Semantic information is defined as physical descriptions about physical elements with examples being thickness and materials of building elements, roof data, and facade data. Physical information is related to the concept of physical spaces which consist of visible and real world spatial objects (Smith and Varzi 2000, Pouliot 2011, Karabin 2014).

The inadequacy of 2D-based methods used for representing 3D RRR information results in serious economic consequences in managing urban areas, particularly those with high-density developments. The first consequence is the knowledge gap about the full spatial extent of 3D RRR typically requires organizations to conduct extra surveying activities in complex ownership situations in Australia. Another implication is that the spatial information about vertically located properties is often stored in proprietary and non-interoperable data environments, which leads to costs associated with duplication and integration of 3D spatial information. For instance, in Western Australia State, the cost of integrating land information is predicted over $1.8 million per annum (CRC for Spatial Information 2008). It affects the reputation of authorities responsible for maintaining the land administration system and providing critical spatial information services to the community. Over the development and establishment of new built assets, unpredictable impairments can be done to other assets, particularly those assets located below the Earth’s surface. The current 2D-based representation of 3D RRR would not effectively support decision making in managing and planning other aspects of urban settings such as launching National Broadband Network for multi-level storey developments (NBN Company 2016). All these factors imply that modelling RRR in 3D digital data environments would provide significant benefits for Australia’s economy. 3D digital management of RRR information unlock the value of this information for a broader community, such as owners, building and facility managers, outside the highly specialized surveying profession.

In parallel with the need for 3D data in land administration, the Architecture, Engineering and Construction (AEC) disciplines involved in the building development process have also experienced the limitations of 2D-based designs in terms of
communicating complex architectural and structural information within multi-storey buildings (Eastman et al. 2011). Consequently, Building Information Modelling (BIM) has emerged as a new paradigm to facilitate collaboration among different AEC actors (Isikdag 2015). As stated in NBIMS (2012), BIM provides a 3D digital and shared data environment encompassing both physical and functional characteristics of built assets, underpinning a reliable basis for decision making over the lifecycle of these assets. Compared to 2D-based means of information sharing, BIM significantly improves productivity and reduces cost and effort for design changes in development phases of complex and multi-story building structures (Arayici et al. 2011, Barlish and Sullivan 2012).

The ‘BIM’ acronym mainly represents two distinct concepts, namely process, and product. Building Information Modelling (BIModelling) relates to a collaborative and multi-disciplinary process to manage a built asset over various phases of its lifecycle (Eastman et al. 2011). The BIM process leverages and leads to the production of a Building Information Model (BIModel), which is a structured 3D spatial dataset(s) describing physical components of the built asset over its lifespan (Eastman 1999). BIM products provide efficient spatial representation and communication of architectural as well as structural elements inside complex built assets. There are multiple actors involved in the development of any built asset, such as architects, civil engineers, builders and owners, and each actor can create and use their distinct BIM product. Throughout the BIM process, these distinct products can be assembled in a common data environment which provides a complete model of the built asset. BIM products not only include tangible spatial objects, such as walls, doors, windows, and slabs but also they can contain intangible volumetric spaces. Additionally, some spatial relationships between tangible and intangible spatial objects are modelled within BIM products (Borrmann and Rank 2009).

The drivers for using BIM in construction projects in Australia include engaging clients in early stages of projects, facilitating collaboration within and across organisations, utilising collaborative lean processes to improve productivity and decrease costs (buildingSMART Australasia 2012). An investigation conducted by McGraw-Hill Construction (2014) shows that business benefits and returns are the main drivers for growing BIM industry in Australia. It has been reported that adopting BIM results in a
return on investment (ROI) of over 25 percent for the vast majority of Australian firms. In addition, 52 percent of these firms indicate their positive view on potential benefits from BIM. In Australia, both state and federal governments have recognised the importance of BIM for designing, managing and operating built and infrastructure assets. At the federal level, the national digital engineering policy principles provide a consistent framework for incorporating BIM in the delivery and management of buildings and infrastructure facilities (Australian Government 2016). At the state level, Queensland government, for instance, has prepared the draft of policy and principles on the use of BIM on the full lifecycle of state infrastructure and built assets by 2023 in this jurisdiction (Queensland Government 2017). These factors indicate that it is highly likely that BIM models for buildings and infrastructure assets will be extensively available in near future.

The open data model for exchanging BIM models across multiple BIM platforms is the Industry Foundation Classes (IFC) standard, and it has been developed for promoting interoperability over the development process of built assets (ISO16739 2013). IFC is an object-oriented data model, and it includes a comprehensive set of entities describing geometric and semantic aspects of a built asset throughout its lifecycle. This standard typically uses a hierarchical spatial structure to store building information. In other words, BIM models in IFC format can be decomposed into manageable subsets such as sites, buildings, stories, spaces and building elements inside stories (Liebich 2009).

BIM models include highly detailed physical information about built assets. However, these models currently do not specify legal information associated with ownership of built assets. Therefore, the potential value of BIM and in particular the IFC data model has recently become a focus of various investigations in the land administration domain (Clemen and Gründig 2006, El-Mekawy and Östman 2012, Isikdag et al. 2015). Although these recent studies showcase various levels of using BIM for supporting land administration functions, none of them has explored how the IFC standard can be extended to accommodate legal information, which plays a fundamental role in adopting BIM for land administration purposes.
1.2 Research Formulation

1.2.1 Research problem
According to the above background and motivation, the research problem to be investigated in this thesis is formulated as:

*From a land administration perspective, the open BIM data model (IFC) in its current form is not capable of managing legal information associated with ownership of properties inside and around multi-storey building developments.*

1.2.2 Research aim
To address the research problem, the aim of this research is:

*To investigate how the open BIM data model (IFC) can be extended to accommodate legal information as a first step towards leveraging BIM for managing land and property information inside and around multi-storey building developments.*

1.2.3 Research questions
In considering the research problem, the following key research questions have been raised:

1. *What are the current challenges associated with recording, managing and communicating RRR information in multi-storey building developments?*
2. *What is the appropriate approach for embedding legal information into the BIM data model?*
3. *What are the advantages of using the extended BIM data model for urban land administration?*
4. *What are the obstacles to fully implement BIM in the current practice of urban land administration?*

1.2.4 Research objectives
In response to the research problem and research questions, and to accomplish the research aim, the following objectives were formulated:

1. *Investigating existing challenges associated with current practice of subdividing legal interests in multi-storey buildings*
2. Discovering limitations of current 3D spatial data models used for the purpose of mapping and registering legal interests.

3. Extending IFC data model with a range of required data elements for managing legal interests inside and around multi-storey building developments.

4. Development of a prototype BIM model to demonstrate feasibility of the extended IFC data model.

5. Evaluation of the proposed extension:
   a) By experts: those specialists involved with building subdivision processes as well as experts involved in the development of the IFC standard.
   b) By prototype: Comparing the integrated prototype BIM model with purely legal and purely physical models using some objective metrics.

1.3 Research Approach

In the domain of information systems, design science research methodology is mainly used to develop an artefact with an embedded solution to address the explicates research problem (Peffers et al. 2007). The artefact can refer to models, constructs, methods, instantiations or any innovative solutions (March and Smith 1995). Over the last decade, design science research methodology has been implicitly adopted in various doctoral dissertations contributing to the information science aspect of land administration domain (Çağdaş and Stubkjær 2011). Although these dissertations did not explicitly adopt design science research methodology, Çağdaş and Stubkjær (2011) argued that the methodology of these investigations is in alignment with the general structure of design science. For instance, Stoter (2004) identified the research problem as “Improving 3D cadastral registration from a technical point of view”. In response to this problem, she proposed “Conceptual and logical models for a 3D Cadastre” as a new artefact and demonstrated this artefact using case studies from the Netherlands and Queensland, Australia. Similarly, the contribution of this thesis is also associated with spatial information science dimension of legal arrangements inside and around multi-storey buildings. More specifically, this research proposes an extension of IFC standard (a new artefact) to incorporate legal information into BIM environment and address the research problem identified in Section 1.2.1. Therefore, the research approach has been developed in accordance with design science research methodology and includes five phases, namely foundation, design and development, demonstration, evaluation, and documentation and communication (see Figure 1.1). Each of these phases is briefly
explained in the following subsections.

1.3.1 Foundation
This phase includes two activities, namely explication of the research problem and defining the requirements for a solution. To define and justify the research problem, relevant literature should be thoroughly investigated. In the context of this study, a variety of scholarly publications were used to review the literature in relevant topics including BIM, land administration and 3D cadastre, and 3D geospatial information systems (GIS). Literature review highlighted both communication and management challenges associated with managing legal information in urban built environments. In addition, BIM and its potential for urban land administration were examined (see Chapter 3). One outcome of the literature review was the precise definition of the research problem (see Section 1.2.1). Moreover, research objectives 1 and 2 were also addressed through reviewing relevant investigations (see Chapter 2).

The requirements were firstly identified through relevant literature. Subsequently, these initial requirements were consolidated and finalized through investigating current subdivision practices for managing legal information in urban built environments (see Chapter 5). In this research, the selected jurisdiction for investigating subdivision practices was Victoria, Australia.

1.3.2 Design
In this phase, a new extension of the open BIM data model (IFC) was designed and proposed as a new artefact to respond to the research problem explicited in the foundation phase. Additionally, the proposed artefact should satisfy the requirements. Extension mechanisms inside schema of IFC standard were adopted to enrich relevant IFC entities with legal information in line with the logic of this standard. These extension mechanisms mainly include the concept of property sets and user defined values (see Section 4.5.2).

1.3.3 Implementation
In the implementation phase, the artefact was realized to respond to the problem in a case study. In this research, the proposed extension to IFC standard (the artefact) was
instantiated as a prototype BIM model of a real multi-storey building. This prototype BIM model showcased the practicability of the extended IFC standard for managing legal information with BIM environment (see Section 6.3).

1.3.4 Evaluation
The evaluation includes using relevant metrics and criteria to measure how well the embedded solution within the artefact can respond to the problem. For this research, three assessments were conducted. Firstly, the proposed IFC extension was assessed based on experts’ opinion. The experts were asked to answer two questionnaires to evaluate the proposed IFC extension regarding its information completeness and logical validity. Secondly, the implemented prototype BIM model, which is an instance of the proposed IFC extension, was compared with its 2D plan version in terms of communicating boundaries and arrangements of legal interests. Finally, the implemented prototype BIM model was compared with its purely legal and purely physical models using various metrics. These metrics include number of objects and geometry batches, visualization speed regarding frame rate, query speed, modelling the spatial structure of legal interests, modelling legal boundaries, and visual communication of legal boundaries.

1.3.5 Documentation and communication
In this phase, the problem and its significance, the artefact and its novelty, the results and findings of the research are documented and communicated to different audiences in the academia, industry, and community via various communication channels such as scientific journals, conference proceedings, professional industry magazines and oral presentations. The targeted audience of this research is academic researchers in the area of 3D cadastre, BIM, land administration and GIS, experts in land surveying, land registration, BIM and 3D modelling, and owners living in multi-storey buildings. Although some parts of this research have been published in both scientific journals and professional magazines, this thesis is the comprehensive documentation of all activities done throughout this investigation. Therefore, the overall structure of the thesis will be explained in the next section.
This thesis comprises eight chapters:

The first chapter, *Introduction*, includes the research background and motivation as well as formulation of the research – research problem, questions, aim, and objectives. Moreover, this chapter provides an overview of the adopted research approach and thesis structure.

The second chapter, *Urban Land Administration: a Review of Challenges*, contains an overview of communication challenges associated with current 2D-based practices in urban land administration. Additionally, issues related to purely legal, purely physical, and integrated data models are presented in this chapter. This chapter provides the response to the first research question.

The third chapter, *Building Information Modelling for Land Administration*, includes an introduction to BIM as well as its benefits in the construction industry. In this chapter, IFC standard is then introduced and compared with other 3D spatial (or physical) data models. Related BIM-based research in land administration domain is also presented to distinguish the difference between this investigation and those relevant research projects.

The fourth chapter, *Research Design and Methods*, provides the justification for
adopting design science in this thesis to address the research problem and accomplish research objectives. The chapter firstly outlines the general framework of the design science. Subsequently, it is explained how the design science can be used in various phases of this research.

The fifth chapter, *Data Requirements in Urban Land Administration: A Case Study in Victoria, Australia*, provides an overview of subdivision processes in urban built environments. Through this process, data requirements in the urban land administration are explicated and presented in this chapter. These requirements include legal objects, physical objects, legal documents, land administration actors, and administrative data.

The sixth chapter, *Design and Implementation of a Proposed Extension of IFC Standard for Urban Land Administration*, firstly describes the appropriate approach to embedding the legal information into the IFC standard by extending IFC entities pertinent to urban land administration. Additionally, the proposed IFC extension is implemented in a prototype BIM model to showcase the viability of this extension. This chapter addresses the second research question.

The seventh chapter, *Evaluation of the Proposed IFC Extension and the Prototype BIM Model*, provides the results of the subjective evaluation of the proposed IFC extension. Also, the results of comparing the prototype BIM model, developed from the proposed IFC extension, with its 2D plan as well as purely legal and purely physical models will be reported in this chapter. In response to the third and fourth research questions, the chapter also highlights the potential benefits and obstacles of using the proposed IFC extension in the current practice of urban land administration.

In the final chapter, *Conclusions and Future Research*, the responses to the research problem, aim and objectives are provided. Additionally, future research directions are identified and suggested in this chapter.

### 1.5 Chapter Summary

In this chapter, issues related to 2D-based methods of representing legal interests in multi-storey buildings have been briefly described. BIM is introduced as a rich and shared knowledge and information resource to manage built assets over the course of
their lifecycle. It is explained that 3D digital data environment of BIM can potentially address issues of 2D-based representations. The research background made the motivation for defining the research problem, questions, aim, and objectives. Subsequently, the research approach was briefly explained to show how the research problem will be addressed in this thesis. This is followed by providing the outline of the chapters.
CHAPTER 2

URBAN LAND ADMINISTRATION: A REVIEW OF CHALLENGES
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2 Urban Land Administration: A Review of Challenges

2.1 Introduction

This chapter first provides an overview of urban land administration in an international context. The chapter also includes a review of current challenges and issues associated with managing and communicating legal arrangements defined in urban built environments. In this research, land administration challenges in urban areas are classified into two broad categories. The first category includes communication challenges resulting from 2D subdivision plans. These include issues associated with inexpert interest holders’ accurate understanding and interpretation of spatial dimension of 3D RRR spaces in complex structures, which are identified through reviewing current 2D-based representation methods. The second category comprises challenges associated with existing spatial data models used for 3D RRR data management. These data models have been developed to address issues of 2D-based approaches; however, these data models still have some limitations in managing and representing complex RRR spaces. Three types of data models will be reviewed, namely purely legal, purely physical, and integrated data models.

2.2 Urban Land Administration

Urban land administration refers to the information and processes required to support subdivision, registration and ongoing management of private, communal, and public legal interests vertically located in complex urban areas (Ho 2014) (see Figure 2.1). Various countries have proposed different approaches to manage the spatial complexity associated with legal interests in urban built environments. This is due to the fact that each country has their own legislative framework, in which they should address issues associated complex legal interests. Stoter (2004) discussed these issues for various jurisdictions including Netherlands, Denmark, Norway, Sweden, and Queensland State of Australia. Below, a summary of urban land administration practices in each of these countries will be provided. In addition, the issues and proposed solutions for urban land administration in the specific context of each country will be discussed.
2.2.1 International research in urban land administration

In the Netherlands, vertically stratified legal interests in urban areas are represented by projecting the spatial extent of them onto a 2D cadastral map. Therefore, 2D land parcels are subdivided into smaller parcels in order to register the legal interests located vertically in above or under the Earth’s surface (Stoter 2004). This method of registration sometimes leads to unclear representation of land parcels. Although this causes minor issues at the time of registration, there would be significant challenges in transferring vertically located legal interests in the post-registration period. The reason is that stakeholders (such as purchaser, seller or mortgagee) involved in the transfer have to understand the full spatial extent of 3D legal interests using information obtained from the 2D cadastral map and deeds stored in the land registry organization (Stoter et al. 2016). Combining descriptive and 2D plans provided in the deed with 2D parcel boundaries to form a 3D image of a vertically located legal interest is a very difficult task. In response, the Netherlands Kadaster conducted an investigation to enhance the registration in complex urban developments and enable 3D digital representation of underground and aboveground legal interests (Stoter et al. 2013). As reported by Stoter et al. (2016), the main finding of this investigation was that a 3D digital approach provides significant benefits compared to the 2D approach in complex
ownership situations. These benefits are better vertical representation of legal interests, cost effectiveness (since the reconstruction of 3D legal objects are not required in future transactions), and no need to provide a 2D-based descriptive information to explain complex situations.

In Denmark, urban land administration practices mainly rely on 2D parcel maps. The Danish Law specifies that ownership rights should be established on 2D land parcels, being unlimited in the vertical dimension (Stoter, Sørensen, et al. 2004). The horizontal division of a property is defined by posing restrictions specified in either Private Law or Public Law. Private Law mainly provides the legal basis for registering rights associated with condominium units and their servitudes such as easements. Rights are not explicitly registered in the cadastral system. However, spatial extent of restricted rights is provided in the title document registered in the land registry. Public Law specifies the legal framework for registering public servitudes or properties, which are owned by public authorities, in the land registry organization. Although the current urban land administration system in Denmark has the ability to register legal interests in 3D, it does not provide the capability to visualize spatial extent of legal spaces in 3D digital data environments (Sørensen 2011), which results in communication difficulties for inexpert stakeholders.

In Norway, a parcel-based land administration system has been adopted to define spatial extent of legal interests (Valstad 2006). The apartment rights must always be associated to the land parcel on which the built asset has been developed. The 3D property legal objects are maintained in the administrative section of the cadastral registration. The footprints of these legal objects are delineated in the 2D parcel map. However, there is no geometric information stored regarding 3D spatial extent of vertically stratified legal objects. Although the recently approved Law in Norway provides the framework for registering 3D property objects, there exist technical challenges in terms of representation and management of these objects in 3D digital systems.

In Sweden, registration of stratified legal interests was not allowed in the vertical dimension before January 2004 (Stoter 2004). Therefore, a new law was endorsed to support legal definition of 3D properties crossing over boundaries of land parcels (Paulsson 2007). The land registry organization registers 3D legal interests. However, requirements for sourcing 3D spatial data about these interests are not specified.
Therefore, there is a need to outline the legislative framework for surveying 3D legal interests. This would enable the current urban land administration system in Sweden to integrate 3D spatial information into its current 2D property map base.

In Queensland State of Australia, urban land administration practices rely on four types of 3D legal interests, namely building, restriction, volumetric, and remainder parcels (Stoter 2004). Building parcels are typically defined by referencing physical structures such as ceilings, walls, and floors. Restriction parcels are delimited by specifying a height or depth which is defined by the distance from the Earth’s surface. Volumetric parcels are spatially defined by valid boundary surfaces and, therefore, are not dependent on 2D parcel boundaries. Remainder parcels refers to those parcels remained after subdividing building and volumetric parcels. Although titles include detailed 3D information, there are some issues with 3D property registration in Queensland. The first issue is that 3D information is presented on analogue paper-based plans, which impedes the interactive visualization of 3D legal interests. This would cause difficulties in interpreting boundaries of parcels with complex shapes. Another issue is that 3D legal property objects are only delineated by coordinates and edges on paper plans. Therefore, it is impossible to check the spatial integrity and validity of 3D legal property objects (Karki 2013). The 3D information about vertically stratified legal interests are not integrated with the current property map base and, therefore, the spatial interaction between adjacent volumetric parcels is impossible to be checked.

2.3 Communication Challenges Resulting From 2D Subdivision Plans

This section highlights communication challenges currently experienced in urban land administration as a result of using 2D-based methods of representation. There has been an unprecedented surge in development of multi-storey buildings in urban built environments over the last decades. These buildings are mainly established within inner parts of urban areas, particularly Central Business District (CBD) area. As an example, Figure 2.2 indicates that most new apartment dwellings in City of Melbourne (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 (Birrell and Healy 2013). Therefore, the vast majority of dwelling construction in CoM is currently in the form of high-rise buildings. This example indicates that urban built environments are becoming a more
and more spatially complex urban built environment, which in turn results in the need to define a variety of stratified and intertwined 3D RRR spaces to manage legal ownership of private, communal and public properties.

Legal ownership of properties in urban built environments is delineated and registered using subdivision plans. Land surveyors prepare these plans. They utilize 2D floor plans as well as cross section diagrams to delineate and show legal boundaries associated with private, communal, and public properties. This medium of communication efficiently represents the spatial extent of legal spaces in simple structures such as single-storey buildings with relatively straightforward structural configurations. However, this practice is challenged by the requirements of multi-storey buildings, which are often not only endowed with complex architectural form, but also functional complexity with usage and access of building facilities differentiated amongst various groups of a building’s inhabitants. For example, a multi-purpose building could have various access requirements to support retail, commercial and residential functions. 2D subdivision plans face challenges in communicating spatial complexity associated with boundaries of volumetric legal spaces defined inside those buildings (Aien et al. 2013). These challenges include (Ho 2014):

- Difficulties in accurate representation of boundaries of legal spaces with irregular forms: The first technical challenge associated with delineating
boundaries in building subdivision plans is that the complex reality of legal spaces with interweaving and irregular shapes may not be effectively recorded and managed via 2D paper-based drawings or even 2D digital plans (see Figure 2.3).

- Use of numerous 2D floor plans and cross-section diagrams to fully represent all legal spaces in high-rise buildings: a large number of 2D diagrams results in difficulties in finding the right floor plan and cross section diagrams that, when viewed together, represents the horizontal and vertical boundaries of a specific legal space (Jazayeri et al. 2014). Consequently, interpretation of legal boundaries for each apartment unit in high-rise developments is a time-consuming task. Additionally, although 2D subdivision plans can be functional to some extent, this 2D-based method of representation might be costly because multiple pages of 2D diagrams are used to describe RRR information associated with superimposed properties in high-rise buildings. 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 CoM (see Figure 2.4).

- Problems related to the inaccurate understanding of textual information: 2D subdivision plans usually include textual notations (see Figure 2.5) which are difficult for non-specialized owners, who have limited background in understanding subdivision plans, to read and interpret accurately (Shojaei et al. 2014).

- Representation of 3D RRR spaces spanning several stories of a building: Although multiple 2D plans can represent legal boundaries for properties restricted to one level, utilizing these plans to communicate the legal limits of properties encompassing parts of several levels is a tough task. Many of multi-storey buildings include commonly owned and managed properties (e.g. corridors, stairwells, and gyms). These common property areas typically pass through several building levels, and it is a very challenging task to map boundaries of these areas into 2D floor plans and cross-section diagrams. This challenge is more severe in comparison with previous ones. In Figure 2.6, a common property area, comprising corridors, lobbies, and stairs, of a multi-
storey building is highlighted in red to provide an example of this challenge.

- Ambiguities in the interpretation of legal boundaries defined by building elements: Understanding of some legal boundaries, which are defined by referencing building elements, could be problematic for inexpert stakeholders. For example, in Victoria, Australia, legal boundaries inside buildings are mainly defined by using one of three spatial relationships with its corresponding building element: the boundary touches either interior or exterior face of the building element, or it corresponds to the (virtual) median line of the building element (Libbis 2015). The referenced building elements typically include walls, windows, ceilings, slabs, and doors. These legal boundaries are often denoted by different types of lines in subdivision plans. As shown in Figure 2.7, some boundaries of LOT 1 are defined by referencing interior face of wall, door, and window. These physical structures are not shown in subdivision plans (see Figure 2.7a). This abstraction could potentially lead to misunderstanding of these boundaries by a person without sufficient knowledge to interpret what the lines mean and hence he/she could easily misinterpret the location of the boundary and RRR information. For instance, a non-specialist owner of LOT 1 may misinterpret interior boundaries as exterior ones. Therefore, he/she may think that the full ownership and responsibility of building elements is entitled to him/her, which is not correct in this case.

- Finally, since the data environment of subdivision plans is analogue and static, it is impossible to view the boundaries of legal spaces in an interactive mode (Stoter, van Oosterom, et al. 2004, Döner et al. 2010). This drawback may affect interpretation and understanding of building legal boundaries in complex situations. Moreover, an analogue data environment does not provide the capability to query, find and measure building legal boundaries (Acharya 2011).

To overcome the challenges mentioned above, there has been an increasing trend towards leveraging 3D digital building models in the cadastral domain. Some of these models comprise solely pure geometric information, such as shape, facade, and texture, about building elements, while others also incorporate semantic information which would support a greater range of building information analysis (Kolbe 2009). Open 3D spatial data models or standards lay the foundation for managing and exchanging 3D
building information in an interoperable environment. Some spatial data models have been developed in land administration domain, some others have been developed in geospatial and BIM domain. These spatial data models, except IFC, and their integration will be reviewed in next section.

Figure 2.3: An example of future complex building structures (Arbre Blanc tower, Courtesy of the Nicolas Laisné® Architecte agency)

Figure 2.4: Multiple pages of plans for subdividing legal spaces in high-rise buildings, adapted from (Rajabifard et al. 2014)
2.4 Review of 3D Spatial Data Models

There are two main dimensions of 3D RRR data management in urban land administration: legal data and physical data (Aien et al. 2013, Jazayeri et al. 2014).
Physical data comprises both spatial and semantic aspects of building elements. Legal data refers to ownership attributes as well as the legally defined extent of legal spaces. 3D data models lay the foundation for supporting different spatial data management functions that can be used for querying and analysing 3D RRR data. Among legal data models for 3D RRR data management, the Land Administration Domain Model (LADM), recently endorsed as an international standard, has received significant attention. This is evident in various research papers recently published for the 4th international 3D cadastre workshop (Van Oosterom and Fendel 2014). Various country profiles of LADM have been developed (Pouliot et al. 2013, Felus et al. 2014, Zulkifli et al. 2014). Among physical data models, CityGML, IndoorGML and IFC standards include physical entities required for 3D RRR data management. Researchers have also investigated the integration of legal data models with physical data models to simultaneously manage both legal and physical dimensions of 3D RRR data (Çağdaş 2013, Gózdz et al. 2014, Rönsdorff et al. 2014). Therefore, in the context of urban land administration, 3D spatial data models can be classified into three main categories, namely purely legal data models, purely physical data models and integrated (legal and physical) data models.

2.4.1 Purely legal data models

Most purely legal (cadastral) data models proposed in the land administration domain are mainly developed based on 2D-based representation methods. The issue with this type of representation is inefficient communication of the spatial dimension of complex RRR spaces. In these data models, 2D land parcels usually provide the basic spatial units to map legal boundaries. This mode of communication is efficient for simpler buildings and developments but may not effectively communicate legal boundaries of properties inside complex and vertical urban developments such as high-rise buildings. Therefore, few 3D legal (cadastral) data models have been recently developed in land administration domain. These include LADM and ePlan model. However, these models support the spatial representation of 3D RRR data with limited capabilities.

2.4.1.1 LADM

As an international standard, LADM provides a conceptual and formal language for describing both semantic and spatial information associated with RRR affecting pieces of land or water, buildings, and airspaces (ISO19152 2012b). LADM seeks two main
goals (Lemmen 2012). First, it lays the foundation for effective and progressive design and development of a land administration system for those countries which currently do not have the advanced infrastructure for managing land and property information. Second, LADM attempts to establish a common language to facilitate communication among land administration actors within one jurisdiction or across various jurisdictions around the globe. Three packages, namely Party, Administrative, and Spatial Unit, and one sub package, Surveying and Spatial Representation, constitute conceptual schema of LADM (Lemmen et al. 2015, p. 538) (see Figure 2.8).

The Party package includes entities for modelling information about different land administration actors (LA_Party) as well as their roles (see Figure 2.9). These actors could include human or organizational actors. Owner, surveyor, notary or conveyancer could be examples of roles assigned to actors. The Administrative package comprises two distinct fundamental concepts, namely RRR (LA_RRR) and basic administrative unit (LA_BAUnit) (see Figure 2.10). The RRR concept is specialized into “LA_Right”, “LA_Restriction”, and “LA_Responsibility” which are used for modelling various types of rights, restrictions, and responsibilities respectively. The concept of the basic administrative unit is adopted in LADM to arrange and combine spatial units with the same or homogeneous RRR. In other words, RRR information assigned to a basic administrative unit shall be unique (Paulsson and Paasch 2015). For instance, spatial units of an apartment unit, its car parks, and storage areas can be assembled in one basic administrative unit which represents a privately held property right within a multi-level building.

The Spatial Unit package and its Surveying and Representation sub package are used for modelling spatial dimension of legal objects (see Figure 2.11). The central entity in this package is “LA_SpatialUnit” which is used for modelling the concept of spatial units (Lemmen et al. 2015). This overarching concept includes various spatial representations of legal interests defined inside any jurisdiction. These representations can be textual descriptions, sketch maps, points, unstructured set of lines, areal and volumetric legal objects (ISO19152 2012, p. 82). In the context of 3D RRR data management, there are two specialized concepts of spatial units, namely building units (LA_LegalSpaceBuildingUnit) and utility networks (LA_LegalSpaceUtilityNetwork). Here, a building unit refers to the legal space defined for a building or a part of it, which is not essentially equivalent to the physical representation of the building. Likewise, the
concept of utility networks in LADM represents legally defined spaces of utilities, which do not essentially equate with their physical counterparts.

Figure 2.8: Packages of LADM standard, adapted from (ISO19152 2012, p. 8)

Figure 2.9: Basic entities of Party package, adapted from (ISO19152 2012, p. 9)
The Surveying and Representation sub-package is mainly used to model topology of boundaries defining spatial units (ISO19152 2012b, p. 32) (see Figure 2.12). There are four key entities in this sub-package: LA_Point, “LA_SpatialSource”, “LA_BoundaryFaceString”, and “LA_BoundaryFace”. “LA_Point” is used for modelling points, which would either represent the location of a spatial unit or define a vertex of 2D or 3D boundaries. “LA_SpatialSource” provides information about a set of observations and measurements associated with points. These measurements include
distances, azimuths, GPS coordinates and so on. “LA_BoundaryFaceString” is adopted for modelling the geometry of curve boundaries through its association with “LA_Point” and “LA_SpatialSource” entities. At least two points must define curve boundaries since start and end points of a curve is required in the simplest case. “LA_BoundaryFace” is used to represent the geometry of surface boundaries through its association with “LA_Point” and “LA_SpatialSource” entities. A surface boundary must be defined by at least three points. This is because a triangle is the simplest type of surface boundary and three points are required to form a triangle.

With the above introduction of LADM in mind, a few challenges of this legal data model are highlighted below.

- First, LADM mainly uses a multi-surface approach, which is not as strong as solid models for modelling 3D spatial objects (Pouliot et al. 2013). In the latest version of this legal model, “createVolume()” and volumeClosed()” methods are used to create volumetric spatial units and ensure the closure of the constructed volume, respectively. Although “createVolume()” method is based on “GM_MultiSolid”, there is no entity in “Surveying and Representation” sub-package to define solid models and use them within this method. In addition, “volumeClosed()” only defines Boolean values. However, Eular-Poincaré formula should be considered as a constraint in this method to ensure closure of volumetric spatial units (see Section 3.3.6.2). These reasons imply that LADM does not adequately support solid models to construct geometry of 3D legal objects accurately. In terms of managing 3D RRR data, solid models can facilitate visualization of 3D legal objects and enable precise volumetric
computations and various 3D spatial analyses required in land administration, such as 3D visibility analysis of properties (Jarroush and Even-Tzur 2004, Navratil and Fogliaroni 2014). This type of analysis would enable the use of 3D RRR data for associated applications predicated on physical building attributes that could have legal implications such as valuation and taxation.

- The second issue is that LADM do not include sufficient semantic information about 3D properties. In the context of Australian jurisdictions, boundaries of legal spaces are mainly defined based on physical structures such as walls, doors, windows or ceilings. In LADM, the “LA_BoundaryFace” entity does not distinguish a wall boundary surface from ceiling boundary surface; neither does it specify whether the boundary is located in the interior, exterior face or median of the physical structure (Aien et al. 2013). Such ambiguity in defining various boundaries can be resolved by enriching LADM with more semantic information. Moreover, sufficient semantic information would eliminate spatial data integration issues and facilitate interoperability of land administration systems with other urban information systems.

- The last issue is that LADM mostly includes legal entities and do not internally incorporate physical information. As mentioned above, LADM uses the concept of spatial units as the basis for managing 3D RRR data. While this concept is able to represent volumetric legal spaces explicitly, it does not accommodate those situations where physical elements are used to delineate the spatial extent of 3D RRR spaces (such as in Australia). In response to this issue, LADM provides a limited capability to connect legal objects to their corresponding physical structures via external links. Only, building unit (LA_LegalSpaceBuildingUnit) and utility network (LA_LegalSpaceUtilityNetwork) classes include extPhysicalBuildingUnitID and extPhysicalUtilityNetworkID attributes to link legal spaces of building units and utility networks to their physical counterparts, respectively (ISO19152 2012b, p. 29). This indicates 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 harmonising semantic information (Isikdag et al.)
Transforming geometric information stems from the fact that geometry of physical objects may be defined by an approach which is different to geometry of legal objects. Semantic harmonisation refers to aligning ontology of LADM with physical data models. Even though these geometric and semantic issues are addressed, there might be some inconsistencies in matching 3D legal objects with their physical counterparts (Stadler and Kolbe 2007). This is why LADM should be internally extended with physical entities.

All above factors imply that LADM currently is unlikely to adequately support 3D RRR data management in urban land administration.

2.4.1.2 ePlan model

Australian jurisdictions have adopted both their national and state ePlan data model based on LandXML schema (ICSM 2010). LandXML is an implementation XML (eXtensible Markup Language) schema for managing cadastral information obtained from surveying measurements and observations (LandXML 2014).

The “Parcel” class in ePlan model is used for managing semantic and spatial information about legal interests (see Figure 2.13). Instances of the “Parcel” class can be composed to form a unique legal interest. The “Parcel” class is specialized into “VolumetricLot” subclass to semantically define legal interests with volumetric spatial extent. The “VolumetricLot” entity is associated with the “Volume” entity to define the geometry of 3D RRR spaces (ICSM 2010, p. 29). A volume in ePlan is a cubic space constituted by polygonal objects, which are its faces. These faces can be both regular and irregular polygons (“Polygon” class), and they define boundaries of 3D RRR spaces. A Polygon is a closed figure that can be defined by at least two lines. The lines would be regular lines (RegularLine class), curves (Curve Class) or Irregular lines (IrregularLine class). “SurveyPoint” and “Observation” classes are used to source geometry of lines from surveying measurements (see Figure 2.13).

The issues with the ePlan model are similar to those of LADM. First, this data model does not support solid models for constructing volumetric legal objects. This may cause inconsistencies in terms of topological closure of volumetric legal objects. Another issue is that the “Polygon” class does not include sufficient semantic information about boundary types defined based on building elements. There is no attribute in this class to
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distinguish a wall boundary from a ceiling one. Additionally, an interior boundary cannot be distinguished from median or exterior one and vice versa. In ePlan, the only entity for defining external association is “DocFileRef” which is used for referencing external documents. This indicates that ePlan does not even provide any external linkage between legal objects and their physical counterparts. Finally, the adopted approach for arranging parts of a legal interest utilizes a reflexive relationship (isRelatedTo) (see Figure 2.13), which leads to difficulties in semantically differentiating a specific part of a legal interest from its whole spatial structure. For instance, a corridor space, which is part of the common property area, could be incorrectly queried as the entire common property area in a spatial database implemented based on ePlan model.

**Figure 2.13:** Parcels and volumetric lots in ePlan model, adapted from (ICSM 2010, p. 31)

### 2.4.2 Purely physical data models

Purely physical models are not particularly designed for the purpose of mapping legal arrangements and boundaries within multi-level buildings. However, they can be harnessed or extended for representing and managing legal information. These models usually manage spatial and semantic information associated with physically existent objects in various levels of details. Among physical models in geospatial domain,
CityGML (Groger et al. 2012) and IndoorGML (Lee et al. 2014) standards provide a comprehensive set of entities, some of which could be potentially used for mapping legal interests within indoor environments. Additionally, IFC standard (ISO16739 2013) in BIM domain provides a wide range of spatial entities which can be adopted for cadastral purposes. Below, we will review the relevant parts of purely physical data models, which can be utilized for the purpose of urban land administration.

2.4.2.1 CityGML

In the domain of geographic information systems (GIS), CityGML standard is widely known for interoperable exchange of 3D geospatial data about urban built environment (Gröger and Plümer 2012). As an application schema of Geography Markup Language (GML), CityGML is becoming a widely used and implemented model for the 3D representation of urban built environments. This 3D geospatial standard aims at defining reference ontology for modelling basic entities, attributes and spatial relationships required in a 3D urban information model. In other words, this standard models topological, geometrical, semantical, and appearance properties associated with 3D urban objects. Two basic models underpin the spatial data model of CityGML (Kolbe et al. 2005): geometric model and thematic model. The geometric model provides both geometrical and topological aspects of 3D urban objects in a consistent and homogeneous framework. The thematic model assigns the geometric model to various thematic urban objects such as buildings, bridges, vegetation, land use, water bodies, transportation facilities, and so on (see Figure 2.14).

![Figure 2.14: An overview of CityGML modules, adapted from (Groger et al. 2012, p. 19)](image-url)
Five Levels-of-Detail (LoD) are distinguished in the CityGML standard to represent 3D urban objects (Gröger and Plümer 2012). Higher LoDs provide more detailed information about 3D city models. The concept of LoD includes both geometric and semantic information. Figure 2.15 represents the concept of LoD to demonstrate how 3D spatial information about buildings is defined within each LoD. LoD0 provides the least detailed information and only defines 2.5D geometry, in which only one height value is defined for each (x,y) coordinate. LoD1 defines urban objects in terms of generalized 3D models as prismatic block models. LoD2 represents the shape of building roofs and walls as well as other structures like dormers and balconies. LoD2 also represents objects for vegetation with more details and it also distinguishes the surface of the water from water ground surface for solid water bodies. In LoD3, the outermost shape of urban objects has the highest level of detail. Very detailed 2.5D surfaces are used to show transportation and land use objects. In addition, vegetation shape, water body, and building objects are shown with detailed aspects. For buildings, bridges, and tunnels, openings are also added as thematic objects in LoD3. LoD4 includes interior structural and architectural elements such as interior walls, furniture, and rooms.

![LoD0, LoD1, LoD2, LoD3, LoD4](image)

Figure 2.15: A building object represented in various LoDs of CityGML standard, adapted from (Gröger and Plümer 2012, p. 16)

Relevant to modelling 3D RRR spaces, the geometry of 3D spatial objects in CityGML standard is developed based on a GML profile. GML, and consequently CityGML, currently uses the boundary representation (B-rep) approach for creating solid models. B-rep provides complete information for adjacent topological relationships (Kolbe 2012); however, constructing B-rep based solid models from the vertex-edge-face database is computationally time-consuming (Nasr and Kamrani 2007). While Constructive Solid Geometry (CSG) is another solid modelling approach that is more
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user-friendly and can facilitate constructing complex 3D RRR spaces (Peres and Benhamu 2009); however, CityGML currently does not support CSG solids (Nagel et al. 2009).

The finest level of detail (LoD4) in CityGML currently provides some data elements for defining physical boundaries of 3D RRR spaces. The potential entity for modelling 3D RRR spaces in CityGML is “Room class” (see Figure 2.16). The boundaries of “Room” are semantically determined through the “boundedBy” relationship (Groger et al. 2012). Currently, this relationship only refers to interior and exterior wall boundaries (InteriorWallSurface and WallSurface classes), and interior and exterior slab boundaries (GroundSurface, FloorSurface, CeilingSurface, OuterFloorSurface, OuterCeilingSurface, and RoofSurface classes). There is no semantic entity for defining median wall and slab boundaries, which is often used as a type of building legal boundary. For openings, such as doors and windows, there is no direct semantic relationship which defines the “Opening” class as a boundary of Room class. Sometimes, columns are used as physical boundaries, especially in parking areas, between legal spaces. In CityGML, “IntBuildingInstallation” class is used for modelling columns inside buildings. This class is associated with “Room” class via a “roomInstallation” relationship, which means that a legal space (an instance of “Room”) may contain a column (an instance of “IntBuildingInstallation”) or reference another column elsewhere in the building. This implies that containment or reference, rather than boundary relationship between legal spaces and columns, is defined.

In essence, the core module of CityGML is a physical model of 3D urban objects. Nevertheless, many 3D urban applications necessitate extending the feature types, attributes, and relations for a particular purpose. In light of this, there is an extension mechanism in CityGML, which is known as Application Domain Extension (ADE) (Kolbe 2009). An ADE is an application schema for CityGML and it is defined in another XML namespace. New types of features are proposed in each ADE, and these features could be subtypes for existing feature types. Moreover, existing feature types can be enriched by incorporating new geometries, attributes, and associations. In Section 2.4.3, investigations harnessing ADE mechanism for modelling legal objects inside CityGML will be explored.
2.4.2.2 IndoorGML

The IndoorGML standard has recently been developed for modelling indoor 3D spatial information required for navigation purposes inside buildings (Lee et al. 2014). The basis of this standard is underpinned by two conceptual frameworks, namely Structured Space Model (SSM) and Multi-Layered Space Model (MLSM). As illustrated in Figure 2.17, SSM specifies the spatial layout of the indoor environment, which is independent of its semantic interpretation. SSM defines two distinct types of spaces: primal and dual ones. The primal space defines the geometry and topology indoor subdivided spaces. The dual space includes a Node-Relation Graph (NRG) induced
from primal space by applying the Poincaré duality (Munkres 1984). This graph models adjacency relationships between indoor spaces and provides the navigation network within indoor environments. MLSM is a combination of multiple space layers of SSM, each of which specifies a distinct semantic interpretation of indoor environment for a specific application. For instance, an MLSM could include a topographic space layer, a Wi-Fi sensor space layer, and a RFID sensor space layer. MLSM also defines interrelationships between space layers (see Figure 2.18).

![Figure 2.17: Structured Space Model used in IndoorGML, adapted from (Lee et al. 2014, p. 24)](image1)

![Figure 2.18: Implementation of Multi-Layer Space Model within IndoorGML, adapted from (Lee et al. 2014, p. 28)](image2)

IndoorGML standard is mainly concentrated on defining cellular spaces and their topological relationships. This standard may not provide detailed semantic and spatial information about 3D indoor objects. However, it provides a mechanism to externally incorporate this information from rich spatial data models such as CityGML and IFC.
For instance, “CellSpace” entity could be defined by “Room” in CityGML or “IfcSpace” in IFC, while “_BoundarySurface” in CityGML or “IfcRelSpaceBoundary” in IFC can be utilized for modelling “CellSpaceBoundary” entity in IndoorGML.

Similar to CityGML, IndoorGML is developed based on GML. IndoorGML is also only supporting B-rep solid modelling approach. In cases where the geometry and semantic of spatial objects in IndoorGML are defined based on IFC, there could be a geometric transformation challenge. This is due to the fact that geometry of IFC objects may be defined by other solid models such as CSG or swept solids. Another challenge is that IndoorGML does not provide the capability to arrange and group indoor space objects (instances of “CellSpace” entity) into a spatial zone or structure. For example, there is no support to associate an apartment space with its parking and storage spaces.

Despite above challenges, there could be two alternatives to investigate the use of IndoorGML in the urban land administration domain (Zlatanova, Oosterom, et al. 2016). One option is to define a new cadastral space layer inside IndoorGML standard. The core module of IndoorGML includes “CellSpace” and “CellSpaceBoundary” entities which describe space objects and their boundaries respectively. These entities could potentially be extended with cadastral information to assign legal rights to indoor spaces. Another solution could be defining an external linkage between IndoorGML and existing 3D cadastral standards. For instance, Zlatanova et al. (2016) have recently investigated the possible synergies between IndoorGML and LADM (Land Administration Domain Model) and found that the concept of spatial units within LADM can be linked to “CellSpace” entity in IndoorGML. This will be investigated in more detail in Section 2.4.3.5.

2.4.2.3 IFC

The Industry Foundation Classes (IFC) standard has been developed as an open and vendor neutral data model to facilitate interoperability across multiple BIM platforms (ISO16739 2013). The IFC standard is object-oriented and comprises a comprehensive set of entities for managing spatial and semantic information about building elements as well as modelling spatial relationships between these elements (Daum and Borrmann 2014). In this section, spatial structure of this standard is only reviewed. The comprehensive review of this standard and its use in urban land administration will be provided in Chapter 3.
The IFC standard uses a hierarchical spatial data model to manage building objects that have a geometric representation or spatial extent (see Figure 2.19). The “IfcProduct” is the most abstract super class in the spatial hierarchy of the IFC standard. It has two subclasses, namely “IfcElement” and “IfcSpatialElement” (Liebich 2009). The former one is the super class of IFC entities used for modelling physically existing elements such as building elements (IfcBuildingElement), and geographic elements (IfcGeographicElement). The latter one is the super class of two entities defining the spatial arrangements within an IFC file. The first one is “IfcSpatialStructureElement” which is a generalization of the elements defining spatial structure of a building project. These elements include the site (IfcSite), buildings (IfcBuilding), building storeys (IfcBuildingStorey), and internal spaces (IfcSpace). The second entity is “IfcExternalSpatialStructureElement” which is the abstract super class for “IfcExternalSpatialElement” which models various types of external spaces, regions, and volumes.

![Figure 2.19: Generalized spatial structure of the IFC standard](image)

### 2.4.3 Integrated data models

The reason for developing integrated data models is that some jurisdictions, such as those of Australia, define arrangements of legal interests within multi-level building developments using both physical structures and cognitive communal spaces. For instance, common properties in Victoria typically consist of not only communal spaces, such as corridors, lobbies, and gym, but also building elements such as walls between two individually owned legal spaces, walls between an individual space and a
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communal space, and ceiling between two levels of a multi-storey building. Physical data models, such as IFC or CityGML, usually provide their own extension mechanism for incorporating legal objects, whereas legal data models, such as LADM, can be connected to physical objects through external linkages. There are various investigations on integrating legal and physical data models, which will be reviewed in the following subsections. Those investigations that adopted IFC in urban land administration will be separately reviewed in Chapter 3.

2.4.3.1 Integrating CityGML and LADM

Proposed approaches for integrating CityGML and LADM mainly suggest that ADE mechanism can be considered as the appropriate approach to mapping LADM into CityGML schema.

Rönsdorff et al. (2014) proposed two options for constructing an LADM-based ADE for CityGML standard. The first alternative is to create a jurisdiction-specific profile of LADM and then implement this profile of LADM as an ADE of CityGML. The second option is to directly implement the fundamental concepts inside LADM, without customizing them for a specific jurisdiction, as an ADE of CityGML. While the latter option was investigated by Rönsdorff et al. (2014), other investigators have explored the former one in the context of different jurisdictions worldwide (Gózdz et al. 2014, Li et al. 2016).

The general LADM-based ADE proposed by Rönsdorff et al. (2014) comprises three feature classes, namely “Parcel”, “LegalSpace”, and “LegalSpaceGroup”. These classes were implemented based on “LA_BAUnit”, “LA_SpatialUnit”, and “LA_SpatialUnitGroup” concepts in LADM, respectively (see Figure 2.20). In order to semantically define the RRR information associated with “Parcel” class, this class was externally linked to “LA_RRR”. The advantage of this integration CityGML and LADM is that it provides the possibility to link physical and legal object using allowed extension mechanism in CityGML and without modifying data structure of LADM. However, this investigation did not give any details in regards to linking relationships between legal spaces and buildings or building parts.
One jurisdiction-specific implementation of LADM-based ADE of CityGML was conducted by Gózdz et al. (2014) within the context of Polish cadastre (see Figure 2.21). This investigation defined links between legal and physical spaces of buildings. For managing 3D legal spaces, this ADE proposed “PL_3DParcel” and “PL_LegalSpaceBuilding” classes which are specializations of “LA_SpatialUnit” and “LA_LegalSpaceBuildingUnit” (from LADM). For modelling physical objects two classes were introduced: PL_building (as a subclass of “Building” in CityGML) and PL_BuildingPart (as subclasses of “BuildingPart” in CityGML). In order to link legal objects to their physical counterparts, association relationships between the proposed legal classes and “_AbstractBuilding” class (from CityGML) were also defined within the ADE. This study found that CityGML standard does not support those elements which are equivalent to non-spatial entities of LADM such as parties (LA_Party), basic administrate units (LA_BAUnit) and RRR information (LA_RRR). Therefore, these classes were also defined within the proposed integrated model. The feasibility of this LADM-based ADE was tested using three case studies, namely a building located above another development, a residential building located on above a public road, and a detached townhouse located on the land parcel. However, all of these implemented case
studies were developed in LOD0 and LOD1 of CityGML, and other higher LODs (LOD2 – 4) were not considered in the implementation.

More recently, another LADM-based ADE of the CityGML was developed and implemented by Li et al. (2016) for Chinese jurisdiction. This ADE includes two separate hierarchies, namely legal hierarchy (represented in yellow in Figure 2.22) and physical hierarchy (represented in light blue in Figure 2.22). With respect to the spatial structure of condominium units defined in Chinese jurisdiction, the physical hierarchy comprised three subclasses of “_AbstractBuilding”, which are “Major-Body”, “Annex”, and “Shared-Object”. “Major-Body” models the representation of the main part of a private legal space. The legally defined spatial extent of a major body is equivalent to its physical extent. “Annex” entity models those building parts which are used by a specific group of condominium units. This entity also provides information about the gross area, construction area and function of annexes (such as a balcony). “Shared-Object” refers to those building parts that are commonly owned and used by all owners of condominium units. Similarly, this entity also provides three attributes, namely gross area, construction area and function (such as staircase or elevator). The legal hierarchy includes two main classes for modelling legal objects: “Building-Use-Part” and “Condominium-Unit”. The former is the subclass of “LA_LegalSpaceBuildingUnit” class within LADM, while the latter is a specialization of “_CityObjectGroup” class defined inside the thematic extension module CityObjectGroup of CityGML. “Building-Use-Part” was designated for modelling subdivision spaces of a building from an administrative or legal aspect. There are two subclasses of “Building-Use-Part” (see Figure 2.22):

- Exclusive-Object: This subclass models an individually owned property unit as well as associated information such as exclusive construction area, construction area of major body, and construction area of major body.
- Fraction-Of-Apportionable-Object: It models the virtual elements constituting an apportionable object. There are two attributes within this entity. One attribute is a fraction, which provides the proportion of the element to the whole apportionable object that it is part of. Another attribute describes the construction area of the element.
The “Condominium-Unit” entity models the legal extent of part of a building, being associated with an individual legal interest. This class is the aggregation of “Exclusive-Object” and “Fraction-Of-Apportionable-Object”. This proposed ADE was implemented for two multi-storey buildings, one with purely residential function and another with mixed commercial and community management functions.

Two major challenges were identified with the integrated data models reviewed above:

- Data conversion challenges: The major challenge with the integrated data models reviewed above is that they link CityGML and LADM through external connections. This means that data is integrated from two heterogeneous databases, which results in two main challenges: geometric conversion and semantic harmonization (Isikdag et al. 2008). The geometric conversion stems from the fact that CityGML utilizes B-rep solids to create 3D physical objects whereas LADM adopts multi-surface geometry to model 3D legal objects. Semantic harmonisation indicates appropriate communication of relevant intelligent data from CityGML to LADM or vice versa.

- Insufficiency in defining semantic connectivity between legal spaces and physical elements: This challenge indicates the reviewed integrated data models also did not provide semantic information about one-to-one spatial relationships between legal objects and their counterpart physical boundaries. For example, a one-to-one spatial relationship between a legal space and a wall boundary was not modelled.
Figure 2.21: An LADM-based ADE of CityGML for Polish Cadastre, adapted from (Gózdz et al. 2014)
Figure 2.22: An LADM-based ADE of CityGML for modelling spatial structure of condominium units in Chinese jurisdiction, adapted from (Li et al. 2016)
2.4.3.2 CityGML and ePlan

Soon et al. (2014) proposed a Web Ontology Language (OWL) for LADM to overcome semantic harmonization challenges in integrating CityGML with the ePlan model. For this integration, the LADM OWL ontology was extended with two new concepts, namely Physical Space Building Unit and Physical Space Utility Network and one new relationship: hasLegalSpace. In this ontology, Physical Space Building Unit was considered as the equivalent to the “_AbstractBuilding” class of CityGML. This is because the physical structure of buildings is defined by the “_AbstractBuilding”. By considering this equivalence and hasLegalSpace relationship between Physical Space Building Unit and Legal Space Building Unit in the LADM OWL ontology, a physical object (building or a part of it) defined within CityGML can be associated with its legal space. As illustrated in Figure 2.23, Spatial Unit and Legal Space Building Unit entities within the ontology were also defined as the equivalent concepts with “Parcel” and “BuildingFormatLot” from ePlan model, respectively. The investigation showed that realization of the proposed linkage between the CityGML and ePlan model could be done via referencing ExternalReference element in the CityGML and DocFileRef element in the ePlan model. However, this proposed framework remains conceptual and is yet to be further implemented and tested for real case studies.

Figure 2.23: Linking CityGML and ePlan via an LADM OWL ontology, adapted from (Soon et al. 2014)
2.4.3.3 **Other CityGML extensions for urban land administration**

In addition to the LADM-based ADEs reviewed in Section 2.4.3.2, a few researchers have recently proposed other legal ADEs of the CityGML standard for urban land administration.

One of the earliest investigations was by Dsilva (2009) who did a simple extension of a building model in CityGML with legal (cadastral) information from a Dutch jurisdiction. This extension comprised two parts. The first part includes legal attributes appended to the “_AbstractBuilding” class, such as building owner, the building registration number, the parcel number of the building, and the building type. The second part contains a new class called “_KadasterApartment” which is particularly used for managing legal information associated with each individual apartment, such as the ownership right, the apartment owner, the ownership type and the number of inhabitants within the apartment. However, Dsilva’s investigation was not sufficient to semantically distinguish land parcels as well as various legal arrangements - such as individually owned and communal properties - defined inside buildings.

Therefore, Çağdaş (2013) developed a more comprehensive extension of CityGML, which encompassed entities used for modelling cadastral parcels and condominium units in the context of Turkish jurisdictions. This extension mainly proposed three new classes, namely the abstract “PropertyUnit” class and instantiable “CadastralParcel” and “CondominiumUnit” classes. The “PropertyUnit” class includes the ownership and taxation information required for any type of property unit. In addition to inheriting attributes of “PropertyUnit”, the “CadastralParcel” has its distinct attributes, such as the number, area, and value of the parcel, required for managing land parcels. Additionally, the spatial extent of “CadastralParcel” is defined through its inheritance from “LandUse” class. The “CondominiumUnit” class is used for modelling individually owned properties inside buildings, and it has its specific legal attributes such as owner’s name, the taxpayer, party share, tax type and so on. This class has composition relationship with “Join Facility” and “Annex” classes, which are respectively used for modelling unlimited and limited commonly owned properties. Unlimited commonly owned properties are for the use and benefit of all owners, whereas limited ones must be used by a specific group of owners. The proposed extension by Çağdaş has been
recently modified and adopted in OGC’s land and infrastructure (LandInfra) conceptual standard (Scarponcini et al. 2016).

2.4.3.4 LandInfra

LandInfra conceptual model was developed to model information about land and infrastructure facilities (Scarponcini et al. 2016). The implementation of LandInfra model is currently under development as InfraGML encoding standard. This OGC standard comprises a number of requirement classes used for modelling facilities, projects, alignments, roads, rails, surveys, land subdivision, and wet (including storm drainage, wastewater, and water distribution systems) infrastructure. In different parts of this standard, some concepts from LADM and LandXML were adopted for modelling legal objects, while some IFC and CityGML entities were utilized for modelling physical objects. Relevant to modelling legal interests, there are two requirements classes in LandInfra:

- **LandDivision**: This includes both administrative (which is defined by “AdministrativeDivision” entity) and cadastral subdivision (legal interests which are defined by “InterestsInLand” entity) of land. “PropertyUnit” class, which is defined as a subclass of “InterestsInLand”, a generalized entity for modelling an individual unit of ownership. In addition, this entity equivalent to the concept of basic administrative unit defined in LADM.

- **Condominium**: It models the concurrent legal interests within buildings, which are mainly private and common properties (see Figure 2.24). Concepts within this requirement class are predicated on the immovable property taxation ADE of CityGML (Çağdaş 2013).

Similar to LADM and ePlan model, one issue with LandInfra is that it only models geometry of boundaries of legal interests and does not distinguish semantic of boundary faces. Another problem is that its implementation standard (InfraGML) only supports B-rep solid models, not other types of solid models such as CSG. This standard only considers physical objects (BuildingParts) for defining condominium units. For other legal interests and land parcels, LandInfra relies on the purely legal concept of spatial units acquired from LADM standard. Another issue is that the shape and location of BuildinParts, which are physical concepts acquired from CityGML, are defined based on LADM’s spatial unit, which is a legal concept (see Figure 2.24). These issues may
stem from the fact that LandInfra is still in early stages of its development and currently does not have enough capacity to model spatial complexity inherent in 3D RRR spaces.

**Figure 2.24: Condominium context diagram, adapted from (Scarponcini et al. 2016, p. 209)**

### 2.4.3.5 Linking IndoorGML and LADM

As mentioned in Section 2.4.2.2, there are two alternatives to link IndoorGML and LADM and assign RRR information to indoor spaces.

The first method is to develop an LADM-based extension module for IndoorGML. IndoorGML comprises a core module as well as extension modules (Zlatanova, Li, et al. 2016, p. 322). Figure 2.25 shows the proposed LADM-based extension of IndoorGML. This approach appears to be straightforward and easy to understand since “LA_SpatialUnit” entity, which is acquired from LADM, can be considered as the subclass of “CellSpace” entity within IndoorGML. Therefore, besides inheriting
characteristic of general space objects in IndoorGML, the defined “LA_SpatialUnit” entity defined within the LADM-based extension module can have its own attributes for managing legal information. Moreover, other important legal entities (LA_BAUnit, LA_RRR, and LA_Party) acquired from LADM were also defined within the extension module.

The second method is to define an external linkage mechanism to associate IndoorGML entities with LADM entities or vice versa (Zlatanova, Li, et al. 2016, p. 325). This approach relies on the fact that IndoorGML provides rich 3D physical (or topographic) information about indoor environments. Since 3D legal spaces should reference physical objects for better understanding and orientation, IndoorGML cells can be externally linked to building units (LA_LegalSpaceBuildingUnit) via extPhysicalBuildingUnitID attribute. Through this linkage, IndoorGML cells can be used to define geometry of legal spaces. However, this approach requires a number of complex spatial computations such as 3D buffer analysis, partitioning wall/ceiling spaces to define median boundaries, and aggregation of room spaces of an apartment to
form its spatial unit. Applying such complex and 3D spatial analyses still needs to be investigated and elaborated using real-world case studies.

### 2.4.3.6 3D cadastral data model (3DCDM)

As proposed in Aien (2013), 3DCDM is an integrated data model managing both physical and legal dimensions of 3D RRR spaces. This model comprises two hierarchies, namely physical and legal ones (see Figure 2.26). Components constituting the physical hierarchy of 3DCDM are PhysicalPropertyObject, Building, Land, Tunnel, UtilityNetwork, and Terrain. The legal hierarchy is composed of four main components: LegalPropertyObject, Survey, CadastralPoint, and InterestHolder.

![Figure 2.26: An overview of legal and physical hierarchies in 3DCDM, adapted from (Aien 2013, p. 208)](image)

Although 3DCDM was a good trial for integrating legal and physical objects, some issues with this data model have been identified:

- 3DCDM utilizes both multi-surface and solid models for modelling the geometry of 3D spatial objects. However, the geometry of spatial objects in 3DCDM is developed based on a GML profile, 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.
• Although 3DCDM was applied to a simple case study, which was a two-storey building comprising three units, one common property, and one easement, for proving its feasibility, this model has not yet been implemented for modelling a complex building in a real case study scenario. This may question the capability of this data model in managing complex RRR spaces.

• The “LegalPropertyObject” class is a generalized definition of legal objects (Aien 2013, p. 222). Spatial arrangements of legal objects are different from each other. For example, a strata lot is composed of legal spaces, while a common property area can be defined by arranging legal spaces and physical structures (such as walls and ceilings) into its whole spatial structure. Therefore, “LegalPropertyObject” entity should be specialized into specific subclasses to semantically distinguish legal objects from each other.

• The association between legal property objects (LegalPropertyObject) and physical property objects (PhysicalPropertyObject) is a very general one (Aien 2013, p. 219). In practice, relationships between legal objects and physical objects are defined specifically. For instance, in subdivision plans, it is typically stated that what type of physical structures belongs to a common property area.

• Another issue is that semantic entities for modelling boundaries referencing structural elements (“_BoundaryType” entity and its subclasses) within the legal hierarchy are redundant ones (Aien 2013, p. 221). The reason is that semantic entities for structural elements were already defined within the physical hierarchy (Aien 2013, p. 236). Therefore, instead of constructing such redundant entities, the “BoundedBy” association relationship of “LegalPropertyObject” entity could have been linked to “_StructuralComponent” class, which is the abstract superclass for modelling structural elements, within the physical hierarchy. This would lead to a more simplified approach to modelling connectivity relationships between legal objects and physical elements.

2.5 Chapter Summary

In this chapter, an overview of urban land administration in an international context and current challenges in urban land administration were reviewed. Two main categories of challenges were identified, namely communication and management ones. Communication challenges indicated that 2D plans currently used in building subdivision practices are difficult to be understood by the general public, which would
lead to misinterpreting and misunderstanding of the spatial extent of 3D RRR (legal) spaces. Data management challenges were identified by reviewing purely legal and purely physical spatial data models and their integration. These challenges are summarized as:

- **Purely legal data models:** LADM and ePlan model do not include sufficient semantic information to distinguish a wide of range legal boundaries defined within a jurisdiction. For example, there is no attribute to differentiate an interior boundary from an exterior one or distinguish a wall boundary from a door boundary. Another issue is that purely legal data models mainly do not support solid models which would be useful for creating valid volumetric spatial objects and, consequently, performing spatial computations on those objects.

- **Purely physical data models:** CityGML and IndoorGML mainly support B-rep based solid models and other types of solid models, such as CSG, are not supported. IndoorGML itself does not provide any semantic information about location (interior, median or exterior) of structural boundaries, although it was notated within the standard that this information could be acquired from IFC or CityGML. CityGML does not support median boundaries.

- **Integrated data models:** These data models mainly developed at a conceptual level and they have not been implemented in complex case study scenarios to prove their viability for modelling complex RRR spaces. Additionally, these models integrate legal and physical objects at general levels and do not provide specifics of relationships between legal spaces and physical elements.

In this chapter, IFC standard, which is a purely physical data model, was also briefly reviewed. Since the main focus of this thesis is mainly on adapting BIM for urban land administration, in next chapter a more comprehensive review of relevant BIM investigations in the context of urban land administration will be presented.
CHAPTER 3

BUILDING INFORMATION
MODELLING FOR LAND ADMINISTRATION
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3 Building Information Modelling for Land Administration

3.1 Introduction

The long-established paradigm within the AEC industry has been mainly predicated on using document-centric methods to store, manage and exchange geometric and semantic information during the development process of a built asset. The exchanged documents among AEC actors typically include 2D-based and sophisticated methods of representing building information. These documents are difficult to be understood by other stakeholders with limited background. Therefore, this paradigm has led to the fragmentation of the AEC industry regarding unexpected project costs, delays, disputes, and so forth.

Advancements in techniques for 3D digital modelling have accelerated the production of 3D physical models of buildings and other urban infrastructure worldwide (Becker et al. 2013). These 3D models have proliferated in different formats and levels of detail (Hammoudi 2011, Kolbe et al. 2011).

Among 3D building models, the most comprehensive and intelligent 3D digital approach to managing information during the lifespan of complex and multi-level buildings is Building Information Modelling (BIM). BIM paradigm has been developed to facilitate communication and collaboration over the course of a building lifecycle (Singh et al. 2011). Industry Foundation Classes (IFC) is the underlying open schema (or data structure) for storing and managing building information within the collaborative environment of BIM (ISO16739 2013).

Since BIM is a very new topic in the domain of land administration, some readers may not be familiar with its concepts. Therefore, the aim of this chapter is to provide a general introduction of fundamental concepts behind the paradigm of BIM and elaborate its importance in land administration domain. Moreover, IFC standard and its relevant entities for urban land administration were described. This would help those readers with limited background in BIM and IFC standard to understand subsequent contents of this thesis. The chapter also provides the justification for choosing IFC
standard as opposed to other 3D spatial data models, particularly CityGML.

### 3.2 BIM

The basis of the BIM-based paradigm is underpinned by two related computer-based models, namely Computer Aided Design (CAD) models, and building product models (Isikdag 2015, p. 1). CAD models comprise a purely geometric representation of building elements in either 2D or 3D. This implies that these models only include sets of polylines and polygons to describe building elements. There is no semantic, functional or intelligent information about building elements stored in CAD models. In response, building product models have been developed to manage both semantic and geometric information about building products (Eastman 1999). These models utilized STEP (STandard for Exchange of Product model data) as a formal standard to enable sharing product data (Pratt 2001). Over the last decade, there have been significant developments in graphics of computers in terms of rendering and manipulating 3D models. Consequently, there has been a considerable trend towards leveraging building product models, resulting in the appearance of BIM-based paradigm in the AEC and facility management industries.

#### 3.2.1 Process and product perspectives on BIM

The widely-used acronym BIM refers to two distinct but closely linked concepts, namely product and process. As a process, BIM (Building Information Modelling) is an approach to creating, managing, deriving and sharing building information among different AEC actors involved in various phases of the building development process to facilitate collaboration and communication among these actors (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). BIM products provide efficient spatial representation and communication of architectural as well as structural elements inside complex buildings (NBIMS 2012). There are multiple actors involved in the development of buildings, such as architects, civil engineers, MEP (Mechanical, Electrical, and Plumbing) engineers, and builders. Each actor can create and use their distinct BIM product. Throughout design and construction phases of the BIM process, these distinct products can be assembled in a
common data environment which provides a complete model of the building (Bazjanac 2006) (see Figure 3.1). This complete model can be subsequently used by owners or facility managers for the purpose of operating and maintaining the building over the post construction period.

Figure 3.1: BIM: process and product perspectives

The main characteristics of a BIM product are (Isikdag et al. 2007, Isikdag 2015, p. 3):

- Object-oriented: Data stored in BIM models is based on object-oriented data structures. These data structures provide the capability to query and analyse BIM models for different applications.
- Information richness: BIM models include a rich data repository comprising both spatial and semantic information about a wide range of building elements.
- Multi-dimensional: BIM models include not only 3D visualization of building components in three dimensions but also manage other dimensions, such as time and cost, over the lifespan of a building.
- Spatially linked: A wide range of spatial relationships between building elements such as connectivity, containment, and hierarchical aggregation, can be supported by BIM models.
• Extensibility: The open IFC standard and proprietary BIM authoring tools, such as Revit, provide extension mechanisms for enriching BIM models with additional data elements, which do not exist in the BIM model, to manage information required in any domain.

• Generation of model views: A subset of BIM model can be extracted to meet requirements of a specific group of AEC actors. These subsets are known as model views, and they can also be aggregated to form a combined model view.

3.2.2 Benefits and challenges of BIM in the AEC industry

Within the AEC industry, BIM has had a significant impact on resolving issues associated with 2D drawings or even 3D CAD models (Mihindu and Arayici 2008, Arayici et al. 2011). A brief review of these benefits are presented below (Ballesty et al. 2007, Azhar 2011):

• Accurate representation of complex buildings: One of the key advantages of BIM is that it can provide an accurate representation of the geometry of various parts of complex buildings within an interactive and integrated data environment.

• Accelerating development process of buildings: Since BIM environment facilitates sharing and reusing building information, building development actors can easily collaborate with each other, which would, in turn, increase the speed of design and construction.

• Facilitating design tasks: Proposed designs for buildings can be faster evaluated in terms of performing and benchmarking simulations and analyses. For example, BIM environment would improve “Daylighting” analysis of a building development. This analysis would help to develop more enhanced and innovative design proposals.

• Costs and time savings: According to an investigation conducted by Centre for Integrated Facilities Engineering at Stanford University (Gao and Fischer 2008), the unbudgeted change in construction projects can be eliminated up to 40 percent through the adoption of BIM-based paradigm. In addition, the accuracy of estimating costs is around 3 percent, which is more accurate in comparison with traditional methods of estimations. The time spent to estimate costs of the project can be reduced up to 80 percent. Moreover, the time to complete each
project was reduced up to 7 percent.

More recently, Barlish and Sullivan (2012) suggested a valid framework or baseline comprising two main categories of metrics for measuring the potential benefits of BIM in AEC projects. The first category is the return metrics, namely change orders, RFIs (Requests for Information) and schedule. The second category is investment metrics including design costs and contractor costs. These metrics were measured using three real-world case studies. Their main finding was that benefits and cost savings of BIM paradigm outweigh its up-front cost and risk of rework over the extended period of time. It was also found that BIM paradigm relies on various factors to be successful in AEC projects (Barlish and Sullivan 2012). Some important factors include project size, proficiency of staff members in BIM, communication of the project team, as well as other organizational external factors. These factors indicate that success of BIM-based paradigm differs from a project to another one. Finally, it was argued that the full potential of BIM-based paradigm has still not been realized, which stems from the fact that there is no sufficient business case of this paradigm for AEC actors (Barlish and Sullivan 2012).

Bryde et al. (2013) indicated that the most frequently stated benefit of BIM-based paradigm is cost and time reduction as well as enhancing control of tasks and activities over the lifecycle of AEC projects. Other benefits reported were communication improvement and coordination enhancement (Bryde et al. 2013). Communication improvement indicates that finding specific information is much easier in integrated data environment of BIM compared to the fragmented environment of traditional 2D drawings. Additionally, the changes in BIM models are better communicated to the owners. Coordination enhancement implies that using BIM would improve workflows and would facilitate integrated design strategies and enable Integrated Project Delivery (IPD).

Although BIM brings many benefits for productivity within the AEC industry, some challenges associated with adoption of BIM need to be still addressed. These challenges can be classified into two main categories, namely institutional and technical ones (Azhar 2011). One institutional challenge is to resolve issues associated with ownership of data in BIM environment, which requires the protection of BIM data via
copyright laws or similar legal channels (Bryde et al. 2013). For instance, if the owner buys the design model, he/she may think that complete ownership of this model is entitled to him/her. However, there might be some proprietary information, within the model, which is entitled to the design team. This proprietary information must be protected when owners use the model in the project. There is no straightforward solution for resolving issues associated with ownership of BIM data and it may differ from one project to another one in accordance with the requirements of project participants (Azhar 2011). One possible solution to avoid copyright issues could be clearly specifying various rights associated with the ownership of BIM data inside the contract documents (Rosenberg 2007). Another legal matter is to determine a responsible party for controlling the accuracy of the data (Thompson and Miner 2006). Updating BIM data and monitoring its accuracy is inevitably associated with taking risks. This issue results in spending more time on preparing and versioning BIM data, which can be considered as a new cost over the development process of the project. Although this cost will be compensated by efficiency gains, it is still a cost that will be incurred within the project. Before full implementation of a BIM-based paradigm, these institutional issues should be appropriately identified.

Bernstein and Pittman (2004) specify three broad categories for technical challenges of a BIM-based paradigm, namely transactional business process evolution, computability of digital design information, and meaningful data interoperability. Transactional business process evolution indicates that there is a need to define appropriate business process models to facilitate data integration within BIM environment. Computability of digital design information indicates the capability of BIM environment to automatically compute various quantities (such as measuring volumes and areas of spaces or rooms defined within the model) from digital data. Therefore, there is a need to move from pictorial BIM products to the computable ones. The most important technical 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 organisation therefore developed the IFC standard to promote interoperability between BIM tools (Liebich 2013).


3.3 IFC Standard

IFC is an open BIM data model which includes physical, spatial and semantic entities describing the whole lifecycle of buildings. As indicated in Figure 3.2, the schema of the IFC standard is modular and includes four main conceptual layers, (ISO16739 2013), namely resource layer, core layer, interoperability layer, and domain layer. Each layer of IFC comprises several subschemas.

![Figure 3.2: Modular structure of IFC standard, adapted from (ISO16739 2013)](image)

3.3.1 Resource layer of IFC

The resource layer is the lowest layer in the conceptual data schema of the IFC standard. This layer includes subschemas which hold basic concepts and generic entities (ISO16739 2013) (see Figure 3.3). Resource level entities cannot exist independently, and their existence is dependent on using them as value type of attributes in higher level entities which are derived from “IfcRoot” class. The subschemas relevant to the scope
of this research are explained below (BuildingSMART 2013a):

- **Actor Resource**: This subschema provides the capability to model information about actors, including people and organizations, which are associated with various tasks and activities (ISO10303-41 2005). Additionally, relationships between individuals and their organizations and relationships between two organizations are also defined within this subschema to support hierarchical institutional structures.

- **Approval Resource**: This subschema includes the fundamental concepts required in approval processes such as for a plan, a design, a proposal, or a change order in construction or facilities management project. Information about requesting and giving approvals as well as approval conditions can be defined by IFC entities provided in this subschema.

- **External Reference Resource**: This subschema enables IFC entities to be linked to external sources of information such as documents, external data libraries, and classification systems. Also, meta-data attributes about these external resources are defined within IFC schema.

- **Geometric Resource Model**: It defines various types of geometric representation approaches for modelling the geometric or spatial form of building elements. These geometric models include CSG, half-spaces, manifold B-rep, faceted B-rep, swept solids, bounding boxes, surface models, and tessellated models.

- **Geometry Resource**: This subschema includes entities for modelling various types of points, curves, surfaces which can be used to define the spatial extent of building elements. Moreover, these entities can be used to describe geometric models defined within “Geometric Resource Model” subschema.

- **Measure Resource**: Various types of measurement units and types, which are typically assigned to quantities, are defined within Measure Resource subschema. Examples are SI units such as meter, square meter, and cubic meters which are used for measuring length, area, and volume of spatial objects, respectively.

- **Topology Resource**: This subschema comprises entities used for defining and orienting topological primitives such as vertex, edge, and face. Additionally, a specialized subtype is defined for each vertex, edge or face to provide their
association with the geometry of a point, curve, or surface, respectively. Moreover, basic topological entities can be aggregated to form spatial topological structures of the path, loop and shell and the integrity of these structures can be validated using constraints.

![Figure 3.3: Subschemas in Resource layer, adapted from (ISO16739 2013)](image)

### 3.3.2 Core layer of IFC

Core layer consists of “IfcKernel” subschema and three core extension subschemas, namely product, process and control extension (see Figure 3.4). “IfcKernel” contains the most abstract entity “IfcRoot” which is specialized into three fundamental and abstract entities (BuildingSMART 2013b):

- **Object definitions (IfcObjectDefinition):** This entity is the abstract superclass for entities capturing different types of objects such as products (IfcProduct), processes (IfcProcess) and controls (IfcControl).
- **Relationships (IfcRelationship):** This entity is the abstract superclass for defining all relationships among objects in IFC. There are six types of relationships: composition, assignment, connectivity, association, declaration, and definition. These relationships are also further specialized in order to define more specific relationships. For instance, “IfcRelSpaceBoundary”, which is a subclass “IfcRelConnects” entity defining general concept of connectivity relationships, more specifically defines connectivity relationships between space objects and building elements.
• Property definitions (IfcPropertyDefinition): This concept defines the generalization of specific groups of properties. Here, property refers to a user-defined attribute that can be assigned to objects via relationships. The subclasses of “IfcPropertyDefinition” are occurrences of property sets, property templates, and property set templates. These entities will be useful for extending and specializing general IFC entities without the need to define new subclasses. For instance, “IfcActor” entity can be extended with property set templates to model information about land surveyors. The naming convention for a group of property sets is “Pset_xxx”.

Product extension of core layer defines the fundamental concepts for modelling products (BuildingSMART 2013c). Here, the term “product” is the generalized concept for those objects which likely have a geometric representation and spatial placement. These objects mainly include various spatial structures, and physical and space elements (For more details see Section 3.3.8). In addition, the grid (IfcGrid), which imposes constraints for placement of elements, and annotations (IfcAnnotation), such as explanatory text, and dimensioning, are defined as specializations of “IfcProduct” entity. Process extension of core layer lays the foundation for modelling concepts required to map processes in terms of logical planning and scheduling of required activities and tasks (BuildingSMART 2013d). These concepts include a definition of work plans (IfcWorkPlan), schedules (IfcWorkSchedule), events (IfcEvent), procedures (IfcProdecure), and tasks (IfcTask). Control extension of core layer comprises basic entities required for controlling objects including products, processes, or resources (BuildingSMART 2013e). More specific control entities include performance histories (IfcPerformanceHistory) and approval associations (IfcRelAssociatesApproval). “IfcPerformanceHistory” is adopted to document the performance of building elements over a specified period. It provides a machine-generated data resulted from building automation systems or human-specified data resulted from manual tasks or activities. “IfcRelAssociatesApproval” is utilized to relate information about approvals to any object such as documents.
3.3.3 Interoperability layer of IFC

Interoperability layer specifies subschemas which contain those IFC entities shared, used and exchanged across multiple AEC domains (see Figure 3.5). Current shared subschemas include (BuildingSMART 2013f):

- Shared building elements (IfcSharedBldgElements): This subschema defines the specialized entities of the abstract “IfcBuildingElement” entity such as walls (IfcWall), doors (IfcDoor), windows (IfcWindow), slabs (IfcSlab), roofs (IfcRoof), and similar elements. These elements form the basic architectural configuration of buildings.

- Shared building service elements (IfcSharedBldgServiceElements): It consists of various entities used for modelling distribution elements required in building services such as electricity, water, and heating. Examples of distribution elements are distribution chambers (IfcDistributionChamberElement), flow controllers (IfcFlowController), flow fittings (IfcFlowFitting), flow segments (IfcFlowSegment), flow terminals (IfcFlowTerminal) and so on.

- Shared component elements (IfcSharedComponentElements): Various types of small parts of buildings, such as accessories and fasteners, are modelled within this subschema.

- Shared facilities elements (IfcSharedFacilitiesElements): Basic concepts of facilities management are modelled in this subschema. These concepts can be used by applications which require sharing information about facilities management related issues.

- Shared management elements (IfcSharedMgmtElements): This subschema comprises the major entities needed for management of projects throughout the
various stages of the building lifecycle. These entities provide the capability to capture and control information about scope, cost, and time of projects.

3.3.4 Domain layer of IFC

The most specific subschemas for each AEC domain are defined within this layer (see Figure 3.6). Entities defined in these subschemas are self-contained, and there is no possibility to further specialize or reference them in other layers (ISO16739 2013). Currently, the domain layer includes subschemas for eight AEC disciplines, namely building controls domain (IfcBuildingControlsDomain), plumbing and fire protection domain (IfcPlumbingFireProtectionDomain), structural elements domain (IfcStructuralElementsDomain), structural analysis domain (IfcStructuralAnalysisDomain), heating, ventilation, and air conditioning (HVAC) domain (IfcHvacDomain), electrical domain (IfcElectricalDomain), architectural domain (IfcArchitectureDomain), and construction management domain (IfcConstructionMgmtDomain).
3.3.5 Object placements and spatial reference systems within IFC standard

As the most abstract entity for representing spatial objects in IFC schema, “IfcProduct” references “IfcObjectPlacement” entity through its “ObjectPlacement” attribute to define the spatial placement of product elements including spatial and physical elements (see Figure 3.7) (Liebich 2009). The abstract “IfcObjectPlacement” entity is specialized into two instantiable subclasses (BuildingSMART 2013g):

- **IfcLocalPlacement**: This entity provides two ways to define spatial placement of products. The first approach is to set an absolute placement of a product with respect to the world spatial reference systems such as WGS (World Geodetic System) 84. Another option is to set a relative placement of a product on the local spatial reference system of another product. For example, levels of a building (IfcBuildingStorey) can be spatially placed with reference to the whole building object (IfcBuilding).

- **IfcGridPlacement**: This entity defines the spatial placement of a product by defining a constraint placement relative to the axes of a design grid (which is defined by the IfcGrid entity). In fact, the location of a product is defined by using virtual intersection and reference directions provided by axes of the grid.

Since IFC standard includes various options to define spatial reference systems in both local and global ways, BuildingSMART suggests the following recommendations for defining spatial placement of main product elements (BuildingSMART 2013h):

- **IfcSite**: Sites shall be placed with respect to the world coordinate system.
- **IfcBuilding**: Spatial placement of buildings shall be defined relative to the local placement of the site on which they are built.
- **IfcBuildingStorey**: Building stories shall be placed with respect to the local placement of their corresponding building.
- **IfcElement**: Spatial placement of physical elements can be defined in various ways depending on their spatial relationships with other spatial or physical elements. One case is defining containment relationships between physical elements and either sites buildings, or building stories. For example, geographic elements, which are defined by IfcGeographicElement (a subclass of IfcElement), can be spatially contained with sites (IfcSite). In this case, a
geographic element should be spatially referenced with respect to local placement of its container (site). Another example is that walls (IfcWall is a subclass of IfcElement) may be spatially contained within building stories. Similarly, spatial placement of walls is defined with respect to their container building storey.

Figure 3.7: Placement and representation of product elements, adapted from (Liebich 2009, p. 115)

The above recommendations indicate that “IfcSite” is the central entity used for defining geospatial reference systems within IFC and placement of other elements are defined relatively. There are three attributes (RefLatitude, RefLongitude, RefElevation) in “IfcSite” entity. These attributes define latitude, longitude and datum elevation from sea level for the reference or origin point of each site, respectively (BuildingSMART 2013i). The origin point of the site is (0, 0, 0) within its local reference system. However, its global placement is typically predefined based on geodetic coordinate values within WGS 84. To define WGS and other world spatial reference systems, two main concepts were considered in IFC schema (Liebich 2009):

- The concept of spatial reference systems: There are two entities for modelling this concept: “IfcCoordinateReferenceSystem” and its instantiable subclass “IfcProjectedCRS”. “IfcCoordinateReferenceSystem” entity models both geodetic datum and vertical datum used in defining a world spatial reference system. The geodetic datum indicates the shape and size of the rotation ellipsoid and this ellipsoid's connection and orientation to the real shape of the Earth. This datum is used for defining geographic coordinates, namely latitude and longitude. Examples of geodetic datum are WGS84, North American Datum 1983 (NAD83), European Terrestrial Reference System 1989 (EUREF89), and
Hayford. Vertical datum indicates the reference plane and base point defining the origin of a height system. Examples of vertical datum are Mean Sea Level (MSL), and North American Vertical Datum of 1988 (NAVD88). “IfcProjectedCRS” is used for defining projected spatial reference systems. Projected spatial reference systems, which are defined by using map projections, convert geographic coordinates to map coordinates (X, Y). “IfcProjectedCRS” entity includes three specific attributes, namely MapProjection, MapZone, and MapUnit. MapProjection attribute provides the name of the map projection such UTM (Universal Traverse Mercator) or Gaus-Krueger. MapZone specifies the zone number of the map project. For example, 38 can be assigned for defining UTM38. MapUnit defines length units (e.g. meter) assigned to coordinate axes of the projected spatial reference system.

- The concept of coordinate transformation operators: Two IFC entities mainly define transformation operators, including the abstract “IfcCoordinateOperation” and its instantiable subclass “IfcMapConversion”. These entities can also be used to transform coordinates from local spatial reference system of the project into the world spatial reference system. “IfcCoordinateOperation” is the abstract concept for defining transformation or conversion between any two spatial reference systems. “IfcMapConversion” more specifically defines the transformation from the local origin of the local spatial reference system to its place within a map (easting, northing, orthogonal height) and to rotate the x-axis of the local spatial reference system within the horizontal (easting/westing) plane of the map.

3.3.6 Solid models within IFC standard

For modelling the shape of spatial elements and physical building elements, “IfcProduct” references “IfcProductRepresentation” entity through its Representation attribute (Liebich 2009, p. 121). This entity could refer to those entities defined in “Geometric Resource Model” subschema to use solid models for defining the shape of 3D objects. Currently, IFC supports various types of solid models (IfcSolidModel). The widely used solid models include B-rep (IfcManifoldSolidBrep), CSG (IfcCsgSolid), and Swept Solid (IfcSweptAreaSolid). Below, these solid modelling approaches are briefly described.
3.3.6.1 **Constructive Solid Geometry (CSG)**

CSG solid modelling approach defines the geometric shape of 3D spatial objects by applying Boolean operators to the standard primitive objects (Rossignac and Requicha 1999). These primitive objects usually include simple shapes such as cuboids, cylinders, pyramids, spheres, cones, and so on. Mainly used Boolean operators used in CSG are union (∪), intersection (∩), difference (−) and geometric transformations such as translation, rotation, and scaling. CSG solid models can be expressed as ordered binary trees, in which the primitive objects are represented as leaf nodes, results of Boolean operators are defined within the internal nodes, and the final CSG model is represented as the root node of the tree. Figure 3.8a shows an example of CSG solid model defined by applying Boolean operators on primitive objects.

![Figure 3.8: Widely used solid models](image)

3.3.6.2 **Boundary representation (B-rep)**

B-rep solid models are merely defined based on a set of connected boundary surfaces (see Figure 3.8b). These boundary surfaces or faces are formed by a graph of edges and vertices (Allen 1984). At least one shell is required to show the final representation of a B-rep solid model. One shell, the outer, shall completely contain all the other shells and no other shell may include a shell. The Euler-Poincaré formula defines the following quantitative relationship among the number of faces (F), edges (E), vertices (V), faces’
inner loops (L), shells (S), and genus of shells (G) in B-rep solid models (Mantyla and Sulonen 1982):

\[ F-E+V-L = 2(S-G) \]

### 3.3.6.3 Swept solid

The fundamental idea behind swept solid models is to represent them by a 2D profile and a predefined curve (Agoston 2005, p. 174). The 2D profile could be a primitive object such as a rectangle, circle or polygon. The volumetric extent of swept solid models is formed by either rotating or translating the 2D profile alongside the trajectory of the predefined curve (see Figure 3.8c). Some building elements, such as walls, columns or beams, can be defined by through applying translational swept solid models.

### 3.3.7 Reasons for selecting IFC standard in this research

Besides IFC, there are other 3D building models developed for exchanging 3D spatial information. These 3D models can be classified into three main categories: purely geometric models, models with structured geometry but limited semantic information, and models comprising structured geometry as well as comprehensive semantics (Stadler and Kolbe 2007, Kolbe et al. 2009). VRML (ISO 2004), X3D (ISO 2005), COLLADA (ISO/PAS17506 2012) and KML (Wilson et al. 2007, 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 (Kolbe 2012). IFC and CityGML standards are not only standards for exchanging 3D data but also they define the spatial data models for BIM and 3D GIS domains, respectively.

Although both IFC and CityGML can be used for modelling spatial and semantic elements of buildings, they differ from each other significantly in terms of semantically modelling the built environment (Gröger and Plümer 2012). The focus of IFC is on design and construction aspects of buildings such as wall, ceilings, beams, and slabs. IFC models typically use a parametric modelling approach to construct 3D spatial objects. Therefore, the whole building element is semantically assigned to one entity.
(such as IfcWall for a wall element). In contrast, CityGML defines an observational view of building elements and building features are modelled in terms of their observable surfaces (Nagel et al. 2009). Therefore, different semantic entities are assigned for observable surfaces of a building element. For example, “WallSurface” and “InteriorWallSurface” are respectively used for semantic modelling of external and internal surfaces of a wall element (see Figure 3.9).

**Figure 3.9, Semantic definition of building elements in IFC (left) and CityGML (right), adapted from (Nagel et al. 2009)**

Here, the reasons for selection of IFC in this research, as opposed to CityGML, will be discussed. First, CityGML only utilizes the B-Rep method for representing the geometry of 3D objects (Kolbe 2012). However, IFC is more flexible in modelling the geometry of 3D objects, and it supports not only B-rep but also other types of solid models such as CSG and swept solids (BuildingSMART 2013j). 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 3.10. 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 using 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 building 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 2014), it is perhaps more feasible that land surveyors would receive 3D building models from architects in IFC format in future rather than CityGML, with which they might use to create 3D digital building subdivisions.

Figure 3.10: A high-rise building with 3D holes (The Elephant building located in Bangkok, Thailand)

3.3.8 IFC entities pertinent to urban land administration

In this part, the relevant parts of IFC schema will be shown using notations of EXPRESS-G diagrams. To understand these notations, the reader is referred to Appendix A. The relevant IFC entities for this research can be classified into four main categories (Liebich 2009, Atazadeh, Kalantari, Rajabifard, Ho, and Champion 2017):

- Spatial elements: “IfcSpatialElement” entity is the superclass for spatial elements. These elements are used for modelling various spatial structures
within an IFC project (see Figure 3.12). Spatial structures can be defined in the non-hierarchical or hierarchical way. Spatial zones (IfcSpatialZone) are non-hierarchical decompositions of an IFC project. For hierarchical spatial structures, there are two main abstract entities:

- “IfcSpatialStructureElement” is the abstract superclass for entities defining site (IfcSite), building (IfcBuilding), building storey (IfcBuildingStorey) and internal space (IfcSpace) objects.
- “IfcExternalSpatialStructureElement” is the abstract superclass for “IfcExternalSpatialElement” entity which is used for modelling external regions and airspaces around the building site.

- Physical elements: “IfcElement” is the abstract superclass for entities modelling physically existent objects (see Figure 3.12). The relevant physical objects are building elements (IfcBuildingElement), distribution elements (IfcDistributionElement), and geographic and civil elements (IfcGeographicElement and IfcCivilElement). 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. Distribution elements represent different types of utility networks inside the building as well as around the building site. Examples are pipes, cables, and ducts. Geographic and civil elements represent geospatial features such as roads, trees, bridges or pavements. Figure 3.11 represents examples of some spatial and physical elements.

- Elements for referencing to documents: Documents can be related to objects via “IfcRelAssociatesDocument” relationship. As external resources, documents can be referenced and metadata about these documents can be managed within IFC. The resource layer of IFC includes “IfcExternalReferenceResource” subschema which links IFC files to external resources. Within this subschema, two main entities provide the basis for managing documents (See Figure 3.13):
  - “IfcDocumentInformation” specifies the metadata about documents such as reference URL for the original file of the document.
  - “IfcDocumentInformationRelationship” is an objectified relationship that relates documents to each other.
• Actor elements: In core layer of IFC, “IfcActor” entity provides the basis for defining various actors involved in the development process of a building project (see Figure 3.14). Three types of actors can be selected via “IfcActorSelect” attribute: a person (IfcPerson), an organization (IfcOrganization), or a person associated with an organization (IfcPersonAndOrganization). These entities are defined in “IfcActorResource” schema within the resource layer. The role performed by actors is defined through “IfcActorRole” entity.

Figure 3.11: An indicative example that illustrates relevant spatial and physical IFC entities
Figure 3.12: Relevant spatial and physical elements in IFC schema
3.4 Related BIM Literature for Urban Land Administration

The benefits of using BIM models in the geospatial domain have been demonstrated for different urban applications, which require both indoor and outdoor spatial information, such as evacuation (El-Mekawy et al. 2012) and fire response management (Isikdag et al. 2008). One of the opportunities of bringing BIM into the geospatial domain is to
enable 3D registration of ownership rights in apartments in a digital environment (Isikdag and Zlatanova 2009) and facilitate land management in urban areas. This implies that land administration, as another area of the geospatial domain, can also utilize BIM for meaningful communication of complex 3D RRR spaces defined inside multi-storey buildings (Frédéricque et al. 2011, Isikdag et al. 2011). However, there remains limited investigation into the feasibility of BIM for urban land administration. This section reviews related work investigating the role of BIM in land administration in order to distinguish the difference between this research and other relevant investigations.

3.4.1 IFC for indoor cadastre

One of the earliest investigations on utilizing BIM for land administration was conducted by Clemen and Gründig (2006), who indicated the need to import different entity types into IFC schema based on processed surveying measurements and observations to manage indoor cadastral information. In this investigation, it was demonstrated that as the IFC data model can support 3D topology and geometric representation of building elements, it could potentially be extended for land surveying purposes by pre-processing raw surveying measurements and observations. The authors emphasized that topology of observations should be distinguished from object topology which is already defined in IFC schema. Therefore, they proposed a list of those concepts which needed to be considered in the indoor cadastral domain of IFC standard. These concepts include:

- Measurement units and conventions: Examples are clockwise or counter clockwise measurement of angles, angles expressed in radiant grad or degree, right or left-hand spatial reference systems
- Raw Observation Value: Examples of this concept are direction, distance, zenith angle, target height, uncertainty
- Observation Node: This concept refers to geodetic or surveying points.
- Observation Edge: This concept connects two observation nodes with each other and is associated with a set of raw observation values.
- Observation Group: This concept can model a set of observation edges with the same translation, orientation and time stamp.
To manage cadastral information in indoor environments, the above-mentioned concepts should be processed before integration into BIM environment. It was emphasized that creation of a new subschema for surveying engineering in domain layer of IFC schema should be developed, which in turn would make engineering surveyors as part of IFC community. However, Clemen and Gründig (2006) did not provide an approach as to how 3D surveying data elements and indoor cadastral data could be meshed into and accommodated within the spatial data model of IFC standard.

3.4.2 Cadastral extension of UBM

More recently, El-Mekawy and Östman (2012, 2015) investigated the capability of IFC standard and CityGML standards for implementing 3D cadastral systems. They proposed that Unified Building Models (UBM) can be extended with four types of boundary surfaces which are required to represent above ground and underground RRR spaces in the context of Swedish jurisdiction (see Figure 3.15). UBM is a reference data model for bi-directional mapping between IFC and CityGML standards, and it facilitates the exchange of 3D spatial information between these standards (El-Mekawy 2010). The proposed boundary surfaces in the cadastral extension of UBM are “Building Elements Surfaces”, “Digging Surfaces”, “Protecting Area Surfaces”, and “Real Estate Boundary Surfaces” (El-Mekawy and Östman 2015). “Building Elements Surfaces” refer to legal boundaries associated with building elements such as slabs and walls. “Digging Surfaces” are virtually defined legal boundaries for underground infrastructure such as tunnels, and underground parking areas. “Protecting Area Surfaces” are utilized to delineate spatial extent of restrictions such as easements. “Real Estate Boundary Surfaces” are delineated based on traditional cadastral survey methods, in which border points and border lines constitute a cadastral object. To showcase the feasibility of the proposed cadastral extension of UBM, it was implemented for a real case study, a hospital building, in ArcGIS environment and various types of RRR spaces defined by the proposed boundary types were visualized (El-Mekawy and Östman 2012).

In a further study by El-Mekawy et al. (2014), the authors highlighted possible solutions as well as associated challenges for adopting BIM in the urban land administration. They argued that BIM would potentially enhance the procedures associated with formation, registration, and visualization of RRR information defined in Swedish
jurisdiction; however, the data environment of BIM model currently does not include RRR information. Moreover, it was highlighted that Swedish property formation process, which means subdividing or consolidating land parcels or properties, is mainly predicated on using digital building information supplied by construction companies in the form of BIM or CAD files. Nevertheless, there is no further use of this digital information after completion of the property formation process. To mitigate these challenges, the proposed cadastral extension of UBM was suggested as one possible solution to facilitate the interaction between BIM and 3D property formation. This indicates that the enrichment of UBM or BIM-based data models with 3D RRR data elements could bring new opportunities to enable further collaboration between land administration and BIM domains.

Finally, El-Mekawy et al. (2015) examined IFC, CityGML, and LADM standards in terms of modelling various types of rights, restrictions, and responsibilities (RRRs) associated with 3D properties in Sweden. The study mainly focused on presenting a theoretical framework to provide the basis for the interaction between 3D physical models, such as IFC and CityGML, and 3D legal models such as LADM. They found that both IFC and CityGML standards do not support legal aspects of 3D properties such as boundaries and RRR information, whereas LADM provides a framework for modelling only legal spaces. Therefore, they found that the proposed extension to UBM would efficiently model legal aspects of 3D properties in comparison with those standards, particularly in complex structures. Another finding was that a full 3D cadastral system should logically incorporate both legal and physical dimensions of 3D properties in urban built environments, which is still a remaining research question that needs to be answered.

Although the proposed cadastral extension of UBM was a good contribution to use BIM models for urban land administration purposes, a few issues associated with this extension were identified in the context of this research:

- The spatial relationships between boundaries and legal spaces were not modelled in this extension. For instance, there is no support for how “Building Elements Surfaces” might reference walls or ceilings bounding a private apartment unit. This limitation applies to those jurisdictions (such as Victoria) that mainly rely on building elements to define legal boundaries.
• 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 such as title or deed.

• The proposed UBM extension is very restricted and does not specify the detailed semantic information about 3D RRR spaces. For example, there is no information about liabilities and entitlements of private legal spaces.

• Cadastral extension of UBM does not distinguish various legal arrangements from each other. For example, “UBMSpace” is the potential entity for modelling legal spaces (see Figure 3.15) and this entity does not provide more semantic information to distinguish a private property from common property space. Moreover, UBM does not provide the capability to arrange different parts of a legal interest in a spatial structure. As an example, various communal spaces such as corridors, lobbies, elevators typically constitute the common property legal interest of a multi-level building, but there is no mechanism in the cadastral extension of UBM to compose instances of “UBMSpace” entity to form the whole spatial structure of common properties.

Figure 3.15: Cadastral extension of UBM, adapted from (El-Mekawy and Östman 2015, p. 275)

3.4.3 IFC for property valuation

Isikdag et al. (2014) pointed out that valuation of properties differs from one jurisdiction to another one. They found that 3D digital data environments could potentially enhance valuation and taxation practices in the future; however, this
improvement differs from one jurisdiction to another since each jurisdiction has its own requirements for valuating properties. Property valuation is mainly predicated on physical world aspects (geometry and material of building element) and legal/virtual aspects (RRR information and zoning of legal spaces). Therefore, Isikdag et al. (2014) investigated linking 3D cadastral (legal) models with 3D semantically enriched physical building models such as IFC, arguing that this could potentially improve property valuation practices. Current practices for determining property values and taxes were investigated in different countries including Turkey, UK, USA, The Netherlands, and Germany. They proposed that integrating 3D RRR information with 3D physical building models in either IFC or CityGML format could potentially provide significant benefits for valuation and taxation of properties in these countries.

In further research by (Isikdag et al. 2015), data requirements for property valuation were identified for each of the above-mentioned countries. These data requirements were classified into two broad categories:

- **Land lots**: 2D spatial data required for valuation of land lots include 2D boundaries of land lots, 2D permit boundaries (such as building or farming), information about providing accessibility and utility services to a land lot, and vegetation information for protecting land lots (i.e. restrictions). Additionally, 3D spatial data requirements include 3D land parcel with possibly additional information about quality and usability, 3D volume space of permit boundaries, and 3D limits of trees, bushes or fences in some jurisdictions.

- **Buildings**: 2D spatial data requirements for buildings include 2D floor plans (ground area and floor areas), orientation and view of the building. In addition, 3D spatial data requirements include detailed 3D indoor building model (LoD4+) for estimating value and cost, separate building parts, and 3D model of the building and its neighbourhood with realistic pictures such as *streetview* images.

One major finding reported by Isikdag et al. (2015) was that the enrichment of 3D digital building models with *streetview* images would provide more detailed information about the quality of the environment surrounding the building, which leads to improving the representation of valuation information associated with apartment
units of the building.

3.4.4 UrbanIT project

The urbanIT integration framework was another relevant research project which focussed on development and implementation of an integrated urban information model by coupling indoor spatial information, sourced from BIM, with outdoor spatial information which comes from geographic information systems (GIS) (Plume and Mitchell 2011). This framework would potentially provide the basis for effective management of spatial information, which would, in turn, enhance current processes for planning, designing and operating urban built environments. In particular, the core of the urbanIT project was a proposed extension to the IFC standard for managing cadastral data both inside buildings as well as land parcels on the site of buildings (Barton et al. 2010). The proposed extension considered “IfcSpace” and “IfcZone” entities for modelling legal spaces defined within multi-storey buildings. In addition, the “IfcSite” entity was also considered for modelling legal boundaries of 2D land parcels on a construction site. To model cadastral attributes, the “IfcSite” entity was enriched with a new property set (Pset_CadastreCommon). This property set comprised four attributes, namely:

- **CadastreType** represents the legal interests associated with land parcel such as road, lot, railway, water feature and so on.
- **CadastreSubType** defines the subtypes of a specific legal interest. For instance, lots can be specialized into strata and stratum lot, standard lot, and standard part lot.
- **LandValuation** provides the predicted value of assets, which could be obtained based on various valuation methods such as Fair Valuation, and Market Valuation
- **Tenure** describes who owns or holds interests in the land.

Although this extension was a good trial for representing cadastral spaces within buildings, three main issues about the cadastral part of UrbanIT were identified:

- It did not investigate how legal boundaries, particularly the range of cadastral boundaries defined inside high-rise and complex buildings, could be mapped
onto their corresponding IFC entities.

- The concept of zones (IfcZone) was used for modelling common property areas, in which only cognitive volumetric spaces (IfcSpace) are used to model constituting parts of common property. However, in notation section of subdivision plans, it is sometimes indicated that physical structures, such as walls and ceilings, pipes inside walls, and cable inside walls, are also deemed to be part of common properties. This implies that “IfcZone” concept is unlikely to adequately manage spatial arrangements of common properties in some circumstances.

- Other important cadastral attributes such lot entitlement and lot liabilities were not assigned as property sets for individually owned lots.

3.4.5 Other recent investigations

Kim et al. (2015) proposed an implementation framework encompassing indoor mapping and as-built BIM models to manage RRR information associated with 3D properties located underground in the context of Korean jurisdiction. The proposed implementation includes four main steps. First, geometric information about infrastructure facilities was modelled using data sourced from terrestrial laser scanners. Subsequently, an as-built BIM model according to results of geometric modelling was constructed. This is followed by defining reference points in order to verify the accuracy of the as-built BIM model. Finally, three approaches were suggested as possible solutions for representing and visualizing 3D underground properties. These approaches include: using isometric views to represent 3D properties, using a 2D land parcel represented with 2D footprints of 3D underground properties, or using 3D (or 2.5D) surface and 3D underground cadastral maps. It is claimed by Kim et al. (2015) that their framework can register RRR information associated with underground legal interests; however, this framework only considers the purely geometric aspects of underground cadastral objects and does not provide semantic mechanisms to assign RRR information for each legal interest. In addition, there is no explanation that how the geometry of physical objects which are obtained from indoor mapping can be used to delineate structural boundaries.

Similar to UrbanIT project, Oldfield et al. (2016) suggested that space objects (IfcSpace) and grouping these spaces as legal zones (IfcZone) would underpin the basis
Building Information Modelling for Land Administration

for utilizing BIM models in the 3D cadastre. It was also reported that boundaries of legal spaces could be modelled by “IfcRelSpaceBoundary”. Using a lakeside restaurant as a case study, two main challenges associated with adopting IFC standard for 3D cadastral purposes were identified, namely the manual extraction of the spatial extent of 3D legal interests from BIM models, and modelling ambulatory boundaries defined by changes in water level of the lake located around the restaurant. For modelling ambulatory boundary, the study proposed to enrich “IfcRelspaceBoundary” with a semantic value for ambulatory boundaries. However, this approach may not be an appropriate method for modelling ambulatory boundaries. Since these boundaries are defined by referencing rivers or lakes, which are currently modelled by “IfcGeographicElement” entity, it could be better to point out that “IfcRelSpaceBoundary” should refer to “IfcGeographicElement” via its RelatedBuildingElement attribute (see Chapter 6). Another contribution by Oldfield et al. (2016) was developing a collaborative BIM-based workflow for cadastral registration using Information Delivery Manual (IDM) approach. The workflow described how cadastral data requirements could be efficiently communicated between project initiators and authorities, which would, in turn, facilitate procedures for obtaining legal spaces from BIM models. One issue with the proposed workflow is that it did not distinguish specific acting roles performed by authorities. For example, responsible authorities (or city councils) were not differentiated from referral authorities such as utility companies.

3.5 Chapter Summary

In this chapter, two distinct but interrelated concepts of BIM were introduced: product and process. The chapter also highlighted some benefits and challenges that AEC industry has observed through the adoption of BIM-based paradigm. The main technical challenge was interoperability and exchange of data among BIM tools. The open IFC standard has been adopted to mitigate this challenge. This standard has four main layers, namely resource layer, core layer, interoperability layer, and domain layer. IFC standard currently supports various types of spatial reference systems as well as transformation between these systems. Moreover, various solid models, such as CSG, B-rep and swept solid, are supported by IFC standard. Since this research adopts IFC standard for modelling 3D RRR spaces, reasons for choosing IFC standard as opposed to CityGML
standard were also discussed. Finally, relevant investigations using BIM for urban land administration purposes were reviewed. Although these reviewed studies show different degrees of leveraging BIM for supporting land administration functions, none of them have explored how the IFC standard can be extended to accommodate a wide range of legal data elements, which is critical for the adoption of BIM for land administration purposes. Thus, in the next section, the research methodology for meshing legal information into the BIM environment will be developed.
CHAPTER 4

RESEARCH DESIGN AND METHODS
4 Research Design and Methods

4.1 Introduction

In previous chapters, the relevant literature in domains of BIM and urban land administration is reviewed to provide the detailed theoretical background for this research. This chapter includes the research methodology and methods that were adopted to respond to the research objectives specified in Chapter 1. Here, one should distinguish “research methodology or paradigm” from “research method” (Johannesson and Perjons 2014). Research methodology indicates the overall plan for executing and monitoring a research investigation. While the research methodology supports and guides the researcher from a high-level perspective, research methods are complementary for conducting the research in more detailed steps. Research methods are applied over various phases of a research methodology for the purpose of collecting and analysing data. Figure 4.1 shows the relationship between methodology and methods.

![Figure 4.1: Research methodology and research methods, adapted from (Johannesson and Perjons 2014, p. 66)](image)

In this chapter, research methodologies pertinent to the land administration domain are briefly explained. Subsequently, it is justified which research methodology is suitable
for conducting this research, followed by an overview of the selected research methodology. The readers should notice that contents of Sections 4.2, 4.3, and 4.4 provide a general background in the research methodologies and methods. This introductory content is fundamental to the research methodology and methods used in various stages of this research, which is explained in more detail in Section 4.5.

4.2 Research Paradigms in Land Administration Domain

The research paradigm underpins the methodological basis for conducting any research project. The research paradigm or methodology in the context of this thesis is defined as “a perspective held by a community of researchers that is based on a set of shared assumptions, concepts, values and practices” (Johnson and Christensen 2008). Over the last decades, a large number of research projects have been conducted within the academic discourse of land administration domain. According to Çağdaş and Stubkjær (2009, p. 870), these research projects could be classified into two distinct and complementary categories of research paradigms, namely behavioural science and design science.

The basis of behavioural science originates from natural science research methodologies (Tashakkori and Teddlie 2010). In behavioural research, institutional settings and behaviour of humans in design, development and use of land administration systems are investigated (Çağdaş and Stubkjær 2009). This research paradigm mainly concentrates on describing, explaining and predicting the existing reality of land administration systems. The behavioural research paradigm helps the researcher to gain knowledge about interaction among people, organizations, and technology in any land administration system. Such knowledge would provide a better insight in terms of identifying and addressing current institutional challenges within land administration domain.

In contrast to behavioural science, design science does not only explain and predict the existing land administration practices but also endeavours to enhance information science aspect of land administration domain by developing a new artefact with an embedded solution in response to a research problem perceived in the real world practices (Çağdaş and Stubkjær 2011). In addition to designing a novel artefact, the knowledge of using such artefact and its impact on the environment of the real world
practices is communicated through this research paradigm. The artefact could be constructed in various forms such as models, methods, and systems (Hevner et al. 2004). In Figure 4.2, the relationships between researchers, research problems, and artefacts are presented in the context of design science paradigm (Johannesson and Perjons 2014).

Figure 4.2: A general overview of design science research paradigm, adapted from (Johannesson and Perjons 2014, p. 4)

In this thesis, design science research methodology has been adopted to conduct the research. The reason for adopting this research methodology is that according to Çağdaş and Stubkjær (2011), design science has been implicitly utilized in various doctoral dissertations contributing to the information science aspect of land administration systems. Some examples of these dissertations include:

- Spatial Cadastral Information Systems – the maintenance of digital cadastral maps by Effenberg (2001)
- 3D Cadastre by Stoter (2004)
- Developing geographic information infrastructures – the role of information policies by van Loenen (2006)
In the above dissertations, new artefacts in the form of models were developed and demonstrated to improve current practices in land administration systems. For instance, Tuladhar (2004) observed the problem “developing a cadastral system in Nepal from a technical point of view”. To address this real world problem, he developed “organizational, static and dynamic models for a parcel-based GIS” as a new artefact using Unified Modelling Language (UML) and demonstrated this artefact in prototype systems.

Similarly, the contribution of this thesis is also on the information science aspect of land administration systems. In this research, the open BIM data model (IFC) will be extended with legal information, which can be considered as a new artefact to respond to the research problem identified in Chapter 1. Therefore, design science is chosen as the appropriate research methodology in this thesis.

4.3 General Overview of Design Science Research Methodology

In general, the overall framework of design science research methodology comprises six major activities, namely identification of the research problem, the definition of the requirements of a solution, design and development of an artefact, demonstrate the artefact, evaluate the artefact and communicate the artefact (Peffers et al. 2007).

Figure 4.3 represents the process model for performing various activities of design science research methodology. It can be seen that there are different ways to commence conducting an investigation based on design science, namely problem-centred, objective-centred, design-centred, and client-centred entry points. In this thesis, the adopted entry point is problem-centred. Each activity of the design science research methodology will be explained in detail in the following subsections.
Figure 4.3: Process model of design science, adapted from (Peffers et al. 2007)
4.3.1 Identification of the research problem

The first activity in any design science research is to investigate and analyse the research problem. In a general sense, the problem is the discrepancy between a desirable state and the current situation in the real world. There are three main sub-activities for identifying the research problem (Johannesson and Perjons 2014):

- **Precise definition:** The research problem should be formulated in a precise shape so that people with different backgrounds can perceive and interpret its definition in the same way. To define a precise problem, the researcher should approach various academic and professional experts in the domain of the problem since each expert has their distinct view or opinion about different dimensions of the problem. By synthesising different expert views, the number of ways that the problem can be perceived could be reduced and consequently, a shared understanding of the problem can be developed. However, if the problem is defined too precisely, it would result in omitting the important aspects of the research and excluding innovative dimensions.

- **Position and justification:** Positioning the research problem in the appropriate context and practice would facilitate its communication and understanding. Justification of the problem for its practice should be done in a way that the relevant stakeholders can agree that it is important and challenging and there is already no solution for it. The importance of the problem should be of interest for not only one specific and local practice but also some global practice.

- **Finding root causes:** The research problem is mainly defined in an impressionistic manner, indicating a feeling of unsatisfactory affairs in current practices. However, such an impressionistic expression is not adequate to communicate an understanding of the problem. Therefore, there should be a so-called root cause analysis to identify, analyse and represent the underpinning causes of the research problem.

4.3.2 Definition of the requirements of a solution

In this activity, the identified research problem is transformed into a set of requirements which should be considered in designing the artefact. This activity mainly responds to the following question:
What are the important requirements to develop the artefact which provides a suitable solution for the explicated problem?

The above question is to be responded by the descriptive knowledge which explains the requirements on the artefact. A requirement can be defined as a property of artefact, guiding its design and development process.

4.3.3 Design and development of an artefact

In this activity, an artefact is created to respond to the research problem and fulfil the requirements defined in the previous activity. The artefacts can be presented in various forms such as constructs, models, methods, and so on (Hevner et al. 2004). This activity describes the process for developing the architecture and structure of functionalities embedded within the artefact (Järvinen 2007). There are three sub-activities for designing and developing an artefact. The first one is imagine and brainstorm, in which new ideas are suggested, or the current ones are further improved. These suggested ideas would later provide the basis for designing the artefact. The second sub-activity, assess and select, is dedicated to the assessment of the suggested ideas so that the researcher can select one or several of them to lay the foundation of the artefact development process. Over the course of the third activity, sketch and build, the artefact is practically created.

4.3.4 Demonstrate the artefact

After designing the artefact, its feasibility to address the explicated research problem should be demonstrated through its use in one real-world case (Peffers et al. 2007). Demonstrating the artefact would indicate its evaluation in a weak manner; if the research problem is addressed by the artefact in one instance, it might be resolved in other cases as well. Furthermore, the demonstration helps to clarify or manifest the abstract concepts behind the artefact for a general audience in a concrete and communicable way. This activity comprises two sub-activities (Johannesson and Perjons 2014). First, a suitable case is selected from real-world practices. Subsequently, the designed artefact is applied to the selected case, and the outcomes are documented.

4.3.5 Evaluate the artefact

The evaluation activity mainly specifies how well the artefact solves the explicated
Building Information Modelling for Urban Land Administration

research problem. In addition, the artefact is also examined in terms of fulfilling the requirements. Three sub-activities are usually conducted for evaluating the artefact (Venable et al. 2012). Firstly, the context of the evaluation is analysed regarding some constraints such as availability of time, budget, people and access to organizations. The second sub-activity is to choose the strategy and goals for evaluation according to the context analysis (Pries-Heje et al. 2008). The last sub-activity is to conduct and perform the evaluation based on the appropriate requirements for the selected strategy.

4.3.6 Communicate the artefact

The results of design science are usually published within both academic and practitioner communities (Gregor and Hevner 2013). Also, these results sometimes would be of interest for general audiences. Communication of the results to researchers needs a rigorous consideration so that they would be able to accurately understand the results, which will likely help them build upon current findings in future investigations.

4.4 General Overview of Commonly Used Research Methods

As indicated in Figure 4.1, the research methods used in research projects are typically categorized into two distinct types, namely data collection and data analysis methods (Denscombe 2010). The following subsections provide a brief introduction to relevant types of data collection and analysis methods, which were used in various stages of this research project.

4.4.1 Data collection methods

Data collection constitutes a vital part of any research project. The collected data can be expressed quantitatively in terms of numerical values such as speed of query and number of search results. Other forms of collected data can be text, sound, images or videos, which mainly refers to qualitative data. Without consideration of data type, data collection methods adopted in this research include interviews, documents, and observations. These methods are generally described below (Denscombe 2010):

- **Interviews**: Interview is a meeting between a researcher and a participant, in which the researcher asks questions from the participant (Kvale 2008). Through analysing interviews, the researcher can elicit complex and valuable information
based on the participant’s opinion, attitude or experience. This type of data collection is useful for acquiring information from experts who possess a deep and unique knowledge of a particular domain. There are three types of interviews, namely structured, semi-structured and unstructured. Structured interviews contain a fixed set of questions with prearranged answers. Semi-structured interviews are also developed according to a predefined list of questions; however, participants can provide the responses in their own words. Unstructured interviews are conducted without asking specific questions and participants can uninhibitedly express their thoughts and feelings about the topic of the interview.

- **Documents**: Documents mainly comprise textual information, but images are also embedded inside them, and audio or video files can supplement documents. Documents are typically categorized into six types, namely governmental publications, organizational reports, scientific publications, newspapers and magazines, personal communications, and social media streams. An advantage of documentary studies is that data can be sourced in a shorter period in comparison with other methods of data collection. However, it is sometimes hard to evaluate the credibility of the documents. For instance, Wikipedia pages can be produced by any person and this questions trustworthiness of the information provided in these pages.

- **Observations**: In this method, the researcher directly studies a practice or phenomenon in the real world. There are two kinds of observations: systematic and participant (Bouchard 1976). Systematic observation allows researchers to collect data in a structured way over a short period by using an *observation schedule*, which includes a predefined structure for recording interactions and events in the real world practice. In participant observation method (Jorgensen 2015), researchers gain a deeper understanding of the observed phenomenon by building a closer familiarity with people over an extended period. This type of observation would generate valid and context-specific findings since researchers are allowed to investigate real world practices in a natural setting without the limitation of observations schedules.

### 4.4.2 Data analysis methods

Through applying data analysis methods, communicable and manageable pieces of
information are deduced from raw data to provide an explanation for a phenomenon under investigation. The reason for using data analysis methods is that the researcher cannot draw any meaningful conclusion without preparing, interpreting and analysing raw data. Typically, data analysis is conducted in two ways as explained below (Borrego et al. 2009):

- **Quantitative data analysis:** These methods are applied to quantitative data, which is numbers (Creswell 2013). Data collected through questionnaires or observations can be expressed by numerical values. There are two main types of methods for quantitative data analysis, including descriptive statistics, and inferential statistics. In descriptive statistics, the researcher merely describes a specific data sample. Inferential statistics is utilized to generalize findings from a particular data sample. In this research, descriptive statistics is used for analysing quantitative data. One typical example of descriptive statistics is to use tables and charts to represent important parts of a sample data. Detailed aspects of quantitative data can be represented in tables, while charts can communicate important dimensions of quantitative data in a more visual and intuitive way.

- **Qualitative data analysis:** These methods are used to analyse qualitative data such as text, images, sounds and videos (Dey 2003). This type of data can be gathered through any data collection method. Main methods of analysing qualitative data include content analysis and discourse analysis. Content analysis is used to quantify the contents of textual information or other types of qualitative data. The main idea behind this method to categorize elements and compute their frequencies in textual descriptions. In content analysis, the meanings of statements are explicitly analysed, whereas discourse analysis explores implicit and obscure meanings from the text.

### 4.5 Methodology and Methods of This Research

This section describes how to use design science research methodology for conducting this research. Additionally, the specific research methods applied over the course of each phase of this research will be described. The research methodology includes five main phases, namely foundation phase, design phase, implementation phase, evaluation
phase, and documentation and communication phase. Table 4.1 shows the timeline for each phase of this research. Some phases were conducted in both academic and industry environment, while others were done in the pure academic environment.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation phase</td>
<td>1 April 2013 – 31 May 2014</td>
<td>Academic and Industry</td>
</tr>
<tr>
<td>Design Phase</td>
<td>1 June 2014 – 31 April 2015</td>
<td>Academic</td>
</tr>
<tr>
<td>Implementation Phase</td>
<td>1 May 2015 – 31 December 2015</td>
<td>Academic and Industry</td>
</tr>
<tr>
<td>Evaluation Phase</td>
<td>1 January 2016 – 30 June 2016</td>
<td>Academic and Industry</td>
</tr>
<tr>
<td>Documentation and Communication phase</td>
<td>Throughout the whole lifespan of the research.</td>
<td>Academic</td>
</tr>
<tr>
<td></td>
<td>The intensive period for writing thesis was 1 July 2016 – 20 November 2016.</td>
<td>Academic</td>
</tr>
</tbody>
</table>

4.5.1 Foundation phase

This phase includes the first two stages of design science, namely explicate research problem and define requirements (see Figure 4.4).

![Figure 4.4: Foundation phase of the research methodology](image)

To explicate the research problem, a review of current literature was firstly done by adopting documentary studies as the data collection method. The studied documents
include:

- **Scientific publications:** This type of documents was mainly used in reviewing the literature and explicating research problem. There are five main types of scientific publications including books, edited book chapters, doctoral and masters theses, journal articles, and conference papers. Examples of books studied in this research include ‘Land Administration for Sustainable Development’ (Williamson et al. 2010), and ‘BIM Handbook’ (Eastman et al. 2011). A good example of edited book chapters studied in this research is ‘Advances in 3D Geo-Information Sciences’ (Kolbe et al. 2011). Examples of doctoral and masters theses include those written in related academic institutions located in various parts of the world such as Delft University of Technology and the University of Melbourne. For this study, examples of relevant journals include International Journal of Geographical Information Science, Automation in Construction, Transactions in GIS, Advanced Engineering Informatics, Land Use Policy, and Computers, Environment, and Urban Systems. Conference papers reviewed in this investigation are mainly those published in FIG working weeks and 3D cadastre workshops, which are provided on the below website:

  http://www.gdmc.nl/3DCadastres/literature/

- **Governmental publications:** For this research, these include documents that Australian government and in particular Victorian government have published to describe legal aspects of managing land and property information. For instance, “Subdivision Act (1988)” and “Planning and Environment Act (1987)” underpin the basis of development and use of land in Australia. In addition, each state in Australia has developed their own regulation for implementing these acts. For example, the Victorian government provides “Subdivision (Procedures) Regulations (2011)”, “Subdivision (Registrar) Regulations (2011)”, and “Planning and Environment Regulations (2015)” to outline and formalize subdivision and development processes of land in Victoria, Australia.

- **Organizational reports:** In this part, documentations associated with relevant
3D standards published standardization organizations were investigated. These standards include those in BIM, geospatial and land administration domains. In BIM domain, various guidelines and reports associated with understanding and implementation of IFC standard, which are published by BuildingSMART organization, were studied. In addition, International Organization for Standardization (ISO) published the full documentation of this standard (ISO16739 2013), which is also reviewed in this research. In the geospatial domain, Open Geospatial Consortium (OGC) developed two standards, namely CityGML (Groger et al. 2012) and IndoorGML (Lee et al. 2014). Both of these standards were thoroughly reviewed. In land administration domain, documentation of LADM standard, which is published as a conceptual ISO standard (ISO19152 2012b), was also investigated by the researcher.

- **Professional magazines:** These include relevant professional magazines in BIM, geospatial and land administration domains. Examples are AECbytes, GIM International, and Land Journal of Royal Institution of Chartered Surveyors (RICS). These magazines typically include short articles, which mainly showcase the practicality of research investigations in real world applications.

- **Personal communications:** In this study, a number of personal communications with the supervisory team as well as other academic researchers and industry experts in BIM and land administration domains was also conducted through face to face conversations or email exchanges. The knowledge of these specialists helped the researcher in refining the research problem.

After reviewing the literature over the course of one year, the precise definition and justification of the research problem were outlined. To recapitulate from Chapter 1, the research problem is defined as:

*From a land administration perspective, the open BIM data model (IFC) in its current form is not capable of managing legal information associated with ownership of properties inside and around multi-storey building developments.*

Literature review has also helped to properly identify root causes underlying the
research problem. These causes mainly include communication challenges resulting from 2D subdivision plans and issues of 3D spatial data models, which were reviewed in Chapter 2, as well as limited BIM research in urban land administration, which is reviewed in Chapter 3.

The next stage of foundation phase is to define requirements that a potential artefact should satisfy to address the explicated research problem appropriately. In other words, the explicated problem is transformed into demands expected from the proposed artefact. In the context of this research, these “demands” are the ability to better communicate and manage legal information associated with ownership of properties inside and around multi-storey building developments. More specifically, this requires the new artefact to capably store, manage and represent the various types of data requirements for managing legal information associated with multi-storey building developments. The knowledge acquired from both literature review and investigation of current subdivision practices is used to define data requirements. These requirements are classified into five main categories (see Chapter 5):

- **Legal objects:** These include various types of legal interests as well as legal boundaries defined inside and around multi-storey buildings in the context of Victorian jurisdiction. Legal interests were classified into main categories, namely primary and secondary ones. A taxonomy of legal boundaries was developed to indicate how the proposed artefact should support the spatial extent of legal interests.

- **Physical objects:** Physical objects do not themselves have legal status; however, these objects can be used to facilitate communicating and managing spatial extent and arrangements of legal objects. For instance, in Victoria, Australia, building elements such as walls and slabs are used to define legal boundaries inside buildings. Additionally, walls or slabs can be part of a common property legal interest.

- **Legal documents:** Various types of legal documents exchanged throughout different phases of building subdivision processes in Victoria were identified. The title, mortgage, and planning permit are the examples of legal documents.

- **Land administration actors:** The subdivision process includes various actors
with their distinct tasks and roles. Some of the actors identified in this research
are land surveyor, city council, owner or developer, referral authorities, and
land registry.

- **Administrative data:** This includes administrative data required for managing
building subdivision projects such as geospatial location, plan number, the
number of lots, and so on.

4.5.2 Design phase

This phase mainly includes design and development of an appropriate artefact to meet
the data requirements identified in the foundation phase. It can be deduced from the
research problem that the open BIM data model, i.e. IFC standard, requires being
extended to accommodate the legal information associated with ownership of properties
in multi-storey building developments. Therefore, the form of the proposed artefact is a
model, i.e. an extended data model of IFC standard.

![Figure 4.5: Design phase of the research methodology](image)

The steps of design phase are shown in Figure 4.5 and described as follows:

**Imagine and brainstorm:** In this sub-activity, various methods of incorporating legal
information into IFC standard were investigated. Although IFC standard is primarily
developed in EXPRESS language, there is also an XML schema of this standard. The
researcher together with his supervisory team had several brainstorming sessions to
produce ideas for extending IFC standard in both EXPRESS and XML schemas. The
identified approaches include:

- Defining new subclasses in either EXPRESS or XML schema
- Using available extension mechanisms in EXPRESS schema
- Establishing an external linkage between IFC standard and existing legal data
  models.
Assess and select: Among the suggested methods in the previous step, “using available extension mechanisms in EXPRESS schema” approach was chosen as an appropriate method for designing the artefact. The justification for selecting this approach was its alignment with strategies that BuildingSMART organization uses for future developments of IFC standard. In addition, it is more optimal approach than defining new subclasses for IFC standard because new attributes and object types can be defined with as minimum change as possible in the current data structure of IFC standard. In other words, there is no need to define new subclasses. The main reason for not adopting options using XML schema is that EXPRESS schema of IFC was primarily developed and then XML schema was copied from it. Moreover, XML schema does not include all IFC entities defined in the EXPRESS schema, and some entities are missing.

Sketch and build: To sketch and build an extension of IFC standard, two steps were done. First, suitable and relevant IFC entities to be used in the proposed extension should be identified. The first step has been already done in Section 3.3.8. Subsequently, the selected extension approach was applied to the relevant IFC entities. In the following subsection, the adopted approach for integrating information into IFC standard will be elaborated.

4.5.2.1 Adopted approach to extending IFC for urban land administration

The adopted approach to extending the relevant IFC entities includes two main parts:

- Property set definitions: The concept of property set definition is used to specialize and extend IFC entities without the need to define new subclasses. Property sets can be assigned to their corresponding IFC entities via ‘IfcRelDefinesByProperties’ relationship. There are two types of property sets that can be assigned to IFC entities, namely statically defined property sets (instances of IfcPreDefinedPropertySet) and dynamically extendable property sets (instances of IfcPropertySet). The statically defined property sets already exist within the IFC specification, and they mainly used for specializing architectural elements. For example, door lining properties (IfcDoorLiningProperties) is used for “IfcDoor” entity. These property sets are not relevant for this research. The relevant ones are dynamically extendable property sets which refer to a set of properties for which the IFC standard only
provides a kind of "meta-model", to be further defined for a specific domain. This means there is no entity definition of this type of property sets within the IFC model. They can be instantiated by assigning a significant string value to the Name attribute of “IfcPropertySet”. The naming convention for a group of property sets is “Pset_xxx”. “IfcProperty” references subclasses of “IfcProperty” entity via “HasProperties” attribute to assemble and group a specific set of attributes. “IfcProperty” is an abstract generalization for all types of properties such as properties with single values (IfcPropertySingleValue), properties with enumerated values (IfcPropertyEnumeratedValue), and properties with values being the type of a resource level entity (IfcPropertyReferenceValue).

- User defined types: Most IFC entities include “USERDEFINED” enumeration to semantically specify a particular type of an IFC entity which does not already exist in IFC schema. For instance, “IfcActorRole” entity includes Role attribute and one possible value for this attribute is “USERDEFINED”. “LAND SURVEYOR” value, which is not already defined as an enumeration value of Role attribute, can be replaced with “USERDEFINED” value (see Figure 3.14).

The detailed explanation of how the selected extension method can be applied to the relevant IFC entities is provided in Chapter 6. In addition to the ways mentioned above, there are general objects, such as IfcProxy and IfcBuildingElementProxy, which can be used for those objects not defined in the IFC schema. It is essential to assign their name and description to provide a semantic meaning for them. These entities were not used in this research since they appeared to be vague concepts for managing legal information.

4.5.3 Implementation phase

In this phase, a prototype BIM model was developed and implemented to provide a demonstration of the developed artefact, which is the proposed extension of IFC standard. As shown in Figure 4.6, the implementation of the prototype model was done in four stages:

- Selection of an appropriate multi-storey development: First, a relatively complex multi-storey building development in the real world should be selected. The justification for choosing the development is that it should include various types of legal interests and boundaries to provide a suitable
demonstration of the concepts used in the proposed use and extension of IFC standard. This step describes the first sub-activity of the demonstrate artefact, which is identifying a suitable case (see Section 4.3.4).

- **Construct BIM model:** For the selected complex development, a BIM authoring tool was used to create the architectural BIM model of the development. This architectural BIM model consisted of various building elements and cognitive spaces, which subsequently was used in defining legal arrangements and boundaries.

- **Exporting BIM model into the format of IFC standard:** The BIM authoring tools have their own proprietary format for storing and managing BIM models. Therefore, the constructed BIM model should be exported into open IFC format to enrich the model based on IFC schema rather than proprietary data structure of BIM authoring tools.

- **Enriching IFC model:** In this stage, the IFC model will be enriched with legal information according to the proposed use and extension of IFC schema. This includes defining various legal interests, legal boundaries, assigning actors, and referencing legal documents. This step corresponds to the second activity of the demonstrate artefact, in which the proposed IFC extension (artefact) is applied to the selected case.

- **Visualizing and querying IFC model:** The final stage of implementation is to visualize and query the final IFC model. Through performing various visualization techniques and query methods, it will be shown how the implemented prototype would provide an appropriate demonstration of the proposed use and extension of IFC standard.
4.5.4 Evaluation phase

A summary of the sub-activities done in the evaluation phase of the research is provided in Figure 4.7. These sub-activities are:

- **Context analysis:** The time for evaluating was around six months (see Table 4.1). The budget for assessing the artefact was provided as a scholarship to the researcher. The people involved in this research were the researcher and his supervisory team. The researcher had both online and face to face meetings with relevant organizations such as BuildingSMART and land registry of Victoria.

- **Selection of strategies:** According to the context analysis, two types of evaluation strategies were adopted, namely subjective and objective assessments. Through the subjective assessment, the validity of the proposed extension of IFC standard was verified based on experts’ opinion. The objective assessment was used to measure the performance of prototype BIM model developed in the previous step.

- **Conducting the evaluation:** The subjective evaluation was undertaken in two aspects, namely information completeness and logical validity of the proposed use and extension of IFC standard. The data collection method used here is semi-structured interviews. There are two groups of participants. The first group comprises experts in land administration domain including land registry experts and land surveyors. The second group is experts having knowledge of the IFC standard. It is found that using 12 participants would lead to “point of saturation” for interview based studies (Galvin 2015). Therefore, this research invited around 6 participants from each group, in total 12 participants. Positions of participants ranged between technical staff and middle management levels. The results of the subjective assessment were communicated using charts. The objective assessment was done in two parts. First, the prototype BIM model was also compared with its 2D plan version. After that the prototype, which is a BIM model comprising both legal and physical information, compared with its purely legal and purely physical models. Various queries and visualization methods on three models performed for the objective assessment. The results were shown in the form of tables and charts.
4.5.5 Documentation and communication phase

In this phase, details of all the previous phases were documented and communicated to both academia and industry communities (see Figure 4.8). For academia, the present thesis includes all the documentation associated with this research. Different parts of this study were published as research articles in relevant journals, namely Transactions in GIS, and International Journal of Geographical Information Science, Computers, Environment, and Urban Systems. In addition, a peer-reviewed conference paper was published and orally presented in FIG working week 2016, and another conference paper in the 5th International FIG Workshop on 3D cadastre has been published. For the industry community, two short articles were published in professional magazines, one in Land Journal of RICS and another one in Position Magazine of SSSI (Surveying and Spatial Sciences Institute). This thesis includes the full documentation which can be used for communicating all activities conducted in this research.
4.6 Chapter Summary

In this chapter, two main research paradigms, namely behavioural research and design science, were identified as methodologies frequently used in research investigations conducted in the domain of land administration. The justification for choosing the design science, rather than behavioural research, as the underpinning framework for conducting this research was provided. Subsequently, the general activities of design science research methodology were briefly overviewed. In order to carry out specific phases of the research methodology, possible research methods for collecting and analysing data were also explored within this chapter. Finally, a comprehensive explanation of the methods and methodology of this research was provided.
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CHAPTER 5

DATA REQUIREMENTS IN URBAN LAND ADMINISTRATION: A CASE STUDY IN VICTORIA, AUSTRALIA
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5 Data Requirements in Urban Land Administration: a Case Study in Victoria, Australia

5.1 Introduction

In this chapter, various data requirements in the context of land administration in an urban built environment will be identified. The contents of this chapter mainly describe “define requirements” stage within the framework of design science. To define an initial set of data requirements, a literature review was firstly done and data elements identified in (Aien 2013) were adopted as those required for managing legal information. This preliminary list of data requirements comprised 3D legal property objects, legal registration documents, and interest holders (Atazadeh, Kalantari, Rajabifard, Ho, and Ngo 2017). The identified data requirements through literature review appeared to be insufficient for addressing spatial and non-spatial complexities associated with managing legal information within urban built environments. One reason is that the general concept of 3D legal property object does not distinguish spatial arrangements of different types of legal interests. For instance, a private interest is composed of only legal spaces whereas a common property legal interest can also comprise physical elements. Another reason is that interest holders are defined in a general way whereas various interest holders and actors with different roles are involved in the current practice of urban land administration.

Therefore, the researcher undertook a placement in a surveying company to identify a more comprehensive range of data requirements according to current practices in the industry environment. In the field of built environment, industry placements, which are a specific type of participant observation method for data collection, provide the opportunity to understand current practices through investigating real-world examples, which is complementary to the theoretical knowledge gained in an academic environment (Frank 2005).

The selected jurisdiction for investigating the current practice of urban land administration is the Victorian State of Australia. All Australian states, particularly Victoria, are fundamentally urbanised regions. According to the 2011 Census, 90.5 percent of the population in Victoria lived in urban built environments (Capuano 2014).
As a result, there has been a significant increase in multi-storey building developments in urban areas of Victoria, particularly Melbourne, to accommodate such large number of population (see Figure 2.1). Therefore, the abundance of multi-storey building developments in urban areas of Victoria with various functional and spatial complexities can be considered as the reason for choosing this jurisdiction to study the current practice of urban land administration.

During the placement period, various types of subdivision plans deemed to represent a comprehensive range of building subdivisions in Victoria were studied (LandVictoria 2015). Although the studied plans include commonly-defined legal interests such as lots and common properties, each plan includes some legal interests which are not defined in other plans. Therefore, the overall investigation of all plans has resulted in expanding and consolidating data requirements, which had been identified from literature review, in accordance with urban land administration practice, which is referred to as building subdivision process in this chapter.

Therefore, this chapter firstly describes current building subdivision process in urban built environments of Victoria, Australia. Subsequently, a detailed explanation of each data requirement created and exchanged throughout the various phases of the building subdivision process will be provided.

5.2 Building Subdivision Process in Victoria, Australia

Building subdivision process is a complex process that involves various entities such as actors, tasks, and documents. Business Process Modelling Notation (BPMN) can be used to facilitate understanding of this complex process (White and Bock 2011). Diagrammatic maps created using BPMN notation represent the whole lifecycle of any business process. Readers are referred to Appendix B which includes an informative description of BPMN notations employed in this research. The lifespan of a typical process for subdivision of buildings in Victoria, Australia mainly includes four phases, namely planning, certification, compliance, and registration. Each phase will be described in detail in the following subsections.

5.2.1 Planning phase

The developer or owner starts the process by identifying a suitable piece of land for subdivision. Once the suitable piece of land has been identified, the land surveyor
conducts the site survey to establish boundaries of the land. Meanwhile, the architect constructs the design model of the building and its architectural elements. Once the developer agrees on the design model of the building, the land surveyor uses the architectural structure of the building as the basis for preparing the subdivision plan of the building. Land surveyors should prepare subdivision plans in alignment with the Subdivision Act (1988) and Regulations (2011b). In preparation of subdivision plans, land surveyors define various types of legal boundaries inside buildings. Subsequently, they propose a range of legal arrangements such as individually owned lots, common properties, and easements. Finally, if there is a need to create any owners corporation, they propose an entitlement and liability value for each individually owned lot, all of which are provided in a tabular form.

The proposed subdivision must be approved under Victorian planning scheme. This planning system is developed based on Planning and Environment Act (1987), which plays a fundamental role in giving a permit for developing and subdividing the land. Therefore, the land surveyor lodges an application for a planning permit to the responsible authority, which is the city council in most cases. City councils mainly assess the planning permit application regarding the following aspects (Department of Planning and Community Development 2012):

- Examination of the proposed subdivision in regards to both state and local planning policy frameworks.
- The capacity of utility networks and other urban infrastructure to service any new lot to be created as a result of the proposed subdivision.
- The possibility of securing access to any new lot.
- Provision of open space and other facilities.
- The consistency of the proposed subdivision with any formerly approved permit.
- The capability of the land to sustain its increased use and development afterwards the subdivision.
- Effect and relation of the proposed subdivision on existing buildings located in its neighbourhood.

According to the above assessment, the city council may undertake the following activities:
• **Referral of planning application:** If the city council decides whether there is any referral required for the proposed subdivision, a copy of the proposal is sent to relevant referral authorities (DELWP 2015). These authorities, such as utility companies, usually likely hold interests over easements and restrictions which are to be created, varied or removed by the proposed subdivision. In addition, the referral process ensures that responsibilities and assets of referral authorities are not adversely affected by the proposed subdivision. The referral authority should respond to referrals within 28 days after receiving the referrals. If additional information is required by the referral authority, the city council should be informed of it within 21 days of receipt of the referrals. Once the referral authority is given the additional information, it has again 28 days to provide responses to the requested referrals. In responding to referrals, a referral authority advises the city council that either it agrees or disagrees with granting of the permit. In some circumstances when the referral authority concurs with the granting of the permit, it requests the city council to include some conditions in the permit.

• **Request for additional information:** In cases where the city council considers that the information provided within the planning permit application is not sufficient to make a decision on the planning application, it can request the land surveyor to provide the city council or a referral authority with additional information (Environment and Planning Act 1987, p. 108).

• **Public notification:** Once the city council is satisfied with the information provided in the planning permit application, it may send a notification to any other person that the grant of the planning permit may cause material detriment to. In most cases, this includes the owners and residents of lots adjoining the proposed subdivision (Environment and Planning Act 1987, p. 104).

After completing the above activities, the city council will decide whether to grant or refuse the application lodged for planning permit. If the city council decides to issue a permit, despite having received objections, it will send a Notice of Decision to Grant a Permit to the land surveyor and associated objectors. This notice indicates that the city council has decided to issue the planning permit. The objectors may appeal against granting of the permit within 21 days of receiving the notice. The planning permit is usually issued with some conditions. There are typically two types of imposed
conditions, namely those imposed by the responsible authority (the city council) as well as the ones imposed by referral authorities. The first type of condition is that the city council may oblige the land owner or the surveyor to do specific actions or provide documents, such as amended plans, for approval. For instance, the city council in most cases must determine open space requirement, which is typically up to five percent of the subdivided land, as a condition of the planning permit (Department of Planning and Community Development 2012, p. 32). The second type of condition is that the landowner must enter into agreements with utility providers, in which they agree with providing services or further referral of plans before certification.

Figure 5.1 provides the BPMN diagram for planning phase. The details of information exchanged in this phase are presented in Table 5.1.

![Figure 5.1: Planning phase of building subdivision process (Refer to Table 5.1 for the details of indices in this figure)]
Table 5.1: Information exchanges in planning phase

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Sender</th>
<th>Receiver</th>
<th>Purpose</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Architect</td>
<td>Owner/Developer</td>
<td>To approve the design of the building</td>
<td>Architectural model of the building</td>
</tr>
<tr>
<td>1</td>
<td>Architect</td>
<td>Land Surveyor</td>
<td>To create subdivision plan of the building</td>
<td>Architectural model of the building</td>
</tr>
<tr>
<td>2</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To receive the permission for use or development of land</td>
<td>Planning permit application</td>
</tr>
<tr>
<td>3</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To receive the permission for use or development of land</td>
<td>Subdivision plan</td>
</tr>
<tr>
<td>4</td>
<td>City Council</td>
<td>Referral Authorities</td>
<td>To receive advice from authorities whose interest may be affected by the grant of a permit</td>
<td>Planning permit application</td>
</tr>
<tr>
<td>5</td>
<td>City Council</td>
<td>Land Surveyor</td>
<td>To inform the land surveyor that planning permit application is rejected</td>
<td>Notice of decision to refuse to grant a permit</td>
</tr>
<tr>
<td>6</td>
<td>City Council</td>
<td>Land Surveyor</td>
<td>To accept permit with objections</td>
<td>Notice of decision to grant a permit</td>
</tr>
<tr>
<td>7</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To ensure that amendments are done</td>
<td>Notice of an application for an amendment to a planning permit</td>
</tr>
<tr>
<td>8</td>
<td>City Council</td>
<td>Land Surveyor</td>
<td>To allow the land surveyor to subdivide the land and building for use and development</td>
<td>Planning Permit</td>
</tr>
</tbody>
</table>

5.2.2 Certification phase

After receiving approval of the planning permit, the land surveyor lodges an application for certifying subdivision plans. It should be noted that the certification process can also
be done concurrently with planning permit process (Subdivision Act 1988, p. 15). However, the certification of subdivision plans is dependent on the approval of planning permit. While in planning phase the role and functions of the city council is underpinned by Environment and Planning Act (1987), this authority undertakes the certification process in regards to the Subdivision Act (1988). The subdivision plans provided in the application for certification must also indicate how conditions imposed in the planning permit are met. After a preliminary assessment, the city council may do the following activities for certifying subdivision plans.

- **Referral of subdivision plans:** Similar to the planning permit process, the application for certification should also be referred to relevant referral authorities if the city council considers that the proposed subdivision affects their legal interests. The referral authorities review the proposed subdivision to according to their imposed conditions on the planning permit. Responses to referrals must be typically provided to the city council within 28 days upon receipt of the application. There could be three decisions made by a referral authority, namely refuse consent, consent to the plan, and require specified alterations.

- **Requesting alternations to subdivision plans:** The city council may request the land surveyor to change the subdivision plan based on its requirements as well as alterations specified by referral authorities. When it is required to modify the subdivision plan, the review time for certification is halted until the land surveyor provides the city council with the altered subdivision plan.

- **Requiring additional information:** If the city council considers that the information provided in subdivision plan is not adequate for certification, it may request further information about the plan only once.

According to the above activities, the city council makes its final decision on the application for certification, which could be refusal or certification of the subdivision plan. A summary of certification phase in BPMN notations is provided in Figure 5.2.
Table 5.2: Information exchanges in certification phase

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Sender</th>
<th>Receiver</th>
<th>Purpose</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To receive certification for the subdivision plan</td>
<td>Application form for certification of plan</td>
</tr>
<tr>
<td>10</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To receive certification for the subdivision plan</td>
<td>Subdivision plan</td>
</tr>
<tr>
<td>11</td>
<td>City Council</td>
<td>Referral Authorities</td>
<td>To assess the subdivision plans by referral authority, particularly easements and restrictions</td>
<td>Subdivision plan</td>
</tr>
<tr>
<td>12</td>
<td>Referral Authorities</td>
<td>City Council</td>
<td>To refuse the consent</td>
<td>Refusal of consent by referral authority</td>
</tr>
<tr>
<td>13</td>
<td>Referral Authorities</td>
<td>City Council</td>
<td>To require specified alterations and conditions</td>
<td>Requirement for alterations to plan</td>
</tr>
<tr>
<td>14</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To address requested alternations of subdivision plan</td>
<td>Altered subdivision plan</td>
</tr>
<tr>
<td>15</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To address request additional information</td>
<td>Altered subdivision plan</td>
</tr>
</tbody>
</table>
5.2.3 Compliance phase

In this phase, a number of requirements, which are typically conditions considered on the permit in the planning phase, should normally be addressed to the satisfaction of city council or referral authority. There are two types of requirements including open space provision and subdivision works. Open space refers to a particular zone of the subdivided land, which is dedicated to public recreation or resort, parkland, and similar purposes. According to (Subdivision Act 1988, p. 32), the term “works” is defined as those works that:

- are required by or for the Council or a referral authority to provide roads or public utility services to the land; and
- are or are to be the responsibility of the Council or a referral authority after the maintenance period.

Prior to commencing subdivision works, the land surveyor should prepare engineering plans according to all specified requirements and imposed conditions in the planning permit. Engineering plans can be lodged in either referral authority or city council or both of them depending on which authority has made requirements. Upon receipt of engineering plans, a decision must be made within 30 days. There could be three possible decisions made by the relevant authority, namely approval, refusal, and request for alterations. After receiving the approval, the land surveyor can commence subdivision works according to the approved engineering plans.

After completion of subdivision works, the city council provides the land surveyor with a statement of compliance (SOC) once the following activities are done:

- The land surveyor has provided the city council with a written advice in a prescribed form (Subdivision (Procedures) Regulations 2011, p.38). This form advises that all
boundaries of roads, reserves, lots, common property areas, and the whole land in the subdivision plan, where appropriate, have been clearly marked out or defined. Additionally, it may notify any substantial discrepancy between subdivision boundaries shown on the certified plan and their counterparts in the real world.

- It is ensured that satisfactory arrangements have been made in accordance with all requirements and conditions placed on the planning permit regarding public works and open space provision. Public works means (Subdivision Act 1988, p. 6):
  - The provision of roads, reserves, open spaces or services within a subdivision
  - Fencing, landscaping, and road works outside the subdivision for roads, reserves or public open space related to the subdivision
  - Works for sewerage, drainage, water supply, power, gas or telephone to connect the subdivision to the system serving properties outside it, excluding works to connect any particular property to the system for the subdivision
  - Other prescribed works

- There is an agreement to secure compliance with all requirements mentioned in the previous item.

Figure 5.3 shows the compliance phase in the form of a BPMN diagram. The next step after obtaining SOC is applying for registration of subdivision plans.
Table 5.3: Information exchanges in compliance phase

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Sender</th>
<th>Receiver</th>
<th>Purpose</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Land Surveyor or Referral Authority</td>
<td>City Council or Referral Authority</td>
<td>To address all requirements and condition placed on the planning permit</td>
<td>Engineering plans</td>
</tr>
<tr>
<td>19</td>
<td>City Council or Referral Authority</td>
<td>Land Surveyor</td>
<td>To refuse to approve the engineering plans</td>
<td>Refusal of engineering plans</td>
</tr>
<tr>
<td>20</td>
<td>City Council or Referral Authority</td>
<td>Land Surveyor</td>
<td>To require specified alterations on engineering plans</td>
<td>Requirement of alternations to engineering plans</td>
</tr>
<tr>
<td>21</td>
<td>City Council or Referral Authority</td>
<td>Land Surveyor</td>
<td>To confirm that engineering plans are consistent with conditions and requirements of city council and referral authority</td>
<td>Approved engineering plans</td>
</tr>
<tr>
<td>22</td>
<td>Land Surveyor</td>
<td>City Council</td>
<td>To notify council that the subdivided land and building have been marked out.</td>
<td>Advice by licensed surveyor</td>
</tr>
<tr>
<td>23</td>
<td>City Council</td>
<td>Land Surveyor</td>
<td>To refuse to approve the statement of compliance</td>
<td>Refusal of statement of compliance</td>
</tr>
<tr>
<td>24</td>
<td>City Council</td>
<td>Land Surveyor</td>
<td>To ensure compliance with agreements and conditions placed on the planning permit</td>
<td>Statement of Compliance</td>
</tr>
<tr>
<td>25</td>
<td>City Council</td>
<td>Land Surveyor</td>
<td>To ensure compliance for specific stage of a staged subdivision</td>
<td>Statement of Compliance for a specified stage of a staged subdivision plan</td>
</tr>
</tbody>
</table>
5.2.4 Registration phase

The purpose of this phase is to register subdivision plans. The application for registration is lodged in land registry organization, which is Land Victoria in this case. Besides certified subdivision plans and issued SOC, current certificate of title (Parent Title) for the subdivided land must be provided. In addition, land registry requires the consent of people who are associated with any mortgage, caveat, and encumbrance affecting the subdivided land (Libbis 2015). If subdivision plans include new common property areas, Owners Corporation information must be additionally provided.

After lodgement, the examiner checks all required documents. In particular, subdivision plans are rigorously examined regarding the correctness of legal interests and boundaries. Once the land registry realizes that all requirements associated with registration are satisfactory, it will register the subdivision plan. At this stage, the new lots or pieces of land legally come into existence. The previous legal definition of the subdivided land does not exist anymore, and its title is not valid. New title documents are issued for new lots. Additionally, mortgage, caveat, and encumbrance documents might be issued, which are the legal documents imposing restrictions on the title documents. After registration, Owners Corporation will undertake responsibilities associated with common property areas. The registration phase is summarized in Figure 5.4.
Figure 5.4: Compliance phase of building subdivision process (Refer to Table 5.4 for the details of indices in this figure)

Table 5.4: Information exchanges in registration phase

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Sender</th>
<th>Receiver</th>
<th>Purpose</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Owner/Developer</td>
<td>Land Registry</td>
<td>To register the legal interests</td>
<td>Certified subdivision plans</td>
</tr>
<tr>
<td>29</td>
<td>Owner/Developer</td>
<td>Land Registry</td>
<td>To provide land registry with the issued</td>
<td>Issued Statement of Compliance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Statement of Compliance</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Owner/Developer</td>
<td>Land Registry</td>
<td>To provide land registry with the current</td>
<td>Current certificate of title (Parent title)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>title information</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Owner/Developer</td>
<td>Land Registry</td>
<td>To provide land registry with owners</td>
<td>Owners corporation information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>corporation information</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Land Registry</td>
<td>Owners Corporation</td>
<td>To manage the common property areas of subdivided development</td>
<td>Registered subdivision plans</td>
</tr>
<tr>
<td>33</td>
<td>Land Registry</td>
<td>Owner</td>
<td>To verify registration of legal of lots</td>
<td>New certificate of titles</td>
</tr>
</tbody>
</table>
5.3 Data Requirements

According to the building subdivision process, five main categories of data requirements in the urban land administration were identified. The reason for the importance of these requirements in the urban land administration is that they provide the basis for managing the spatial complexity associated with legal information defined in urban built environments. These categories include legal objects, physical objects, legal documents, land administration actors, and administrative data (see Figure 5.5). Among these data requirements, legal objects play a core role in the urban land administration and data requirements in other categories are to some extent linked to legal objects. Although subdivision plans include legal objects, in the notation section of these plans it is stated that physical objects are used to define spatial arrangements of legal objects. Therefore, physical objects category is identified based on contents of subdivision plans. Legal documents category is identified based on the documents exchanged throughout building subdivision process. As indicated in Tables 5.1 to 5.4, there are many legal documents exchanged over the course of building subdivision process. However, in this research, an important subset of legal documents is selected, which is critical in each phase of building subdivision process. Land administration actors are mainly referred to those actors who play a major role in performing various activities of building subdivision process. Administrative data category is identified as essential information for certifying and registering subdivision plans.

Figure 5.5: Data requirements in building subdivision process
5.3.1 Legal objects

There are two main types of legal objects, namely legal interests, and legal boundaries. Legal interests are classified into two categories, namely primary and secondary ones. Legal boundaries define the spatial extent of each legal interest. Also, attributes are required for managing semantic information about legal interests. Some attributes are common among all legal interests, while other attributes are required for each specific legal interest. A list of attributes common among all legal interest is brought in Table 5.5. If there are specific attributes for any legal interest, these attributes will be brought in the following subsections for their corresponding legal interest.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal Interest Name</td>
<td>This attribute shows the name of a legal interest. For each legal interest, a specific naming convention is used. For example:</td>
</tr>
<tr>
<td></td>
<td>• Lot: [%] / [Plan Number] e.g. 1/PS123456</td>
</tr>
<tr>
<td></td>
<td>• Common property: CM [#]/ [Plan Number] e.g. CM1/PS123456</td>
</tr>
<tr>
<td></td>
<td>• Reserve: RES [#]/[Plan Number] e.g. RE51/PS123456</td>
</tr>
<tr>
<td>Legal Interest Unit</td>
<td>This attribute describes whether the legal interest consists of one part or multiple parts.</td>
</tr>
<tr>
<td>Legal Interest State</td>
<td>This attribute describes the state of legal interest in subdivision plans. Its state could be created, affected, extinguished, and existing.</td>
</tr>
<tr>
<td>Legal Interest Class</td>
<td>This attribute refers the specific type of legal interest. Its possible values include lot, common property, road, easement, reserve, crown allotment, crown portion, restriction, depth limitation, and airspace.</td>
</tr>
<tr>
<td>Legal Interest Area</td>
<td>This attribute shows the measured area of legal interest.</td>
</tr>
<tr>
<td>Land Use</td>
<td>This optional attribute can be used to specify the land use of a primary legal interest. For instance, land use of a lot could be residential, commercial, and mixed.</td>
</tr>
</tbody>
</table>

5.3.1.1 Primary legal interests

Primary legal interests are base level parcels that constitute the continuous cadastral fabric. This means that there is no gap between two primary legal interests and they cannot overlap each other. These legal interests include lot, common property, road, reserve, and crown parcel.
• **Lot**: Lot can be classified into land lot and volumetric lot. Land lot is defined in undeveloped land (see Figure 5.6). This type of lot can be represented by land surface. A volumetric lot can typically include two main parts: apartment unit and accessory part (see Figure 5.7). There are two types of accessory part: parking space and storage space. The legal attributes peculiar to a lot are brought in Table 5.6.

![Figure 5.6: Example of a subdivided land lot](image)

![Figure 5.7: Parts of a volumetric lot defined within a subdivision plan](image)
Table 5.6: Required attributes specific to lot

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot Liability</td>
<td>The proportion of the administrative and general expenses that each lot owner is obliged to pay.</td>
</tr>
<tr>
<td>Lot Entitlement</td>
<td>The share of interest that each lot owner has in the common property area</td>
</tr>
<tr>
<td>Volume</td>
<td>This attribute shows the measured volume of a volumetric lot</td>
</tr>
<tr>
<td>Address</td>
<td>This attribute should be used to provide the address of lots</td>
</tr>
</tbody>
</table>

- **Common property:** A common property is spatially defined as communal legal spaces (such as corridors and lobbies) plus physical structures (such as walls and ceilings) which are for the benefit and use of a specific group, or usually all, of the owners through their membership in an owners corporation. The legal attributes specific to the common property are brought in Table 5.7. There are two types of common property, namely unlimited and limited. The unlimited common property is for the use and benefit of all owners, whereas limited one must be used by a specific group of owners. In Figure 5.8, common property No. 1, which is highlighted in red, is unlimited which means that all lot owners can use and benefit from this common property. However, other common properties are for the benefit and use of specific owners. For example, common property No. 5, which is highlighted in green, is commonly owned by owners of lots with numbers from 101N to 115N. An additional aspect of common properties is that they also include physical structures. However, 2D cross-section and floor plan views of only communal legal spaces are represented and physical structures are abstracted for the sake of simplicity (see Figure 5.8). Instead, in notation section of the subdivision plan, it is stated that which physical structures belong to the specific common property area. For example, for all lots in Figure 5.8:

“All walls defining boundaries, floor and ceiling slabs, columns, internal service ducts, conduits, pipe shafts, and electricity consumer mains cables within the building and courtyards are deemed to be part of common property No. 1”
Table 5.7: Required attributes specific to common property

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Property Type</td>
<td>There are two types of common property: Limited and Unlimited. Unlimited commonly owned properties are for the use and benefit of all owners, whereas limited ones must be used by a specific group of owners.</td>
</tr>
<tr>
<td>Land Affected</td>
<td>This includes a list of those lots that are affected by the owners corporation being responsible for managing the common property.</td>
</tr>
<tr>
<td>Limitation Details</td>
<td>This attribute is optional, and it should be used to provide limitation details for limited common properties.</td>
</tr>
</tbody>
</table>

Figure 5.8: Unlimited and limited common properties

- **Road**: This type of legal interest is for the benefit and use of public. Road usually includes carriageway, pavement, verge, and kerb. A complete list of road types is provided in Victorian ePlan Handbook (LandVictoria 2016). An example of road legal interest created in a subdivision plan is highlighted in red in Figure 5.9.

- **Reserve**: Similar to Road, this type of legal interest is for the benefit and use of public. Reserve includes those land parcels owned by the city council (see Figure 5.10). City council usually uses these parcels to establish parks or similar amenities. Similar to a land lot, the reserve can be represented by land surface.
• **Crown Parcel**: This legal interest refers to those land parcels owned by the government. Similar to land lots, crown parcels can be represented by land surface (see Figure 5.11). Crown land constitutes almost one-third of Victoria, and these parcels are allocated for public use, which typically includes national parks and state forest, freeways, recreation areas, hospitals and sporting facilities (DELWP 2016).
5.3.1.2 Secondary legal interests

Secondary legal interests provide benefits and/or pose restrictions on primary legal interests. These legal interests can spatially intersect with primary legal interests. They include easement, restriction, depth limitation, and airspace.

- **Easement:** Easement represents utility networks which provide benefits or pose restrictions on the original land parcel that the building has been developed on (see Figure 5.12). This legal interest can itself be either physical (visible) elements, such as utility elements outside the buildings and roads, or it can be invisible external spaces surrounding utility elements.

- **Restriction:** Restriction is a type of covenant which defines an area on one or more lots where limitations on the use of land apply. For example, in Figure 5.13, owners of lots 5 and 7 shall not construct any building requiring sewerage services in the hatched area. Table 5.8 includes those legal attributes which are specifically required for managing easement and restriction.

- **Depth limitation:** Depth limitation is a form of restriction that originates from the original crown grant. The spatial extent of depth limitation can be determined by underground volumetric spaces external to the building. The spatial extent of this legal interest is not delineated in subdivision plans. Only its length is notated in the fact sheet of subdivision plans.

- **Airspace:** Airspace is a form of legal interest that its spatial extent is defined above the ground and external to the building. An example of airspace is height limitation.
which specifies the maximum use of the above ground space for constructing a building. The spatial extent of this legal interest is not delineated in subdivision plans. Only its length is notated in the fact sheet of subdivision plans. Table 5.8 includes those legal attributes which are specifically required for managing depth limitation or airspace.

Figure 5.12: An easement highlighted in red

Figure 5.13: An example of restriction area, adapted from (LandVictoria 2016)
Table 5.8: Required attributes specific to easement and restriction

<table>
<thead>
<tr>
<th>Legal Interest</th>
<th>Attributes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easement or Restriction</td>
<td>Land Benefited</td>
<td>This attribute refers to those legal interests benefiting from the easement or restriction.</td>
</tr>
<tr>
<td></td>
<td>Land Burdened</td>
<td>This attribute refers to those legal interests on which the easement or restriction impose a burden.</td>
</tr>
<tr>
<td></td>
<td>Easement Width</td>
<td>The width of the easement measured in length unit (e.g. meter).</td>
</tr>
<tr>
<td></td>
<td>Easement Origin</td>
<td>The number of the plan from which the easement is originated.</td>
</tr>
<tr>
<td>Easement</td>
<td>Easement Purpose</td>
<td>Easements can be utilized for a variety of purposes. Examples are Drainage, Powerline, Sewerage, Floodway, and Wetland. The complete list is provided in “Victorian ePlan Handbook, Section 2 -Victoria Reference Data List” (LandVictoria 2016)</td>
</tr>
<tr>
<td>Restriction</td>
<td>Restriction Description</td>
<td>Textual description of the restriction</td>
</tr>
<tr>
<td></td>
<td>Restriction Expiry Date</td>
<td>This attribute is for those restrictions having an expiry date.</td>
</tr>
</tbody>
</table>

Table 5.9: Required attributes unique to depth limitation or airspace

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>The length of the depth limitation or the height of the airspace, which is typically measured in the meter.</td>
</tr>
<tr>
<td>Land Applied</td>
<td>Those created lots to which the depth limitation or airspace applies.</td>
</tr>
<tr>
<td>Upper Limit</td>
<td>This attribute shows the lower limit of the depth limitation or airspace from the site level.</td>
</tr>
<tr>
<td>Lower Limit</td>
<td>This attribute shows the upper boundary of the depth limitation or airspace from the site level.</td>
</tr>
</tbody>
</table>
5.3.1.3 Legal boundaries

A range of subdivision plans deemed to represent a comprehensive variety of types of subdivisions was used to develop a taxonomy of legal boundaries. The legal basis for defining legal boundaries in Victoria is underpinned by the Subdivision (Registrar’s Requirements) Regulations (2011b). In the cadastral domain, there is a dichotomy between general and fixed boundaries. The developed taxonomy is the expanded version reflecting this dichotomy (see Figure 5.14).

![Figure 5.14: Taxonomy of legal boundaries in Victoria, Australia](image)

5.3.1.4 General boundaries

General boundaries are boundaries that are specified and observed based on real world, tangible spatial objects. In building subdivision plans, there are three main types of general boundaries: structural, ambulatory and projected.

Structural boundaries are defined and measured by considering the building itself or a part of it. These boundaries can be classified into four categories: interior, median, exterior and other.

Interior structural boundaries are delineated by the interior face of building elements (see Figure 5.15). This means that all internal fixtures, coverings, and waterproof membranes attached to walls, ceilings, and floors are part of the relevant lot legal interest (LandVictoria 2015). For walls, doors, and windows, the internal surface is used to delineate interior boundary. For floor slabs, interior boundary is defined by referencing the upper surface, whereas, for ceiling slabs, this boundary is defined as the underside of the suspended ceiling.
Median structural boundaries lie along the imaginary surface passing through the centreline of building elements. In other words, a median boundary is delineated through referencing a surface having the same distance from both exposed surfaces of a building element. This boundary is delineated to divide the legal of its corresponding building element between the abutting legal spaces. Figure 5.16 represents an example of median boundaries to illustrate how these boundaries are depicted and notated in subdivision plans.

Exterior structural boundaries are delineated through referencing external surface of building elements. These boundaries indicate that the whole of relevant building elements is contained within the corresponding legal interest. For instance, as illustrated
in Figure 5.17, the boundary between Lot 1 and common property No.1 should be interpreted that the wall, window, and door are completely part of the Lot 1.

“Other” structural boundaries are delineated through referencing some location, other than median, inside the building elements. For example, in Figure 5.18, each level includes a suspended ceiling and elevated floor, and there is a slab between them. As indicated, the upper boundaries touch the underside face of the slab and lower boundaries touch the upper face of the slab. This means that both boundaries are inside the whole building element at a location other than the median surface.

As a specific type of general boundary (Williamson et al. 2010, p. 360), ambulatory
boundaries are defined based on observing the movement of dynamic natural features such as coastlines and river borders (DELWP 2014). In Figure 5.19, the floor plan for the ground level of a development comprising four multi-story buildings is represented, and the southern boundary of one of the common properties (Common Property No.1) is delineated by referencing the Yarra river. The location of this boundary may change slowly and unperceivably over time.

Projected boundaries are mainly used to define balconies and terraced areas of buildings. It is mainly delineated by extending structural boundaries in both horizontal as well as vertical directions. These boundaries are represented by thick broken lines in cross section diagrams (Figure 5.20a). However, in floor plans, projected boundaries are delineated by thick continuous lines. The study showed that it was unusual to extend vertical building elements, such as walls, in horizontal directions in any condition. This means that floor plans can only show vertical projections (Figure 5.20b).
Figure 5.20: Projections in subdivision plans, a) Boundary delineation in cross section diagrams, b) Boundaries labelled “P” in the first floor are defined by projection.

5.3.1.5 Fixed boundaries

Fixed boundaries in subdivision plans are boundaries that are specified based on surveying measurements such as distance, angle, and azimuth. In subdivision plans, this type of boundary is usually utilized to define the spatial extent of parking and storage areas in buildings. In Figure 5.21, boundaries of a parking area in the basement level of a building are represented and it can be seen that fixed boundaries are delineated through their corresponding distances and azimuths which are annotated alongside the boundary lines.

Figure 5.21: Fixed boundaries in subdivision plans
5.3.2 Physical objects

Physical objects can facilitate the communication of legal interests with boundaries referencing physical elements. In addition, these elements can also themselves represent parts of a legal interest. Although the spatial extent of physical objects is not explicitly represented in subdivision plans, it is notated that how these objects define boundaries of legal interests and how they also constitute parts of legal interests (see Table 5.10).

<table>
<thead>
<tr>
<th>Physical object</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building elements</td>
<td>These physical structures can be used to show the boundaries between legal interests. While walls, windows, doors, and columns provide vertical boundaries, ceilings and floors represent the horizontal upper and lower limits of legal interests. Additionally, building elements can constitute parts of common property area.</td>
</tr>
<tr>
<td>Distribution elements</td>
<td>Distribution elements inside the building can constitute parts of common property areas. Examples are ducts, conduits, pipe shafts, and electricity cables. Distribution elements outside buildings can be defined as easements. Examples are drainage, water supply, and other services.</td>
</tr>
<tr>
<td>Geographic elements</td>
<td>These elements can be used to represent geographical easements located around the building site. They can also be used for referencing ambulatory boundaries (e.g. rivers).</td>
</tr>
<tr>
<td>Civil elements</td>
<td>These elements can be used to define the spatial extent of roads. Therefore, they can be used to represent either part of common property area (which is a road) or an individual road legal interest.</td>
</tr>
<tr>
<td>Site elements</td>
<td>These elements represent the surface of the land, on which the building is developed. They can be used to represent those legal interests whose spatial extent is associated with the land surface. These include crown parcels, land lots, reserves, and restrictions.</td>
</tr>
</tbody>
</table>

5.3.3 Legal documents

Legal documents include the legal evidence or fact to specify and certify the interests to be granted for a rightful claimant. As indicated in Section 5.2, there are a large number of legal documents exchanged throughout building subdivision process. Here, the
important ones playing a key role in this process are selected as the main required legal documents. These include planning permit, certification, statement of compliance (SOC), engineering plan, title, parent title, mortgage, caveat, and encumbrance (see Table 5.11).

<table>
<thead>
<tr>
<th>Legal Document</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning permit</td>
<td>This document provides permission and conditions to use and develop a piece of land.</td>
</tr>
<tr>
<td>Certification</td>
<td>This document ensures that the proposed subdivision is satisfactory for the city council.</td>
</tr>
<tr>
<td>Statement of Compliance</td>
<td>This document ensures that required activities, such as subdivision works, are undertaken in compliance with agreements and conditions placed on the planning permit.</td>
</tr>
<tr>
<td>Engineering plan</td>
<td>If conditions in the planning permit require works to be undertaken (e.g. construction of roads, drainage, and services), engineering plans may be necessary. In such cases, statement of compliance will not be issued until the Engineering plans have been approved.</td>
</tr>
<tr>
<td>Title</td>
<td>Each title document provides an official record of proprietorship of a specific lot. It contains guaranteed information on any person entitled to an interest in the land lot or volumetric lot described on the title document.</td>
</tr>
<tr>
<td>Parent title</td>
<td>Parent title provides the legal description of the land before its subdivision.</td>
</tr>
<tr>
<td>Mortgage, caveat, and encumbrance</td>
<td>These documents pose restrictions on the title document.</td>
</tr>
</tbody>
</table>

5.3.4 Land administration actors

Several stakeholders are involved in the process of subdividing and managing legal interests in buildings. The important actors with a description of their acting roles are provided in Table 5.12.
Table 5.12: Land administration actors

<table>
<thead>
<tr>
<th>Actor</th>
<th>Role Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Surveyor</td>
<td>Land surveyor delineates all legal interests in subdivision plans</td>
</tr>
<tr>
<td>Owner</td>
<td>This actor owns a particular lot.</td>
</tr>
<tr>
<td>Owners Corporation</td>
<td>Owners Corporation is the legal entity responsible for controlling the use and maintenance of common property areas.</td>
</tr>
<tr>
<td>Land registry</td>
<td>This actor registers all legal interests and issues title documents for lots.</td>
</tr>
<tr>
<td>City Council</td>
<td>This authority issues planning permit, certification, and SOC documents. It also owns reserve legal interests.</td>
</tr>
<tr>
<td>Referral Authority</td>
<td>This actor mainly owns easements and restrictions. Therefore, it may impose conditions and requirements on the planning permit and specifies whether the easements have been appropriately defined in the subdivision plan. It usually refers to utility companies providing services to buildings.</td>
</tr>
<tr>
<td>Developer</td>
<td>This actor has the intention to use and develop a piece of land.</td>
</tr>
</tbody>
</table>

5.3.5 Administrative data

Administrative data are extracted from the fact sheet of subdivision plans. It can be classified into two categories, namely survey header and plan information. Survey header is the information about the address and geospatial position of the subdivided development such as parish, township, and approximate geographic coordinates (see Table 5.13). Plan information provides metadata for the plan of subdivision such as plan number, plan area and plan stage, the number of lots (see Table 5.14).
Table 5.13: Required attributes of survey header

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>It defines the world latitude at the reference point of the subdivided development.</td>
</tr>
<tr>
<td>Longitude</td>
<td>It shows the world longitude at the reference point of the subdivided development.</td>
</tr>
<tr>
<td>Elevation</td>
<td>Datum elevation at the reference point of the subdivided development relative to the sea level.</td>
</tr>
<tr>
<td>Address</td>
<td>Address information about the subdivided development</td>
</tr>
</tbody>
</table>

Table 5.14: Required attributes of plan information

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan Number</td>
<td>Plan number of the subdivided development</td>
</tr>
<tr>
<td>Stage Number</td>
<td>Stage number of the subdivided development</td>
</tr>
<tr>
<td>Lots Number</td>
<td>Number of lots in the subdivided development</td>
</tr>
<tr>
<td>Head of Power</td>
<td>This provides the legislation that the subdivision is based on.</td>
</tr>
<tr>
<td>Survey Format</td>
<td>This is the type of survey. Examples are volumetric or building format. Each jurisdiction has its own list of survey types.</td>
</tr>
<tr>
<td>Status</td>
<td>This attribute provides the reason for the lodgment of the survey file.</td>
</tr>
<tr>
<td>Administrative Date</td>
<td>The time of the survey</td>
</tr>
</tbody>
</table>

5.4 Chapter Summary

In this chapter, building subdivision process in urban built environments of Victoria, Australia, was investigated. This process typically comprises four main phases, namely planning phase, certification phase, compliance phase and registration phase. Through this process, a wide range of data requirements in the context of Victorian urban land administration system was identified. These requirements were classified into five main categories including legal objects, physical objects, legal documents, land
administration actors, and administrative information. Legal objects play a fundamental role throughout the subdivision process, and all other data requirements are associated with this category. For instance, physical objects are required to appropriately record, manage and communicate the spatial extent of some legal interests. Also, legal documents, such as titles, provide legal validity of legal interests, such as lots.

The next chapter will explain how these data requirements can be modelled inside a BIM environment by developing an extended version of IFC standard.
CHAPTER 6

DESIGN AND IMPLEMENTATION OF A PROPOSED EXTENSION OF IFC STANDARD FOR URBAN LAND ADMINISTRATION
6 Design and Implementation of a Proposed Extension of IFC Standard for Urban Land Administration

6.1 Introduction
This chapter comprises “Design the artefact” and “Demonstrate the artefact” steps within the framework of design science. The proposed artefact is designed by developing a new extension of IFC standard for urban land administration in Victoria. This proposed extension describes that how data requirements elicited in the previous chapter can be appropriately addressed. For demonstrating the proposed IFC extension, a prototype BIM model will be then implemented to showcase how this artefact can be used for managing legal information associated with a real multi-storey development located in Melbourne, Victoria.

6.2 Proposed Extension of IFC
The IFC version adopted in this research is IFC4 since “IfcSpatialZone” entity, which is the suitable concept for modelling spatial arrangement of various legal interests, is a new one in this version of IFC standard. The proposed extension and use of IFC standard is predicated on relevant IFC concepts as well as extension mechanisms explained in Section 4.5.2. In line with the logic of the IFC standard, these relevant concepts will be extended to model legal information with as minimum change as possible in the current data structure of IFC. Various EXPRESS-G diagrams will be used to facilitate understanding of the proposed entities and their relationships. Within these diagrams, the existing entities will be represented according to the colouring scheme used in IFC standard. To understand these diagrams and their colouring scheme, readers are referred to Appendix A. To distinguish the proposed entities from the existing ones, they will be represented in red in all diagrams.

6.2.1 Adopted approach for modelling legal interests in IFC
Spatial zones are generally utilized to compose invisible spatial elements (instantiable subclasses of “IfcSpatialElement”) as well as physical elements (instantiable subclasses of “IfcElement”) in a non-hierarchical approach for a specific purpose (e.g. lighting or thermal activity of the building). Currently, IFC standard supports different types of
spatial zones in buildings. As indicated in Figure 6.1, the PredefinedType attribute uses IfcSpatialZoneTypeEnum enumeration data type to specify the type of a spatial zone. “IfcSpatialZone” entity is related to its constituent elements via “IfcRelReferencedInSpatialStructure” objectified relationship. This relationship utilizes the RelatedElements attribute to refer to a set of elements (subclasses of “IfcProduct” entity) referenced in a spatial zone (see Figure 6.1). In other words, “IfcRelReferencedInSpatialStructure” relationship is used to formulate what elements define a spatial zone for each legal interest. In addition, attributes of each legal spatial zone can be defined as new property sets (instances of “IfcPropertySet”). These property sets can be assigned to their corresponding legal spatial zone via “IfcRelDefinesByProperties” relationship. Another important factor in assigning property sets is that they can also be attached to each element constituting a specific legal spatial zone. For instance, when a volumetric lot only consists of one space, both “IfcSpace” and “IfcSpatialZone” entities can be used to model the volumetric lot. In this case, proposed property sets for volumetric lots can be either assigned to “IfcSpace” or “IfcSpatialZone” depending on which entity was used to model the volumetric lot. Therefore, a list of IFC entities, in addition to “IfcSpatialZone”, to which each property set is applicable will be provided. Some attributes (property set) are common among all legal interests. Table 6.1 provides this property set, which can be assigned to any legal interest. Depending on the type and spatial arrangement of a legal interest, this property set can be applied to “IfcSpatialZone, IfcZone, IfcSpace, IfcSite, IfcExternalSpatialElement, IfcCivilElement, IfcGeographicElement, IfcBuildingElement and IfcDistributionElement” entities.
6.2.2 Primary legal interests in IFC

6.2.2.1 Volumetric Lot

Three types of internal spaces (IfcSpace), namely apartment unit, parking space and storage area, constitute a spatial zone for an individually owned volumetric lot. Therefore, RelatedElements attribute should only reference a set of “IfcSpace” entities to define a spatial zone of a volumetric lot (see Figure 6.2). Table 6.2 provides the specific attributes (Pset_Lot) for both land and volumetric lots. For volumetric lots, this
A property set can be applied to “IfcSpatialZone, IfcSpace, and IfcZone” entities. Moreover, Table 6.3 includes the other important attributes of the lot, which already exist in IFC standard.

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Property Type</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>LotLiability</td>
<td>IfcPropertySingleValue</td>
<td>IfcPositiveRatioMeasure</td>
</tr>
<tr>
<td>LotEntitlement</td>
<td>IfcPropertySingleValue</td>
<td>IfcPositiveRatioMeasure</td>
</tr>
</tbody>
</table>

Table 6.3: Other existing attributes of lot

<table>
<thead>
<tr>
<th>Name</th>
<th>Corresponding IFC entity</th>
<th>Relevance for Lots</th>
</tr>
</thead>
<tbody>
<tr>
<td>GrossVolume</td>
<td>Qto_SpaceBaseQuantities which is applied to IfcSpace</td>
<td>This can be used to determine the volume of a volumetric lot</td>
</tr>
<tr>
<td>BuildingAddress</td>
<td>Attribute of IfcBuilding</td>
<td>This attribute can be used to provide the address of lots.</td>
</tr>
</tbody>
</table>

Figure 6.2: Volumetric Lot in IFC
6.2.2.2 **Land Lot**

Spatial zone of a land lot also include site elements showing the land surface for the land lot. Therefore, `RelatedElements` attribute should reference a set of “IfcSite” entities (see Figure 6.3). However, this spatial zone can have its own placement and geometric representation to show its legal boundaries. For a land lot, both attributes brought in Table 6.2 and Table 6.3 can be applied to “IfcSpatialZone and IfcSite” entities.

![Figure 6.3: Land lot in IFC](image)

6.2.2.3 **Common Property**

Spatial zone of common property can comprise internal and external spaces, building elements, distribution elements inside buildings and, in some cases, roads. Therefore, `RelatedElements` attribute should reference a set of “IfcSpace, IfcExternalSpatialElement, IfcBuildingElement, IfcDistributionElement, IfcCivilElement, and IfcGeographicElement” entities (see Figure 6.5). In addition, Table 6.4 provides the specific attributes (Pset_CommonProperty) for common property spatial zones. This property set can be applied to “IfcSpatialZone, IfcZone, IfcSpace, IfcExternalSpatialElement, IfcBuildingElement, IfcCivilElement, and IfcGeographicElement” entities.
### Table 6.4: Proposed property set for common property

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Pset_CommonProperty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Property Type</td>
</tr>
<tr>
<td>CommonPropertyType</td>
<td>IfcPropertyEnumeratedValue</td>
</tr>
<tr>
<td>LandAffected</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>LimitationDetails</td>
<td>IfcPropertySingleValue</td>
</tr>
</tbody>
</table>

#### 6.2.2.4 Road

Spatial zone of a road includes civil and geographic elements constituting different parts of the road. There are two types of roads, namely existing and new ones. “IfcGeographicElement” is used for modelling existing roads, while “IfcCivilElement” is used for modelling new roads. Therefore, it is suggested that RelatedElements attribute should reference a set of “IfcGeographicElement, and IfcCivilElement” entities (see Figure 6.4). The attributes of roads are only the common ones brought in Table 6.1. For roads, they can be applied to “IfcSpatialZone, IfcCivilElement, and IfcGeographicElement” entities.

![Figure 6.4: Road in IFC](image-url)
Design and Implementation of a Proposed Extension of IFC Standard for Urban Land Administration

Figure 6.5: Common property in IFC
6.2.2.5 Reserve
Spatial zone of reserve includes site elements showing the land surface for the reserve. Therefore, \texttt{RelatedElements} attribute should reference a set of “\texttt{IfcSite}” entities (see Figure 6.6). However, this spatial zone can have its own placement and geometric representation to show its legal boundaries. The attributes of reserves are only the common ones brought in Table 6.1. For reserves, they can be applied to “\texttt{IfcSpatialZone} and \texttt{IfcSite}” entities.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{Figure_6.6_Reserve_in_IFC}
\caption{Reserve in IFC}
\end{figure}

6.2.2.6 Crown Parcel
Spatial zones for crown parcel also include site elements showing the land surface for the crown parcel. Therefore, \texttt{RelatedElements} attribute should reference a set of “\texttt{IfcSite}” entities (see Figure 6.7). However, this spatial zone can have its own placement and geometric representation to show its legal boundaries. The legal attributes of crown parcels are only the common ones, which are already brought in Table 6.1. For crown parcels, they can be applied to “\texttt{IfcSpatialZone} and \texttt{IfcSite}” entities.
6.2.3 Secondary legal interests in IFC

6.2.3.1 Easement

Easement spatial zones can consist of distribution elements, geographic elements, civil elements and external space objects surrounding those elements. Therefore, RelatedElements attribute references a set of “IfcDistributionElement, IfcGeographicElement, IfcCivilElement, and IfcExternalSpatialElement” entities for modelling easements (see Figure 6.8). In addition to the property set brought in Table 6.1, Table 6.5 includes the attributes (Pset_RestrictionCommon) which are common between easements and other restrictions. The attributes (Pset_Easement) peculiar to the easement are also provided in Table 6.6. For easements, both “Pset_RestrictionCommon” and “Pset_Easement” property sets can be applied to “IfcSpatialZone, IfcExternalSpatialElement, IfcGeographicElement, IfcCivilElement, and IfcDistributionElement” entities.

6.2.3.2 Restriction

Spatial zone of a restriction includes site elements showing the land surface for the restricted area. In addition, the restriction can also be applied to external spaces around buildings, such as building envelopes, and material of building elements, such as
colours and setbacks of walls. Therefore, RelatedElements attribute should reference a set of “IfcSite, IfcExternalSpatialElement, and IfcBuildingElement” entities (see Figure 6.9). In addition to property sets brought in Table 6.1 and Table 6.5, the attributes (Pset_Restriction) provided in Table 6.7 should also be used to manage information about restrictions. For restriction, these property sets can be applied to “IfcSpatialZone, IfcExternalSpatialElement, IfcSite, and IfcBuildingElement” entities.

Table 6.5: Property set common between easement and restriction

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Pset_RestrictionCommon</th>
<th>Property Type</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>LandBenefited</td>
<td>IfcPropertySingleValue</td>
<td>IfcText</td>
<td></td>
</tr>
<tr>
<td>LandBurdened</td>
<td>IfcPropertySingleValue</td>
<td>IfcText</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.8: Easement in IFC
Table 6.6: Specific property set for easement

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Pset_Easement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Property Type</td>
</tr>
<tr>
<td>EasementWidth</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>EasementOrigin</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>EasementPurpose</td>
<td>IfcPropertySingleValue</td>
</tr>
</tbody>
</table>

Table 6.7: Specific property set for restriction

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Pset_Restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Property Type</td>
</tr>
<tr>
<td>RestrictionDescription</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>RestrictionExpiryDate</td>
<td>IfcPropertySingleValue</td>
</tr>
</tbody>
</table>

6.2.3.3 Depth Limitation

Spatial zone of depth limitation can be defined by referencing “IfcExternalSpatialElement” entity which models external spaces (see Figure 6.10). The specific attributes (Pset_DepthLimitationOrAirspace) for depth limitation is brought in
Table 6.8. This property set can be applied to “IfcSpatialZone and IfcExternalSpatialElement” entities.

6.2.3.4 Airspace

Spatial zone of airspace can also be defined by referencing “IfcExternalSpatialElement” entity which models external spaces (see Figure 6.11). The specific attributes for airspaces are the same as depth limitations (see Table 6.8).

Table 6.8: Specific property set for depth limitation and airspace

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Pset_DepthLimitationOrAirspace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Property Type</td>
</tr>
<tr>
<td>Length</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>LandApplied</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>UpperLimit</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>LowerLimit</td>
<td>IfcPropertySingleValue</td>
</tr>
</tbody>
</table>
6.2.4 Modelling legal boundaries inside IFC standard

Within IFC schema, “IfcRelSpaceBoundary” entity plays a key role in modelling both geometry and semantic of boundaries associated with various legal interests. First, geometric representation of legal boundaries will be firstly elucidated in Section 6.2.4.1. Subsequently, semantic entities for distinguishing different types of general and fixed boundaries within IFC standard will be investigated in Section 6.2.4.2.

6.2.4.1 Modelling geometry of boundaries in IFC

Figure 6.12 represents the entities used for modelling the geometry of legal boundaries. The most abstract entity for representing geometry is “IfcConnectionGeometry” which is associated to “IfcRelSpaceboundary” via ConnectionGeometry attribute. For legal interests with 3D volumetric extent, legal boundaries are represented as surfaces or faces. Therefore, “IfcConnectionSurfaceGeometry” subclass should be used in this case for defining the geometric connection between two legal spaces. This subclass includes entities which define surface boundaries of spaces through connective relationships: SurfaceOnRelatingElement relationship specifies whether the connection is a surface (IfcSurface) or a face with an associated surface (IfcFaceSurface) via “IfcSurfaceOrFaceSurface” entity. Geometry and placement of the boundary surface are
defined relative to its relating legal space. Additionally, the optional “SurfaceOnRelatedElement” relationship provides the geometry and placement of the same surface within the local coordinate system of the related legal space.

For legal interests associated with land surfaces, such as crown parcels, reserves, or restrictions, the geometry of legal boundaries should be represented as curves or edges. Therefore, in this case, “IfcConnectionCurveGeometry” subclass can be used to define boundaries between legal interests delineated with 2D spatial extent. CurveOnRelatingElement relationship specifies whether the connection is a bounded curve (IfcBoundedCurve) or an edge with an associated curve (IfcEdgeCurve) via “IfcCurveOrEdgeCurve” entity. Additionally, the optional “CurveOnRelatedElement” relationship provides the geometry and placement of the same curve within the local coordinate system of the related parcel.

![Diagram of relevant entities for modelling the geometry of legal boundaries in IFC](image)

**Figure 6.12: Relevant entities for modelling the geometry of legal boundaries in IFC**

### 6.2.4.2 General boundaries in IFC

For modelling structural boundaries, “IfcRelSpaceBoundary” entity should reference “IfcBuildingElement” class (or its subclasses) through “RelatedBuildingElement” relationship (see Figure 6.15). Additionally, the value of “IfcPhysicalOrVirtualEnum”
attribute must be set to PHYSICAL since structural boundaries reference physically existent spatial objects. Both interior and exterior structural boundaries can be semantically distinguished from each other by specifying their corresponding enumerator from “InternalOrExternalBoundary” enumeration. There is currently no enumerator defined for median and “other” boundaries to differentiate them from other types of structural boundaries (see Figure 6.15). Therefore, it is suggested that “InternalOrExternalBoundary” should be enriched with “Median” and “USERDEFINED” values which respectively provide the semantics for median and “other” structural boundaries. Figure 6.13 provides an example that illustrates how an interior wall boundary between two apartment units can be modelled using IFC entities.

Although there is no physical manifestation for projected boundaries, these boundaries can be similarly modelled by referencing building elements since projected boundaries are delineated through extrusion of structural boundaries. For instance, the boundary surface referencing a wall in a balcony area can be extended to delineate its projection up to the ceiling. Therefore, there does not appear to be a need to define a specific IFC entity for projected boundaries.
For modelling ambulatory boundaries, “IfcRelSpaceBoundary” entity should reference “IfcGeographicElement” class through “RelatedBuildingElement” relationship (see Figure 6.15). “IfcGeographicElement” is the semantic entity for modelling geographic features such as rivers, lakes, trees and roads. Within this entity, the “PredefinedType” attribute specifies the type of geographic element. For modelling rivers and coastlines, this attribute should be set to “RIVER” and “COASTLINE” respectively.

6.2.4.3 Fixed boundaries in IFC

To model fixed boundaries, “IfcRelSpaceBoundary” entity should reference “IfcVirtualElement” class through “RelatedBuildingElement” relationship (see Figure 6.15). Additionally, the value of “IfcPhysicalOrVirtualEnum” attribute must be set to VIRTUAL because surveying measurements are not tangible in the real world. Figure 6.14 provides an example to illustrate how a fixed boundary between two car park areas can be modelled using IFC entities.

![Diagram of fixed boundaries in IFC](image)

Figure 6.14: Mapping a fixed boundary within IFC standard
Figure 6.15: Semantic entities for modelling legal boundaries in IFC standard
6.2.5 Assigning actors to spatial zones

Some actor roles, such as owners, have already been defined in IFC schema. The other roles can be set by UserDefinedRole attribute. For assigning actors, the “IfcRelAssignsToActor” relationship is used. This relationship has three specific attributes: 1- RelatingActor: It references information about the actor itself 2- ActingRole: The role that actor plays within the context of the assignment 3- RelatedObjects: It refers to those objects, which are legal interests in this context, with which the actor is associated. For example, as illustrated in Figure 6.16, common property legal interest is assigned to “Owners Corporation Manager” actor with “manage” acting role. Likewise, all other actors can be assigned to their corresponding legal interest in the same way. Table 6.9 provides a list of actor roles with their corresponding legal interests.

![Diagram of IfcRelAssignsToActor relationship](image)

**Figure 6.16: Assigning Owners Corporation to common property**

<table>
<thead>
<tr>
<th>Actor Role</th>
<th>Actor Type</th>
<th>Acting Role</th>
<th>Legal Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land surveyor</td>
<td>IfcPerson</td>
<td>Delineate</td>
<td>All legal interests</td>
</tr>
<tr>
<td>Owner</td>
<td>IfcPerson, IfcOrganization</td>
<td>Own</td>
<td>Volumetric Lot, Land Lot</td>
</tr>
<tr>
<td>Owners Corporation Manager</td>
<td>IfcPersonAndOrganization</td>
<td>Manage</td>
<td>Common Property</td>
</tr>
</tbody>
</table>
6.2.6 Referencing and managing legal documents

For referencing and managing information about legal documents, it is required to instantiate “IfcDocumentInformation” class for each legal document. “IfcDocumentInformation” currently provides a rich amount of metadata about documents (see Table 6.10). Other required attributes of legal documents, such as Volume and Folio Number, can be provided through Description attribute or referencing the URL for the location of legal documents. Table 6.11 includes these extra attributes for each legal document.

Table 6.10: Current Attributes of “IfcDocumentInformation” entity, extracted from (ISO16739 2013)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>document name</td>
</tr>
<tr>
<td>Description</td>
<td>Description of the document and its content</td>
</tr>
<tr>
<td>Location</td>
<td>Resource identifier or locator provided as URI, URN or URL, of the document information for online references</td>
</tr>
<tr>
<td>Purpose</td>
<td>Purpose of the document</td>
</tr>
<tr>
<td>IntendedUse</td>
<td>Intended use for this document</td>
</tr>
<tr>
<td>Scope</td>
<td>Scope of this document</td>
</tr>
<tr>
<td>Revision</td>
<td>Document revision designation</td>
</tr>
<tr>
<td>DocumentOwner</td>
<td>Information about the person and/or organization acknowledged as the 'owner' of this document. In some contexts, the document owner determines who has access to or editing right to the document</td>
</tr>
<tr>
<td>Editors</td>
<td>The individuals and/or organizations who have created this document or contributed to it</td>
</tr>
</tbody>
</table>
CreationTime | Date and time stamp when the document was originally created.
--- | ---
LastRevisionTime | Date and time stamp when this document version was created.
ElectronicFormat | Describes the media type used in various internet protocols, also referred to as "Content-type", or "MIME-type (Multipurpose Internet Mail Extension)", of the document being referenced.
ValidFrom | Date when the document becomes valid.
ValidUntil | Date until which the document remains valid.
Confidentiality | The level of secrecy of the document.
Status | The current status of the document. Examples of status values that might be used for a document information status include: DRAFT, FINAL DRAFT, FINAL REVISION.

Table 6.11: Extra attributes about legal documents to be included in Description attribute of “IfcDocumentInformation” entity.

<table>
<thead>
<tr>
<th>Legal Document</th>
<th>Extra Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning Permit</td>
<td>Permit Number, Possible conditions and requirements</td>
</tr>
<tr>
<td>Certification</td>
<td>Plan Number of surveyor’s subdivision plan version</td>
</tr>
<tr>
<td>Statement of Compliance</td>
<td>Council Reference Number, Office of Titles Plan Number, Plan Number of surveyor’s subdivision plan version</td>
</tr>
<tr>
<td>Engineering Plan</td>
<td>Engineering Plan Number</td>
</tr>
<tr>
<td>Title</td>
<td>Volume Number, Folio Number, Security Number</td>
</tr>
<tr>
<td>Parent Title</td>
<td>Volume Number, Folio Number</td>
</tr>
<tr>
<td>Mortgage</td>
<td>Reference Number, Mortgagee Name, Mortgage Date</td>
</tr>
<tr>
<td>Caveat</td>
<td>Reference Number, Caveator, Caveat Date</td>
</tr>
<tr>
<td>Encumbrance</td>
<td>Reference Number and Encumbrance Date</td>
</tr>
</tbody>
</table>

It is also possible to instantiate “IfcDocumentInformationRelationship” entity to define relationships between two documents (see Figure 6.18). In the proposed IFC extension, this entity is used to define relationships between the “Title” document and other legal
documents, such as mortgage and caveat, created in the registration phase of building subdivision process.

“IfcDocumentInformationRelationship” has three specific attributes to relate two legal documents: 1- RelatingDocument: This attribute refers to the document that acts as the referencing document in a relationship. In this research, the relating document is the “Title” document. 2- RelatedDocuments: This attribute refers to documents that act as the referenced documents in a relationship. The related legal documents here are “Parent Title”, “Mortgage”, “Caveat”, and “Encumbrance”. 3- RelationshipType: The value of this attribute describes the type of relationship between two legal documents. For example, the relationship type between “Title” and “Parent Title” is “Refers to”, while “Restricted By” is the relationship type between “Title” and “Caveat” and “Encumbrance”.

Among the legal documents mentioned in Table 6.11, “Title” document is directly associated with primary legal interests as well as their interest holders (see Figure 6.17). For instance, “IfcRelAssociatesDocument” can be used to relate “Title” document to its owner and lot. The RelatingDocument attribute should refer to “Title” document information. Here, the RelatedObjects attribute should include both “IfcActor” and “IfcSpatialZone” entities which can respectively model the owner and lot.

Some legal documents are exchanged between land surveyor and city council as it was discussed in Section 5.3.3. These include planning permit, certification, statement of compliance and engineering plan. “IfcApproval” entity can be used to define the approval process for these documents (see Figure 6.19). Those attributes of “IfcApproval” entity, which are essential for this research, are described in Table 6.12.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifier</td>
<td>A unique identifier for the approval of the legal document.</td>
</tr>
<tr>
<td>Name</td>
<td>Name given to the approval. For example, approval of the statement of compliance.</td>
</tr>
</tbody>
</table>
Description: A general textual description of the legal document that is being approved.

TimeOfApproval: Date and time of the decision on approval of the legal document.

Status: The result or current status of the approval of the legal document. Possible values could be Requested, Processed, Approved, Not Approved.

Qualifier: Textual description of special constraints or conditions for the approval. For example, conditions and requirements of a planning permit can also be included here.

RequestingApproval: The actor that is acting in the role for requesting the approval. For this research, “LAND SURVEYOR” actor should be assigned to this attribute.

GivingApproval: The actor that is acting in the role specified for giving the approval. Here, “CITY COUNCIL” actor should be allocated to this attribute.

ApprovedResources: The set of relationships associated with resource objects which are under approval process. In the context of this research, it should be associated with legal documents (instances of “IfcDocumentInformation” entity) via “IfcResourceApprovalRelationship” entity.

Figure 6.17: Associating title document to its owner and volumetric lot legal interest.
Figure 6.18: Modelling Legal documents used in registration phase within IFC
Figure 6.19: Modelling legal documents exchanged between city council and land surveyor within IFC schema
6.2.7 Administrative information

Survey header information about the location of the development such as geographic coordinates and postal address has already been provided as attributes in the “IfcSite” entity (see Table 6.13). Plan information can be added as a property set which is assigned to “IfcProject” entity (see Figure 6.20). This property set is brought in Table 6.14.

![Diagram of Pset_AdministrativeInfo and IfcSite entities within IFC schema](image)

**Figure 6.20: Administrative subdivision information within IFC schema**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RefLatitude</td>
<td>IfcCompoundPlaneAngleMeasure</td>
</tr>
<tr>
<td>RefLongitude</td>
<td>IfcCompoundPlaneAngleMeasure</td>
</tr>
<tr>
<td>RefElevation</td>
<td>IfcLengthMeasure</td>
</tr>
<tr>
<td>SiteAddress</td>
<td>IfcPostalAddress</td>
</tr>
</tbody>
</table>
Table 6.14: Proposed property set for incorporating plan information into “IfcProject”

<table>
<thead>
<tr>
<th>Property Set Name</th>
<th>Pset_PlanInfo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Property Type</td>
</tr>
<tr>
<td>PlanNo</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>StageNo</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>LotsNo</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>HeadOfPower</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>SurveyFormat</td>
<td>IfcPropertyEnumeratedValue</td>
</tr>
<tr>
<td>Status</td>
<td>IfcPropertySingleValue</td>
</tr>
<tr>
<td>AdministrativeDate</td>
<td>IfcPropertySingleValue</td>
</tr>
</tbody>
</table>

6.3 Prototype implementation

To demonstrate the viability of the proposed use and extension of IFC standard for urban land administration, a prototype BIM model for a complex development, which comprises one multi-storey apartment (Building A) and some multi-level townhouses, located in Melbourne was developed. There are two reasons for selecting this development. Firstly, this development includes common types of 3D legal interests such as volumetric lots, common properties, and easements. Secondly, various types of legal boundaries, except ambulatory ones, were defined in different parts of the development. Therefore, representation and communication of almost any legal boundary type can be compared in both BIM environment and subdivision plans.

The implementation of prototype includes three main steps, namely authoring BIM model, enriching BIM model, which is in IFC format, with legal information, and visualizing and querying final BIM model.

6.3.1 Authoring BIM model

To construct the BIM model, Autodesk Revit software was used since it is one of the more well-known BIM authoring tools utilized in the AEC industry for 3D modelling of complex developments (Kurul et al. 2013). First, 2D architectural floor plans for each
level and cross-section diagrams in CAD format were imported into the Revit Environment. These CAD plans include a 2D representation of the architectural elements of the development. Subsequently, various 3D building elements, such as doors, walls, and windows, were created by extruding their footprints in the 2D CAD plans. The subdivision plan of the development was then used to delineate different types of legal boundaries. The correctness of these boundaries was checked and verified by consulting the land surveyor who prepared the subdivision plan of the development.

For structural boundaries, Revit has the capability to automatically create the boundary by checking the “Room bounding” attribute. In addition, the location of each structural boundary is set to an interior, median, exterior or other position inside the physical structure as specified in the subdivision plan of the development. Fixed boundaries were modelled using “Room Separator” tool. The delineated legal boundaries specify the 3D delimitation of various space parts of volumetric lots, such as apartment units, parking areas, and storages, as well as those of common properties such as elevators, corridors, and lobbies. Each legal space was automatically constructed by applying the “Room” tool in Revit once its constituting boundaries were defined. After defining all legal spaces, the prototype BIM model was converted from the native format of Revit into open IFC format. The summary of steps for constructing the prototype BIM model is outlined in Figure 6.21.
6.3.2 Enriching BIM model with land administration data

In this stage, the exported BIM model in IFC format was enriched according to the proposed use and extension of IFC standard as specified in Section 6.2. To automate the process of enrichment, XBIM Application Programming Interface (API) toolkit is used. This API provides various capabilities in terms of manipulating IFC files such as reading, enriching, writing and querying these files. The enrichment of the BIM model includes the following steps:

- Definition of legal spatial zones
- Assignment of property sets associated with each legal interest
- Assignment of land administration actors
- Incorporating and referencing information about legal documents
- Adding administrative information to the IFC project.

6.3.3 Visualization and query of final BIM model

After finalizing the enriched BIM model, it was imported into Solibri Model Viewer (SMV) software, which provides 3D visualization of IFC files. SMV has the capability to show defined legal spatial zones in the more user-friendly way. Also, all attributes
and property sets assigned to legal interests can be viewed in SMV environment. More importantly, SMV clearly highlights and represents boundaries of legal spaces. For querying the BIM model, XBIM toolkit is used. The results of query speed measurements will be discussed in Chapter 7. Figure 6.22 shows an overall spatial extent of the implemented prototype BIM model. In addition, administrative information, which is defined as property set of “IfcProject” entity, and attributes of the project site (IfcSite) are shown in this figure. Here, various parts of the implemented BIM model are represented below to showcase the practicability of the BIM environment for managing legal information.

6.3.3.1 Primary legal interests within the prototype model

A typical example of the volumetric lot spatial zone can comprise one apartment unit, one car park, and one storage area (see Figure 6.23). Additionally, for each volumetric lot, various attributes defined as property sets can be accessible through the attribute manager of SMV. For instance, as illustrated in Figure 6.23, it can be seen that liability and entitlement of LOT-303 are 220 and 100 respectively, which can be found by only clicking on the specified zone for this lot. This makes it easier for users to find information about each volumetric lot defined inside complex developments.

For building A, the common property spatial zone includes not only various communal spaces, such as corridors, stairs, and elevators but also physical structures such as walls, columns, and slabs (see Figure 6.24). Parts of communal spaces passing through several levels of buildings can be assembled inside common property spatial zone, and this would make it easier manage such complex legal arrangements. In addition, those building elements, such as walls and columns, defined as part of the common property spatial zone can be easily located inside BIM environment. This implies that common property areas are more clearly communicated in BIM environment since there is no abstraction of physical structures.
Figure 6.23: An instance of private property spatial zone

Figure 6.24: Common property spatial zone of building A
The selected development does not include subdivision of other primary legal interests such as roads, reserves, and crown parcels. However, illustrative examples of these legal interests were also created within the prototype BIM model to showcase how they can be mapped within BIM environment. Figure 6.25 shows a spatial zone of a road comprising two parts. It can be seen that the value of “Legal Interest State” attribute for this spatial zone is “Existing”. This means that road parts are defined by “IfcGeographicaElement”, rather than “IfcCivilElement”, which is used for modelling existing roads. Figure 6.26 shows an indicative example for reserve legal interests. In this case, two parcels, each of which defined through instantiating “IfcSite” entity, constitute the reserve spatial zone. It can be seen that Melbourne City Council holds legal ownership of these reserves. In addition, “Gross Area” quantity was used to calculate the whole area of the reserve, which is 24.62 m². Similarly, Figure 6.27 shows that two crown parcels are defined as site entities, and they are referenced in the spatial zone for crown legal interest.

Figure 6.25: An indicative example of road legal interest
6.3.3.2 Secondary legal interests within the prototype model
Among secondary legal interests, only easements were defined in the selected
development. An instance of easement spatial zone typically comprises a utility element, such as water pipeline, and its surrounding space (see Figure 6.28). For the easement shown in Figure 6.28, it can be seen through the attribute manager of SMV that all lots are on the plan are affected by this easement. In addition, BIM environment can also facilitate access to other valuable information such as purpose, width, and origin of the easement.

For other secondary legal interests, which are restrictions, depth limitations, and airspaces, indicative examples were constructed inside prototype BIM model to show these secondary interests can be potentially modelled within BIM environment.

Similar to reserves, spatial arrangements of restrictions are modelled via defining land parcels constituting various parts of a restriction spatial zone (see Figure 6.29). It can also be seen that owners of all lots in the plan shall not construct any building requiring sewerage in the restriction spatial zone.

Figure 6.28: An easement spatial zone
Figure 6.29: An indicative example of restrictions

Figure 6.30 shows the depth limitation spatial zone for building A. Typically, in subdivision plans depth limitations are only described through textual information, indicating the length of depth limitation. However, BIM environment can be used to visually represent spatial extent of these legal interests.
Airspace legal interests can also be modelled through defining external spaces around the building. Figure 6.31 shows a specific instance of airspace spatial zone, which indicates the height limit of the building.

![Airspace spatial zone](image)

**Figure 6.31: An indicative example of airspace**

**6.3.3.3 Examples of structural boundaries within the prototype model**

Among legal boundaries, interior, median, and exterior structural boundaries were prevalently defined inside the selected development. In this section, it is explained how the prototype model can represent different types of structural boundaries. In Figure 6.32, only the legal spaces for legal interests have been shown, and it is hard to find the position of the boundary between two abutting legal spaces. This means that purely legal representation of 3D legal interests itself cannot adequately communicate the type and position of structural boundaries. However, incorporating physical objects facilitates communication of structural boundaries. As indicated in Figure 6.33, boundaries touch the interior faces of the wall and the door. The owners can visually distinguish door boundaries from wall boundaries, and the location of boundaries can be interpreted as interior ones. As another example, Figure 6.34 shows that the boundary between apartment units 206 and 205 is passing through the median of the wall and each owner has a right or responsibility on the half of wall on their side. Finally, Figure 6.35 represents that the boundaries touch the exterior face of the walls and the owner of the apartment unit 206 has the full right or responsibility on those walls. These examples illustrate that building elements can be utilized as auxiliary elements to resolve ambiguity in accurate understanding of various structural boundaries within
multi-storey buildings.

Figure 6.32: Legal representation in the prototype BIM model

Figure 6.33: Interior structural boundaries

Figure 6.34: Median structural boundaries
6.3.3.4 **Information about legal documents and actors linked to the prototype model**

Information about legal documents was also linked to the BIM model. “IfcDocumentInformation” entity was instantiated to manage meta-data about each legal document. For example, Figure 6.36 shows meta-data about Title document which was certified for LOT-303. These attributes can be viewed through attribute manager of SMV.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidentiality</td>
<td>Only Land Victoria has access to the document</td>
</tr>
<tr>
<td>Creation Time</td>
<td>2013-03-20</td>
</tr>
<tr>
<td>Description</td>
<td>Volume No. 10546, Folio No. 725, Security No. 6134</td>
</tr>
<tr>
<td>Document Owner</td>
<td>Land Victoria</td>
</tr>
<tr>
<td>Editors</td>
<td>Mr. Chris Mcray, Mr. David Clarke</td>
</tr>
<tr>
<td>Electronic Format</td>
<td>PDF</td>
</tr>
<tr>
<td>Intended Use</td>
<td>For registering the ownership of Lot 303</td>
</tr>
<tr>
<td>Last Revision Time</td>
<td>2013-03-28</td>
</tr>
<tr>
<td>Name</td>
<td>Title for Lot 303</td>
</tr>
<tr>
<td>Purpose</td>
<td>To provide official record of proprietorship of Lot 303</td>
</tr>
<tr>
<td>Revision</td>
<td>Final Revision</td>
</tr>
<tr>
<td>Scope</td>
<td>No Scope is defined</td>
</tr>
<tr>
<td>Status</td>
<td>FINAL</td>
</tr>
<tr>
<td>Valid From</td>
<td>2013-03-28</td>
</tr>
<tr>
<td>Valid Until</td>
<td>2113-03-28</td>
</tr>
</tbody>
</table>

**Figure 6.36: An example of meta-data attributes about legal documents**

In addition to meta-data about legal documents, “IfcApproval” was also instantiated to
model the approval process for various legal documents such as planning permits, statements of compliance, certifications, and engineering plans. For instance, the approval attributes for the planning permit for subdividing the selected development is extracted from attribute manager of SMV and shown in Figure 6.37.

![Approval attributes](https://data.melbourne.vic.gov.au/PlanningPermits/PP2031A.PDF)

**Figure 6.37:** An example of approval attributes assigned to legal documents

Finally, different types of actors were assigned to their corresponding legal interests. For instance, Figure 6.38 shows that the manager of Owners Corporation was assigned to the common property No. 1 through instantiating “IfcRelAssignsToActor” entity.

![IfcRelAssignsToActor](https://data.melbourne.vic.gov.au/PlanningPermits/PP2031A.PDF)

**Figure 6.38:** Assignment of manager of Owners Corporation to the common property

### 6.4 Chapter Summary

In this chapter, an extension and use of IFC standard to support digital management of 3D data resulting from building subdivision process was proposed. In particular, the main contribution has been extending the concept of spatial zones to lay the foundation for managing complex legal interests. Additionally, relevant geometric and semantic IFC entities for modelling legal boundaries in the BIM environment were identified. It was also investigated how information about land administration actors and legal documents can be defined inside IFC standard. Table 6.15 provides a summary of legal data elements and corresponding IFC entities and possible property sets used for modelling each legal element. To emphasize the feasibility of the proposed extension of
Design and Implementation of a Proposed Extension of IFC Standard for Urban Land Administration

IFC standard for effective visualization of legal interests, a prototype model was implemented for a complex development located in an urban built environment. It was shown that how legal information can be managed and accessed within 3D digital data environment of BIM.

In next chapter, the assessments for the proposed IFC extension and the implemented prototype BIM model will be presented.

<table>
<thead>
<tr>
<th>Legal Data Element</th>
<th>Modelling the legal data element in IFC extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric Lot</td>
<td>• IFC entities: IfcSpatialZone, IfcSpace, IfcZone</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon, Pset_Lot</td>
</tr>
<tr>
<td>Land Lot</td>
<td>• IFC entities: IfcSpatialZone, IfcSite</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon, Pset_Lot</td>
</tr>
<tr>
<td>Common Property</td>
<td>• IFC entities: IfcSpatialZone, IfcZone, IfcSpace,</td>
</tr>
<tr>
<td></td>
<td>IfcExternalSpatialElement, IfcBuildingElement, IfcCivilElement,</td>
</tr>
<tr>
<td></td>
<td>IfcGeographicElement</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon, Pset_commonProperty</td>
</tr>
<tr>
<td>Road</td>
<td>• IFC entities: IfcSpatialZone, IfcCivilElement,</td>
</tr>
<tr>
<td></td>
<td>IfcGeographicElement</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon</td>
</tr>
<tr>
<td>Reserve</td>
<td>• IFC entities: IfcSpatialZone, IfcSite</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon</td>
</tr>
<tr>
<td>Crown Parcel</td>
<td>• IFC entities: IfcSpatialZone, IfcSite</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon</td>
</tr>
<tr>
<td>Easement</td>
<td>• IFC entities: IfcSpatialZone, IfcExternalSpatialElement,</td>
</tr>
<tr>
<td></td>
<td>IfcGeographicElement</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon, Pset_RestrictionCommon, Pset_Easement</td>
</tr>
<tr>
<td>Restriction</td>
<td>• IFC entities: IfcSpatialZone, IfcExternalSpatialElement, IfcSite,</td>
</tr>
<tr>
<td></td>
<td>and IfcBuildingElement</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon, Pset_RestrictionCommon, Pset_Restriction</td>
</tr>
<tr>
<td>Depth Limitation</td>
<td>• IFC entities: IfcSpatialZone, IfcExternalSpatialElement</td>
</tr>
<tr>
<td></td>
<td>• Property Sets: Pset_LegalInterestCommon, Pset_DepthLimitationOrAirspace</td>
</tr>
</tbody>
</table>
Building Information Modelling for Urban Land Administration

Airspace
- IFC entities: IfcSpatialZone, IfcExternalSpatialElement
- Property Sets: Pset_LegalInterestCommon, Pset_DepthLimitationOrAirspace

Internal Boundary
- IfcRelSpacBoundary.RelatedBuildingElement = IfcBuildingElement
- IfcRelSpacBoundary.PhysicalOrVirtualBoundary = Physical
- IfcRelSpacBoundary.InternalOrExternalBoundary = INTERNAL

Median Boundary
- IfcRelSpacBoundary.RelatedBuildingElement = IfcBuildingElement
- IfcRelSpacBoundary.PhysicalOrVirtualBoundary = PHYSICAL
- IfcRelSpacBoundary.InternalOrExternalBoundary = MEDIAN

External Boundary
- IfcRelSpacBoundary.RelatedBuildingElement = IfcBuildingElement
- IfcRelSpacBoundary.PhysicalOrVirtualBoundary = PHYSICAL
- IfcRelSpacBoundary.InternalOrExternalBoundary = EXTERNAL

Other Boundary
- IfcRelSpacBoundary.RelatedBuildingElement = IfcBuildingElement
- IfcRelSpacBoundary.PhysicalOrVirtualBoundary = PHYSICAL
- IfcRelSpacBoundary.InternalOrExternalBoundary = USERDEFINED

Projected Boundary
- It is typically dependent on its corresponding structural boundary. If it is modelled independently, then the followings are applied
  - IfcRelSpacBoundary.RelatedBuildingElement = IfcVirtualElement
  - IfcRelSpacBoundary.PhysicalOrVirtualBoundary = VIRTUAL

Ambulatory Boundary
- IfcRelSpacBoundary.RelatedBuildingElement = IfcGeographicElement
- IfcRelSpacBoundary.PhysicalOrVirtualBoundary = PHYSICAL

Fixed Boundary
- IfcRelSpacBoundary.RelatedBuildingElement = IfcVirtualElement
- IfcRelSpacBoundary.PhysicalOrVirtualBoundary = VIRTUAL

Geometry of Boundaries
- For boundaries in 2D space:
  - IfcRelSpacBoundary.ConnectionGeometry = IfcConnectionCurveGeometry
- For boundaries in 3D space:
  - IfcRelSpacBoundary.ConnectionGeometry = IfcConnectionSurfaceGeometry

Land surveyor
- IFC entity: IfcPerson
- IfcActorRole.UserDefinedRole = DELINEATE

Owner
- IFC entity: IfcPerson, IfcOrganization
### Design and Implementation of a Proposed Extension of IFC Standard for Urban Land Administration

- **IfcActorRole.UserDefinedRole = OWN**

<table>
<thead>
<tr>
<th>Role</th>
<th>IFC entity</th>
<th>Role Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owners Corporation Manager</td>
<td>IfcPersonAndOrganization</td>
<td>IfcActorRole.UserDefinedRole = MANAGE</td>
</tr>
<tr>
<td>Land registry</td>
<td>IfcOrganization</td>
<td>IfcActorRole.UserDefinedRole = REGISTER</td>
</tr>
<tr>
<td>City Council</td>
<td>IfcOrganization</td>
<td>IfcActorRole.UserDefinedRole = CERTIFY, OWN</td>
</tr>
<tr>
<td>Referral Authority</td>
<td>IfcOrganization</td>
<td>IfcActorRole.UserDefinedRole = CONTROL, OWN</td>
</tr>
<tr>
<td>Developer</td>
<td>IfcPerson, IfcOrganization</td>
<td>IfcActorRole.UserDefinedRole = DEVELOP</td>
</tr>
<tr>
<td>Legal Documents</td>
<td>IfcDocumentInformation, IfcApproval</td>
<td>Description attribute of IfcDocumentInformation</td>
</tr>
<tr>
<td>Survey Header Information</td>
<td>IfcSite</td>
<td></td>
</tr>
<tr>
<td>Plan Information</td>
<td>IfcProject</td>
<td>Property set: Pset_PlanInfo</td>
</tr>
</tbody>
</table>
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CHAPTER 7

EVALUATION OF THE PROPOSED IFC EXTENSION AND THE IMPLEMENTED PROTOTYPE BIM MODEL
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7 Evaluation of the Proposed IFC Extension and the Implemented Prototype BIM Model

7.1 Introduction

In previous chapter, an extension of the IFC standard was designed and implemented as a new artefact for managing legal information within BIM environment. The contents of this chapter describe “evaluate the artefact” stage within the framework of design science. This chapter includes three assessments. First, the proposed IFC extension will be evaluated by experts involved in urban land administration as well as those specialists involved in the development of IFC standard (Section 7.2). Subsequently, the implemented prototype BIM model, which is an instance of the proposed IFC extension, will be compared with its 2D plan version (Section 7.3). Moreover, the barriers to fully implement and adopt a BIM-based approach in current urban land administration practices will be discussed (Section 7.3.3). Finally, the prototype BIM model will be compared with purely legal and purely physical models (Section 7.4). These assessments will determine the validity of the proposed IFC extension as well as performance of its implementation.

7.2 Subjective Evaluation of the Proposed IFC Extension

Currently, there is no a globally accepted framework for assessing quality of data models or standards (Gosain and Heena 2015). Many researchers have proposed subjective rating of factors specifying the quality of data models (Assenova and Johannesson 1996, Moody 1998, 2003, Poels and Dedene 2000, Krogstie 2013, Gosain and Heena 2015). Through a comprehensive review of these investigations, five quality factors were considered as the widely used ones for subjective evaluation of data models. In the context of this research, these factors are defined as:

- Completeness: This factor is used to assess the proposed IFC extension in terms of meeting data requirements in urban land administration.
- Correctness: This factor specifies to what extent the proposed IFC extension is consistent with the rules for extending IFC standard. This is the most important aspect for assessing logical validity of the proposed extension.
• Simplicity: This means that the proposed IFC extension includes as minimum as possible number of data elements and relationships. In other words, there is no redundant data element in the proposed IFC extension.

• Understandability: It refers to as the ease with which the proposed data elements and their relationships can be understood by experts of IFC standard

• Implementability: This indicates the feasibility of implementing the proposed IFC extension within a prototype BIM model.

In evaluating data models, such as the proposed IFC extension in this research, there are two groups of experts, namely domain experts and modelling (Schenck and Wilson 1994). Domain experts, who are considered as land administration experts in this research, only assess the requirements of data model. In this research, this means the information completeness of the proposed extension. Therefore, it is not required for them understand the structure and complexities of IFC standard. On the other hand, the modelling experts, who are IFC experts in the context of this research, assess the logical validity of data models. Therefore, they do not need to comment how much the proposed data requirements are complete. They only encode these data requirements, whatever these requirements are, to the current structure of IFC standard. In this research, firstly the data requirements and information completeness of the proposed IFC extension were assessed and revised accordingly. After that, the revised data requirements were encoded to IFC standard as new extension, which was subsequently evaluated by IFC experts.

Therefore, the above mentioned quality factors are classified into two main categories, namely information completeness and logical validity. Information completeness refers to only completeness quality factor, while logical validity consists of other factors including correctness, simplicity, understandability, and implementability. There are two groups of participants in this research. The first group comprises experts in land administration domain including land registry experts and land surveyors. The second group is those experts having knowledge of the IFC standard. For each group, one questionnaire is specifically designed to assess the proposed IFC extension. The first group evaluated the proposed extension in terms of information completeness since these experts have a thorough understanding of the required legal information in urban built environments. The second group assessed the logical validity of the proposed
extension since their expertise can help the researcher to refine the proposed extension in line with the current data structure of the IFC standard.

A few months prior to conducting interviews, a draft version of the report describing the proposed IFC extension was provided to all participants and the researcher had personal meetings with them to give a detailed explanation of the proposed extension and clarify the unclear parts. According to unstructured feedback from these meetings, the report for the proposed IFC extension was finalized and all participants were asked to read a final report of the proposed IFC extension before conducting interviews.

Since the subjective evaluation of the proposed IFC extension was dependent on the professional expertise of the invited participants, the ethical considerations of interviews were sent to Human Research Ethics Committee of Melbourne University. This committee assessed this research rigorously to ensure that any potential risk have minimal impact on the participants. The possible inconvenience for the participants was the time that they spent on reading the report for the proposed IFC extension as well as the interview time. In addition, the ethics committee confirmed that this research project does not include any potential risks to non-participants. During the interview, the following documents were given to each participant:

- The plain language statement: This document provides a short description of the research project in a simple language. This document is brought in Appendix D.

- Consent form: In this form, it is stated that participation in this research is completely voluntary. Participants had the right to withdraw at any stage, or to withdraw any unprocessed data they have supplied, they are free to do so without prejudice. They also agree that each participant may be identifiable as a participant due to the small sample size. However, the confidentiality of the information they provided will be safeguarded, subject to any legal requirements. It was also mentioned in the consent form that responses and comments provided by each participant will be kept confidential. The consent form is brought in Appendix E.

- The questionnaire: This document includes the questions that each participant is required to answer for evaluating the proposed IFC extension.
The interviews started with reading the plain language statement and signing the consent form. Subsequently, each participant will be asked to complete their specific questionnaire. All the experts were interviewed through online or face-to-face conversations. The type of interviews was semi-structured. This means that some questions can be answered by choosing a predetermined set of allowed responses, while other questions allow respondents to formulate the answers in their own words. The reason for evaluating the proposed IFC extension through semi-structured interviews was that participants can easily respond to questions with predefined answers and outline which part of the extension is either correct or incorrect. Additionally, if there are shortcomings in some parts of the proposed extension, they can precisely communicate these shortcomings by providing their comments on open-ended questions. It is found that using 12 participants would lead to “point of saturation” for interview based studies (Galvin 2015). Therefore, around 6 participants were invited from each group, in total 12 participants. Positions of participants ranged between technical staff and middle management levels.

By analysing participants’ answers in the questionnaires, it was specified how many participants who agree or disagree in each part of the proposed extension. If the number of the disagreed people is more than or equal to agreed people for a particular part of the proposed extension, that part of the proposed extension was revised according to the participants’ comments provided in the open-ended questions.

7.2.1 Information completeness

In this part, three professionals from Land Victoria, which is the land registry organization in Victoria, as well as three land surveyors from various land surveying companies in Victoria were interviewed. Questions shown in Table 7.1 were asked of the land administration experts to find out their opinions in regards to the various aspects of completeness. These aspects include completeness of legal interests, legal attributes, legal boundaries, legal documents, land administration actors, and administrative data modelled within the proposed IFC extension.
Table 7.1: Questions for assessing information completeness of the proposed IFC extension

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Questions</th>
<th>Possible Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In your opinion, do you think that each legal interest, modelled by the proposed extension, includes its required parts? For example, all parts of an individual volumetric lot can be modelled by the proposed extension.</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>2</td>
<td>Is there any legal interest that has not been considered in the proposed IFC extension?</td>
<td>Comments</td>
</tr>
<tr>
<td>3</td>
<td>Do you think that proposed attributes for each legal interest are comprehensive?</td>
<td>Yes, No, and missing attributes</td>
</tr>
<tr>
<td>4</td>
<td>Do you think that existing and proposed data elements for modelling each legal boundary are comprehensive?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>5</td>
<td>Is there any other type of legal boundary which has not been considered in the proposed IFC extension?</td>
<td>Comments</td>
</tr>
<tr>
<td>6</td>
<td>Do you think that the proposed extension includes the required attributes for managing metadata about all types of legal documents?</td>
<td>Yes, No, and Missing attributes</td>
</tr>
<tr>
<td>7</td>
<td>Is there any legal document which has been not considered in the proposed IFC extension?</td>
<td>Comments</td>
</tr>
<tr>
<td>8</td>
<td>Is there any land administration actor who has not been considered in the proposed IFC extension?</td>
<td>Comments</td>
</tr>
<tr>
<td>9</td>
<td>Do you think that administrative attributes required in subdivision plans are comprehensively considered in the proposed IFC extension?</td>
<td>Yes, No, and Missing attributes</td>
</tr>
</tbody>
</table>

Completeness of legal interests was evaluated through Questions 1 and 2. As indicated in Figure 7.1, spatial arrangements of most legal interests have been considered in the proposed extension according to responses of participants to Question 1. Only, completeness of restriction was not comprehensively modelled. Before evaluation, this
legal interest was initially considered as a spatial zone constituting only a set of site elements. However, four land administration experts expressed that restrictions can also be applied to external spaces around buildings, such as building envelopes, and material of building elements, such as colours and setbacks of walls. Therefore, the spatial zone defined for restrictions was refined in the proposed IFC extension (see Section 6.2.3.2). One expert was disagree with defining depth limitation and airspace interests as separate entities, arguing that these interests can be considered as part of common property interest or title documents. However, the other five experts stated that depth limitation and airspace interests can be defined separately in some circumstances.

In response to Question 2, all participants stated that the legal interests considered in the proposed IFC extension covers all types of subdivision plans and there is no other legal interest, which needs to be included in the extension, in the context of Victorian jurisdiction.

![Figure 7.1: Completeness of legal interests (Responses to Question 1)](image)

In Question 3, the land administration experts were requested to provide their view on the completeness of legal attributes (see Figure 7.2). The missing attributes for each legal interest were also provided by the participants. Attributes common to all legal interests (Pset_LegalInterestCommon) were considered comprehensive by three experts. However, the other three experts mentioned that “Land Use” attribute is missing in this category. Therefore, this attribute was added to “Pset_LegalInterestCommon”. For legal
attributes specific to lots, the majority of experts mentioned that “Stage” attribute should be optionally included in “PSet_Lot” to distinguish staged lots. Staged lots are created and modified in various phases of a staged subdivision. The other missing attributes were “Upper Level” and “Lower Level” of depth limitation and airspace interests. These attributes were also incorporated into “Pset_DepthLimitationOrAirSpace”.

Completeness of legal boundaries was assessed through analysing responses of participants to Questions 4 and 5. The vast majority of legal boundaries identified in this extension were considered by experts to be comprehensive and cover all types of boundaries defined in subdivision plans (see Figure 7.3). For “other” structural boundaries, two participants responded that the proposed IFC extension may not be able to cover subtleties of these boundaries. However, the researcher argued that IFC provides semantic and geometric definition of all types of building elements. Therefore, it is feasible to semantically define these boundaries. Moreover, it is also possible to define the geometry of boundaries in any position inside structural elements.

![Figure 7.2: Completeness of legal attributes (Responses to Question 3)](image)

In response to Question 6, all participants confirmed that metadata of most legal documents is complete (see Figure 7.4). For only mortgage documents, four participants recommended that “Bank Name” attribute should be changed to “Mortgagee Name” since banks do not always hold mortgage over title document. Therefore, the name of
this attribute was revised in the proposed IFC extension. Additionally, the response of participants to Question 7 was that some legal documents, which are exchanged between city council and land surveyor, are missing in the proposed IFC extension. These include certification, statement of compliance, and engineering plan. Therefore, the proposed IFC extension was revised to model these legal documents as well (see Section 6.2.6).

![Figure 7.3: Completeness of legal boundaries (Responses to Question 4)](image)

In Question 8, most participants confirmed that the actors considered in this extension play major roles in conducting activities in various phases of subdivision process. Only, one participant suggested that other actors should also be considered. These include purchaser, builder, mortgagees, and conveyancers. It is also possible to define these actors using “IfcActor” entity. However, other five participants did not consider these actors as essential ones.

Finally, in Question 9 the majority of participants confirmed that administrative data considered in the proposed extension is adequate (see Figure 7.5). Two participants suggested that “Plan information” category should be enriched with annotations. However, the researcher argued that annotations are already considered in IFC standard and can be modelled using “IfcAnnotation” entity. One participant stated that “Survey header” category should be enriched with more attributes according to subdivision plans. However, this participant did not specifically mention the missing attributes.
7.2.2 Logical validity

The logical validity of the proposed IFC extension was evaluated by IFC experts who were mainly from different chapters of BuildingSMART organization across the globe, including Australasia, UK, and Norway. In this part, the correctness of the proposed IFC extension was firstly evaluated in specific parts of this extension (Questions 1 to 7 in Table 7.2). This mainly includes correctness of legal interests, legal attributes, legal boundaries, legal documents, land administration actors, and administrative data modelled within the proposed IFC extension. In addition, other aspects of the logical validity, including simplicity, understandability and implementability of the overall structure of the proposed IFC extension, were generally assessed (Questions 8 – 14 in Table 7.2).
<table>
<thead>
<tr>
<th>Question Number</th>
<th>Questions</th>
<th>Possible Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In your opinion, do you think that “RelatedElements” attribute of “IfcRelReferencedInSpatialStructure” objectified relationship correctly refers to constituting elements of each legal interest?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>2</td>
<td>Do you think that each proposed property set were correctly defined and assigned to their corresponding IFC entity?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>3</td>
<td>Given that all boundaries except median and other physical boundaries are defined in current IFC standard, do you think that enriching “IfcInternalOrExternalEnum” with “MEDIAN” and “USERDEFINED” enumeration values is the correct approach to incorporate those boundaries into IFC standard?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>4</td>
<td>Do you think that “IfcDocumentInformation” can adequately manage metadata associated with the following legal documents?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>5</td>
<td>Do you think that “IfcDocumentInformationRelationship” entity was properly used to model relationships among legal documents mentioned in the previous question?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>6</td>
<td>Do you think that the actors were correctly assigned to legal spatial zones?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>7</td>
<td>Do you think that the actors were assigned correctly to their corresponding legal documents?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>8</td>
<td>In your opinion, do you think that “IfcProject” and “IfcSite” entities are the appropriate data elements to manage administrative information about building subdivision projects?</td>
<td>Yes, No, and Additional comments</td>
</tr>
<tr>
<td>9</td>
<td>According to the definition of simplicity, what score do you give to the simplicity of the proposed IFC extension?</td>
<td>1 (Poor), 2 (Fair), 3 (Average), 4 (Good), 5 (Excellent)</td>
</tr>
<tr>
<td>10</td>
<td>In what part/s of the proposed extension, in your opinion, there are redundant data elements?</td>
<td>Comments</td>
</tr>
</tbody>
</table>
Evaluation of the Proposed IFC Extension and the Implemented Prototype BIM Model

11. According to the definition of understandability, do you think that how much the proposed IFC extension is understandable? 1 (Poor), 2 (Fair), 3 (Average), 4 (Good), 5 (Excellent)

12. Which parts of the proposed extension are difficult to be understood by its potential users? Comments

13. According to the definition of implementability, to what extent, in your opinion, the proposed extension is implementable? 1 (Poor), 2 (Fair), 3 (Average), 4 (Good), 5 (Excellent)

14. In your view, which part of the proposed extension is infeasible to be implemented in a real world case study scenario? Comments

Correctness of spatial structure of each legal interest was evaluated through Question 1. Most participants agreed that the concept of spatial zones is correctly defined for managing spatial structure of each legal interest (see Figure 7.6). One IFC expert suggested using only “IfcSite” entity for modelling land lot, crown parcel and reserve interests. However, the researcher argued that sometimes more than one land parcel (IfcSite) is used to define these legal interests. Therefore, it is better to define a spatial zone comprising a set of “IfcSite” entities (see Section 6.2.2). Another issue was modelling the legal spatial zone of roads. Three participants considered only “IfcCivilElement” for modelling the legal spatial zone of roads, whereas the other three participants suggested that “IfcGeographicElement” should also considered. Since “IfcCivilElement” is for modelling new roads and “IfcGeographicElement” can be used for defining existing roads, both of these entities were defined as parts of legal spatial zone of roads.

The correctness of proposed property sets (legal attributes) assigned to each legal interest was evaluated through Question 2 (see Figure 7.7). Before the assessment, it was considered that these attributes can only be applied to spatial zones. However, most participants stated that legal attributes could also be applicable to elements constituting each spatial zone. For example, “Pset_Lot” can be applied to “IfcSpace” if a volumetric lot is only defined as one space. Therefore, in addition to IfcSpatialZone, a list of IFC entities to which each property set can be applied was provided in Sections 6.2.2 and 6.2.3. Some attributes were also considered as duplicate with existing attributes in IFC.
These include area, volume, occupancy type and building address. Therefore, these existing attributes were separated from proposed ones (See Sections 6.2.2 and 6.2.3).

![Figure 7.6: Correctness of each legal interest (Responses to Question 1)](image)

![Figure 7.7: Correctness of legal attributes (Responses to Question 2)](image)

Since all legal boundaries except median and other structural boundaries are defined in current IFC standard, participants were asked in Question whether the method used for modelling median and other structural boundaries is correct. In response, most participants preferred that “IfcInternalOrExternalEnum” should be enriched with
“MEDIAN” and “USERDEFINED” values to model median and other structural boundaries within IFC schema (see Figure 7.8). However, one participant stated that this could also be done by attaching these values as property set to “IfcConnectionGeometry” entity.

![Figure 7.8: Correctness of proposed legal boundaries in IFC (Responses to Question 3)](image)

With respect to correctness of legal documents, all participants responded “YES” to Question 4 and verified that “IfcDocumentInformation” is the appropriate entity for managing metadata about any legal document as well as referencing the original file of each legal document (see Figure 7.9). Moreover, responses of IFC experts to Question 5 confirmed that “IfcDocumentInformationRelationship” was properly used to define relationships between two legal documents.

![Figure 7.9: Correctness of managing and referencing legal documents in IFC (Responses to Question 4)](image)
In response to Question 6, IFC experts stated that most actors were assigned correctly to their corresponding legal interests (see Figure 7.10). The issue was only with assignment of Owners Corporation actor, which was considered as “IfcOrganization” entity. Most participants considered that “IfcPersonAndOrganization” entity can be a better option since the manager on behalf of Owners Corporation is responsible for managing common properties. Two participants were suggested to use “IfcOccupant” for owner actors. It was discussed with these participants that “IfcOccupant” is only considered for modelling individuals occupying the lots and it is not adequate enough to model all types of owners. For example, if the owner is an organization, “IfcOccupant” cannot model it. In contrast, “IfcActor” is more flexible and can model both person and organizational owners.

![Figure 7.10: Correctness of assignment of land administration actors to legal interests in IFC (Responses to Question 6)](image)

In Question 7, all participants verified that owner is correctly assigned to title document. In addition, they confirmed that city council and land surveyor actors were correctly assigned to planning permit document through the use of “IfcApproval” entity (see Figure 7.11).
The final question (Question 8) in regards to correctness of the proposed IFC extension was about appropriate selection of “IfcSite” and “IfcProject” entities for modelling administrative information. All participants confirmed that these entities were correctly selected. “IfcSite” already includes attributes for modelling geographic coordinates. IFC experts confirmed that it is the correct approach to assign administrative information as a property set to “IfcProject” entity (see Figure 7.12).

According to response of the IFC experts, the overall ratings of the simplicity, understandability, and implementability of the proposed IFC extension were shown in Figure 7.13. In Questions 9 and 10, the IFC experts were asked to evaluate the overall simplicity of the proposed IFC extension. Most experts thought that there is no significant redundancy in the proposed IFC extension, except that some attributes in proposed property set duplicate with existing property sets. These duplicate attributes were previously identified in Question 2. In Questions 11 and 12, the understandability of the proposed IFC extension was assessed. The majority of experts stated that the content and diagrams used in the proposed IFC extension was easy to understand for them. However, it should be noticed that these experts had knowledge of IFC standard. This means that the proposed extension might be difficult to be understood by people without background in IFC standard. Finally, in response to Questions 13 and 14, five experts verified that it is highly likely to implement the proposed IFC extension in real
world case studies. However, the full implementation needs to be investigated and tested further with land administration actors involved in building subdivision process.

![IFC experts’ opinion about simplicity, understandability, and implementability of the proposed IFC extension (Responses to Questions 9, 11, and 13)](image)

### 7.3 Comparing the Prototype BIM Model with the Subdivision Plan of the Development

There are recognized limitations of current 2D-based practices in representing and communicating information about legal arrangements within multi-storey developments. These include complex representations that are challenging for users to comprehend, reliance of textual descriptions and drafting methods for representing different boundary types, and multiple pages of information that makes locating information about individual properties difficult. The prototype BIM model developed in this research demonstrates some clear advantages in overcoming these communication challenges. Visualizing these legal arrangements and their boundaries in a 3D digital environment is easy to understand and supports the community’s understanding of who owns what, and where. In particular, the ability to model spatial structure of legal arrangements and connective boundary relationships supports the practice of using a building’s physical structure to define legal interests. In the following subsections, widely defined legal interests, which are volumetric lot and common property, as well as legal boundary types resulting from the implemented prototype BIM model are compared with their 2D plan version.

#### 7.3.1 Volumetric lots and common properties

The proposed extension of IFC standard as well as the implemented prototype would bring benefits in managing and visualizing complex legal interests within multi-storey buildings. These benefits are discussed below.

- In subdivision plans, the spatial extent of volumetric lots are delineated in various floor plans and cross sectional diagrams (see Figure 7.14a). Interest
holders often find it difficult to find and locate relevant information pertaining to these legal interests within multiple pages of subdivision plans. BIM models usually store building data in a hierarchical data structure (building, building storey, spaces, and so on) and users can leverage this hierarchy to navigate and locate building elements. Finding legal spaces (carpark, storage and apartment unit) associated with a specific private property might be difficult for the owner of that property inside complex and tall buildings due to the large number of legal spaces defined inside each building storey. However, this can be facilitated by grouping an owner’s various legal spaces into a single spatial zone via “IfcRelReferencedInSpatialStructure” relationship (see Figure 7.14b).

- The building elements, which are part of common property areas, are not represented in subdivision plans (see Figure 7.15a); they are simply described using notations. This abstraction may not provide a clear image of the spatial extent of common properties for their responsible owners corporations. However, as shown in Figure 7.15b, the representation of building elements as part of common property spatial zones in a BIM environment could help owners corporations visually perceive the building elements for which they have responsibility of management.

- It is difficult to measure and compute volume of legal spaces within subdivision plans. In addition, mapping complex volumetric legal spaces into cross section diagrams and floor plans is a very difficult task. In contrast, the IFC standard supports a variety of solid models, such as B-rep, sweep and CSG, for modelling 3D shape of objects. This provides the ability to not only create and represent valid volumetric RRR spaces with various spatial complexities, but to also carry out 3D computations such as volume measurement.

- Current building subdivision practices in Victoria, which are mainly based on 2D analogue plans, could potentially progress to a collaborative and 3D digital data environment of BIM by utilizing the proposed IFC extension. 2D and analogue environment of subdivision plans results in difficulties in communicating valuable legal information to broader communities. However, intelligent and digital data environment of BIM enriched with legal information would facilitate the communication of subdivision information with other stakeholders with limited background in building subdivision profession.
Figure 7.14: Volumetric lot, a) plan version, b) in BIM environment

Figure 7.15: Common property, a) plan version, b) in BIM environment
7.3.2 Legal boundaries

In this section, various legal boundaries inside the prototype BIM model are compared with their counterparts within subdivision plans. Below, it is discussed that how a BIM environment would enhance the communication of various legal boundaries by improving on the visual representation.

- Interior structural boundaries: Figure 7.16 represents two apartment units (No. 203 and 204) within the second level of the apartment building, in which the interior boundary between the units were highlighted in both plan version and BIM environment. For a person without a specialist background in terms of understanding subdivision plans, it is hard to interpret the location of boundary in this case. In contrast, it can be intuitively perceived inside BIM environment that the boundaries of apartment units are delineated by the internal surfaces of the wall. This would communicate that neither owner of the apartment units has any rights to the wall, which would subsequently be a part of the common property.

- Median structural boundaries: Some townhouses are represented in Figure 7.17, which shows two abutting townhouses (No. 2 and 3) and the position of their common median boundary in both subdivision plan and BIM environment. A land surveyor might define a median boundary through the use of an “M” annotation alongside the boundary line (see Figure 7.17a). However, the owners of these townhouses may have difficulty in terms of understanding this boundary. When represented in a BIM environment, this boundary is unambiguous, as shown in Figure 7.17b. Each owner can clearly understand that their legal interest is spatially extended up to the half of the wall on their side.

- Exterior structural boundaries: As illustrated in Figure 7.18, a typical example of external boundary for townhouse No. 4 is highlighted in both subdivision plan and BIM environment. In the notation section of the subdivision plan it is implicitly indicated that this boundary is an external one. However, the owner of townhouse No. 4 may not accurately interpret its location (see Figure 7.18a). Mapping this boundary into BIM environment, as illustrated in Figure 7.18b, could be more congruous with the visual perception of non-specialists. This would easily communicate that the building element associated with the boundary (in this case, the wall) completely belongs to townhouse No. 4.
• Projected boundaries: For projected boundaries, the BIM environment can represent these automatically by extruding the physical boundary surfaces in both vertical and horizontal directions (see Figure 7.19). In subdivision plans, these can be misinterpreted similar to structural boundaries since their location is dependent on the position of their corresponding structural boundaries. However, modelling in a BIM environment can facilitate communication of these boundaries in the same way as structural boundaries.

• Fixed boundaries: Figure 7.20 shows that how fixed boundaries associated with a car park area can be represented in both subdivision plans and the BIM environment. Interpretation of fixed boundaries in subdivision plans can also be difficult for owners. For instance, in Figure 7.20a, azimuth values annotated alongside boundaries of carpark of unit 304 may seem strange for the owner and she/he might get confused in terms of interpreting those values. Another issue is that owners may only look at the floor plan of their car park area and they think that the legal space of their car park is up to the ceiling. However, in cross section diagrams it is sometimes indicated that the vertical extension of the car park is only up to two meters. The remaining space from height of two meters to the ceiling is part of the common property area. This is more clearly communicated in a BIM environment, which can provide an integrated and interactive view of all legal spaces (see Figure 7.20b).
Figure 7.17: Median boundary, a) plan version, b) in BIM environment

Figure 7.18: Exterior boundary, a) plan version, b) in BIM environment

Figure 7.19: Projection boundary, a) plan version, b) in BIM environment
7.3.3 Obstacles to using a BIM-based approach for urban land administration

Although a BIM-based approach provides benefits for urban land administration, there are some barriers to fully implement and adopt BIM and IFC standard in current procedures. These obstacles are classified into two categories, namely institutional and technical ones.

The major barriers for using BIM and IFC standard are likely to be institutional ones. The current institutional arrangements for managing legal interests in urban built environments 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 urban land administration practices and would arguably apply to the adoption of the proposed IFC extension in existing urban land administration procedures.

To fully implement the proposed IFC extension aligned with current building subdivision procedures, there are two main technical obstacles. One technical issue is that the architectural BIM model is created in the design phase of building and, after the construction phase, this model may not precisely represent the reality of boundaries in the real world. Therefore, verification of the architectural BIM model is required by land surveyors to check its conformance with the as-constructed model in reality. Another technical obstacle is associated with information redundancy in architectural
BIM models. Not all of the physical building elements are used for modelling spatial extent and boundaries of legal zones. For example, walls and furniture, such as desks and chairs, located within apartment units are not required for managing legal spatial zones. To overcome this issue, BIM models should be generalized by removing those unessential physical elements. This generalization would also reduce the data volume of the BIM model, which would, in turn, enhance the speed of visualizing and querying the model.

7.4 Comparing the prototype BIM model with purely legal and purely physical models

In this section, the integrated prototype BIM model will be compared with purely legal and purely physical BIM models. Therefore, purely legal model and purely physical model of the selected multi-level development were also constructed. Defining legal interests in purely legal model and purely physical model would be different to the implementation of the integrated model, which was explained in Chapter 6. These differences are described below and they will affect the querying of BIM models:

- In order to create a purely legal BIM model of the development, subdivision plans for this development were used. Only internal and external legal spaces (instances of IfcSpace and IfcExternalSpatialElement) are used to define volumetric lots, common properties, and easements within the legal model (see Figure 7.21a).

- Architectural plans are used to construct the purely physical model of the development. Various building elements such as its walls, ceilings, floors, doors, and windows were constructed (see Figure 7.21b). To define legal interests in physical model, two new attributes were assigned to each building element: CorrespondingLegalInterests and BoundaryPosition. CorrespondingLegalInterests includes legal interests which are associated with the building element. BoundaryPosition defines whether the exterior or interior face of the building element is used to delineate the legal boundary.

All models were prepared in Autodesk Revit environment. Since Revit software has its own proprietary and closed data format for storing BIM models, all BIM models were converted into open IFC files which can be visualized and queried in any BIM-based
platform. Solibri Model Viewer was used for visualization of BIM models in IFC format. The reason for selecting Solibri Model Viewer was that a recent investigation of BIM visualization tools found that this viewer performs well in comparison with other tools used for viewing BIM models (Johansson et al. 2015). To perform various queries on BIM models, xBIM toolkit\(^1\) was used since it provides the ability to query and manipulate IFC files. The specifications of the workstation used for querying and visualizing BIM models include an Intel Core i7 340 GHz CPU, 4GB of RAM, AMD Radeon HD 6350 GPU running Windows 7 x64. In order to minimize the effect of other tasks of the operating system on the measurement related to querying and visualization of each BIM model, all user installed processes and applications were shut down. Only essential processes of the operating systems were running. This indicates that the side effect of other task was the minimum and measurements were calculated for each BIM model in the same condition.

The adopted metrics for comparing the models include a number of objects and geometry batches, visualization speed regarding frame per second, query time, modelling the spatial structure of legal interests, modelling legal boundaries, and visual communication of legal boundaries. The number of objects and geometry batches metrics are suggested the appropriate measures for the size and complexity of BIM models (Amor et al. 2007). The frame per second (FPS) metric is typically used to measure visualization speed and real-time interaction with BIM models (Johansson et al. 2015). The query time metric is also an important factor when a user wants to search for and retrieve specific information from BIM models (Schweizer 2015). Modelling the spatial structure of legal interests metric is suggested based on the fact how various parts of a legal interest can be managed within each BIM model. Modelling and visual communication of legal boundaries metrics is defined to explore the ability of each BIM in terms of delineating a legal boundary and intuitive understanding of the legal boundary (Aien et al. 2013, Shojaei 2014).

7.4.1 Number of objects and geometry batches

In order to measure number of objects and geometry batches, xBIM toolkit was used since it provides functions for counting objects and geometry batches within IFC files. Table 7.3 compares the BIM models in terms of number of objects and number of

\(^1\) More details about xBIM is provided on https://github.com/xBimTeam
geometry batches. These metrics are used for measuring the size of BIM models. “Number of objects” metric refers to all spatial objects contained within each BIM model. A geometry batch refers to number of parts constituting each spatial object. For instance, windows are composed of two batches, one for the frame and the other for the glass, while walls typically include one batch. It can be seen in Table 7.3 that legal BIM model has the minimum size, whereas the largest size belongs to the integrated model. Another result is that there is a considerable difference between legal model and physical model in terms of both number of objects and geometry batches. This stems from the fact that one part of a legal interest, for example an apartment unit of a volumetric lot, can be spatially defined by only one legal space object (IfcSpace), whereas at least six physical objects, including four walls (IfcWall) and two slabs (IfcSlab), are required to define spatial extent of the same part of a legal interest. This indicates that storing legal models would be easier than physical models.

Figure 7.21: BIM models, a) Purely legal model b) Purely physical model c) Integrated model (In legal and integrated models, the invisible common property space between building and townhouses was not shown for clarity purpose)
Table 7.3: Number of objects and geometry batches in each BIM model

<table>
<thead>
<tr>
<th>BIM Model</th>
<th>Number of objects</th>
<th>Number of geometry batches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal model</td>
<td>173</td>
<td>173</td>
</tr>
<tr>
<td>Physical model</td>
<td>1562</td>
<td>1954</td>
</tr>
<tr>
<td>Integrated model</td>
<td>1735</td>
<td>2127</td>
</tr>
</tbody>
</table>

7.4.2 Visualization speed

Real time rendering performance of BIM tools is fundamental to interaction with BIM models. Frame rate or frame per second (FPS) represents the visualization and rendering speed of graphical applications. In 3D environments, a threshold FPS value of 15 Hz is essential for smooth interaction with 3D models. However, an FPS value of around 60 Hz in highly interactive 3D environments, such as 3D games, is required to provide a smooth interaction with the user. Visualizing and rendering BIM models requires less interactivity in comparison with gaming environments. Existing literature suggests that an FPS value of 30 Hz is acceptable to interact with BIM models (Johansson et al. 2015). Most BIM tools, such as Solibri Model Viewer, provide the ability to view BIM models from various viewpoints. The common viewpoints supported by BIM tools include top, bottom, front, back, right, left, and isometric. Therefore, minimum, maximum and average FPS values were measured over a 60 second interaction time with each BIM model from each viewpoint. The results of FPS measurements are represented as series of charts in Figure 7.22. These charts show trends of visualization speed in BIM models as discussed below:

- Rendering performance of all BIM models was the smoothest when the models are represented from top viewpoint. In this viewpoint, the FPS values were fluctuated between 35 Hz and 45 Hz, which is even more the recommended FPS value of 30 Hz.
- Isometric viewpoint was the worst case scenario for all BIM models, indicating that FPS values were around essential threshold (15 Hz). In some occasions, FPS values were lower than 15 Hz and interaction with all models was not smooth in the isometric viewpoint.
- In most viewpoints, the FPS values of the physical model are found more than those of the legal model, although the number of objects for physical model is
more than the legal model. The largest difference between FPS values of purely physical model and those of purely legal and integrated models was observed in front viewpoint. The smoothest interaction with purely physical models can be explained by the fact that volume of the 3D space occupied by building elements is less than volume of the legal spaces. Therefore, interacting with the physical model was smoother than the legal model.

- The integrated model was the least interactive model in comparison with purely legal and purely physical model since the volume of space occupied by this model is the summation of volumes of both legal spaces and physical building elements.

### 7.4.3 Semantic query time

Since the selected development only includes volumetric lots, common properties and easements, semantic queries for finding these legal interests were executed. Initially, there were significant discrepancies in the time measured for queries. Approximately, after running queries in 30 times, the observed differences between two consecutive runs were insignificant (less than one millisecond) in another five times execution of each query. Figure 7.23 shows the average value of the query execution time for the selected legal interests in each BIM model. Overall, queries in the legal model were executed faster than the physical model. One reason is that because the total number of objects in the legal model was fewer than in the physical model. Another reason is that while only one legal space is sought within legal model to query a specific part of a legal interest, at least six objects, namely four walls and two ceilings, should be sought to query a specific part of a legal interest. Unsurprisingly, querying of legal interests took the longest time interval in the integrated model since it has the largest number of objects. Another result is that querying time for the common property of the building is more than strata lots and easements in all BIM models. The reason is that common property is composed of a large number of parts in comparison with strata lots and easements. For example, in integrated model, a common property includes walls between lots and ceilings between levels, corridors, lobbies, elevators, and stairs, whereas a volumetric lot include maximum four spaces (apartment unit, storage space, and two car park spaces) and easements typically comprise two parts such as a utility element and a legal space around that element.
Figure 7.22: Minimum, maximum and average FPS for each model from various viewpoints in Solibri Model Viewer
7.4.4 Modelling spatial structure of legal interests

As presented in Chapter 5, spatial structure of legal interests can be defined based on composition of both physically tangible objects and cognitive spaces. Table 7.4 shows how purely legal model, purely physical model and integrated models have the capability to support spatial structure of legal interests. Among the models, integrated model have the potential capability to support and manage spatial structure of all legal interests since it supports both visible and invisible objects. The purely physical model can partially support some legal interests such as volumetric lots and common properties. However, other legal interests such as depth limitation and crown parcels cannot be spatially defined within a purely physical model. The legal model is able to completely support spatial structure of some legal interests; however, common properties, easements, and roads may not be effectively arranged by purely legal models since these models do not include physical elements, which sometimes are defined as part of those legal interests.

7.4.5 Managing legal boundaries

For managing legal boundaries, two distinct concepts should be differentiated from each other: modelling and visual communication. Modelling means that a specific boundary type can be stored and recorded within a 3D model irrespective of the approach used for its visualization. Visual communication can be defined as communicating a specific boundary type merely through graphical or image-based representations. The following subsections elucidate how modelling and visual communication of each legal boundary
can be supported in each BIM model.

Table 7.4: Modelling the spatial structure of legal interests in BIM models (–: not supported, +: partially supported, ++: completely supported)

<table>
<thead>
<tr>
<th>Legal interest</th>
<th>Physical Model</th>
<th>Legal Model</th>
<th>Integrated model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric Lot</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Land Lot</td>
<td>_</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Common Property</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Road</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Reserve</td>
<td>_</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Crown Parcel</td>
<td>_</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Easement</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Restriction</td>
<td>_</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Depth Limitation</td>
<td>_</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Airspace</td>
<td>_</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

7.4.5.1 Modelling legal boundaries

Table 7.5 shows the capability of each model for storing and recording different types of boundaries. Both legal and integrated models would have the ability to model all sorts of legal boundaries. In contrast, the physical model is only able to model interior and exterior structural boundaries as well as ambulatory ones. Median structural boundaries as well as fixed and projected boundaries do not have a physical manifestation. Therefore, it is impossible to model these boundaries within a purely physical model.

Table 7.5: Feasibility of modelling legal boundaries in each BIM model (–: not supported, +: supported)

<table>
<thead>
<tr>
<th>Legal boundary</th>
<th>Physical Model</th>
<th>Legal Model</th>
<th>Integrated model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior structural boundary</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Boundary Type</td>
<td>Purely Legal Model</td>
<td>Purely Physical Model</td>
<td>Integrated BIM Model</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------</td>
<td>-----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Median structural boundary</td>
<td>_</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Exterior structural boundary</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Ambulatory boundary</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Projected boundary</td>
<td>_</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Fixed boundary</td>
<td>_</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

### 7.4.5.2 Visual communication of legal boundaries

All BIM models were assessed in terms of visually communicating each boundary type. Figure 7.24 represents how structural boundaries can be visually represented in each BIM model. In the purely legal model, it is difficult to intuitively disambiguate the location and type of boundary (see Figure 7.24a). In the purely physical model, interior and exterior boundaries can be visually distinguished from each other (see Figure 7.24b and Figure 7.24c); however, this model is not capable of modelling and visualizing median boundaries. The integrated BIM model is able to visually communicate all types of structural boundaries (see Figure 7.24d, Figure 7.24e, and Figure 7.24f).

Figure 7.25 shows fixed boundaries in both purely legal and integrated models. Although fixed and projected boundaries can be modelled within purely legal models, communicating these boundaries with inexpert interest holders can be problematic in purely 3D legal data environment. In Figure 7.25a, fixed boundaries of carpark spaces in the purely legal BIM model are highlighted in blue. It is not visually clear whether the vertical extent of these boundaries touch the ceiling or not. However, the integrated model would facilitate visual communication of vertical extent of fixed boundaries for non-technical people. Figure 7.25b shows that a common property space exists between carpark space and ceiling, indicating that the owner does not hold complete legal ownership of the space between the ceiling and the floor of his/her carpark area. On the other hand, Figure 7.25c represents that carpark space vertically extends up to the ceiling. In this case, the owner can easily understand that upper boundary of his/her carpark space is horizontally delimited by the ceiling.

In Figure 7.26, projected boundaries associated with a balcony area of an apartment unit were highlighted. In purely legal model, it is hard to imagine how location of these boundaries is projected from their corresponding physical structures. In contrast, the integrated model would provide more accurate understanding of these boundaries.
Figure 7.26b shows that project boundaries are defined based on interior faces of walls and ceiling, while Figure 7.26c indicates that exterior faces of walls and ceiling are utilized to define projected boundaries. A summary of supporting visual communication of legal boundaries in each BIM model was provided in Table 7.6.

Figure 7.24: Comparing visual communication of structural boundaries in BIM models: a) Visually ambiguous structural boundary in legal model b) Interior structural boundary in physical model c) Exterior structural boundary in physical model d) Interior structural boundary in integrated model e) Median boundary in integrated model f) Exterior structural boundary in integrated model
Figure 7.25: Visual communication of fixed boundaries in purely legal and integrated BIM models, a) Visually ambiguous vertical extent of boundaries of a carpark b) Boundaries do not touch the ceiling c) Boundaries of the carpark touch the ceiling

Figure 7.26: Visual communication of projected boundaries in purely legal and integrated BIM models, a) Visually ambiguous projected boundary in legal model b) Interior projected boundary in integrated model c) Exterior projected boundary in integrated model
Table 7.6: Visual communication of legal boundaries in each BIM model (–: not supported, +: supported)

<table>
<thead>
<tr>
<th>Legal boundary</th>
<th>Physical model</th>
<th>Legal model</th>
<th>Integrated model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior structural boundary</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Median structural boundary</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Exterior structural boundary</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Ambulatory boundary</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Projected boundary</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Fixed boundary</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
</tbody>
</table>

7.5 Chapter Summary

In this chapter, the proposed IFC extension was evaluated by both land administration and IFC modelling experts. Five aspects including completeness, correctness, simplicity, understandability and implementability were identified as the key factors for subjective assessment of the proposed IFC extension. The overall feedback from both land administration and IFC experts was positive about this extension although some parts of it were required to be revised as advised by these experts.

After subjective assessment, the second part of this chapter was dedicated to comparing the implemented prototype BIM model, with its subdivision plan version. This comparison indicated that BIM environment would facilitate communication and management of legal interests and legal boundaries in urban built environments for a broader community of stakeholders involved in building subdivision process. In addition to benefits, the institutional and technical obstacles to use a BIM-based approach in current urban land administration practices were discussed.

Finally, the prototype BIM model was compared with its purely legal and purely physical models using some objective metrics including number of objects and geometry batches, visualization speed in terms of frame rate, query time, modelling spatial structure of legal interests, modelling legal boundaries, and visual communication of structural boundaries. Overall, these metrics showed that querying and interacting with purely legal or physical models are easier than integrated ones. In contrast, integrated models would be able to better manage spatial structure of legal
interests and visually communicate legal boundaries defined in urban built environments.
CHAPTER 8

CONCLUSIONS AND FUTURE RESEARCH
Conclusions and Future Research

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8 Conclusions and Future Research

8.1 Introduction

This concluding chapter highlights main outcomes and findings of the research. It elucidates how the identified research problem, research aim and research objectives have been addressed over various stages of this research. Moreover, potential directions for expanding the outcomes resulted from this research within future research projects will be discussed.

8.2 Addressing Research Aim and Objectives

To recapitulate from Chapter 1, the aim of this research was:

To investigate how the open BIM data model (IFC) can be extended to accommodate legal information as a first step towards leveraging BIM for managing land and property information inside and around multi-storey building developments.

In order to accomplish the research aim, the current data structure of the IFC standard was investigated to decipher an appropriate approach for incorporating legal data elements into this standard. More specifically, relevant entities suitable for modelling legal information were identified and proposed in the IFC standard. These relevant entities have been extended to model legal information with as minimum change as possible in the current data structure of IFC. The adopted approach for extending relevant IFC entities with legal data elements has been mainly predicated on using the extension mechanism provided within current schema of IFC standard. This extension mechanism comprised two main parts, namely property sets and user defined values. The proposed extension of the IFC standard demonstrated how legal information could be logically embedded in this standard.

To emphasize the feasibility of the proposed IFC extension, a prototype BIM model for a real world multi-storey development was implemented. Implementation of the prototype model showed that BIM environment would be potentially leveraged for managing legal information associated with land and properties within urban built environments. In addition, the implemented prototype showcased the potential benefits
of BIM environment in comparison with existing 2D-based practices in urban land administration within real world case studies. The main benefits can be summarized as:

- Communication benefits: The interactive, integrated and 3D digital data environment of BIM would facilitate the communication of legal information with a wider community of stakeholders with limited background in building subdivision profession. This mainly includes improving understanding of legal boundaries and distinguishing boundary types from each other within BIM environment.

- Management benefits: In complex and multi-storey building developments, spatial and physical elements constituting each legal interest are typically dispersed in various parts of these developments. BIM environment would facilitate management of legal interests since it has the capability to assemble and arrange spatial and physical elements into the spatial zone of each legal interest by using spatial relationships. This would also make it easier to find and query different parts of each legal interest.

The accomplishment of the research aim is also based on consecutive stages conducted to address five key research objectives defined in Chapter 1. Below, it will be elucidated how each research objective has been met throughout this research.

8.2.1 Research Objective 1

*Investigating existing challenges associated with current practice of subdividing legal interests in multi-storey buildings*

To address this research objective, relevant literature in the context of urban land administration was reviewed in Sections 2.2 and 2.3 to highlight existing challenges resulted from current subdivision practices. There are recognized limitations of current 2D-based practices in representing and communicating information about legal interests within urban built environments. These include:

- Complex representations that are challenging for inexpert users to comprehend, reliance of textual descriptions and drafting methods for representing different boundary types, and multiple pages of information that makes locating information about each legal interest difficult. This implies that 2D plans are
challenging for owners in terms of their ability to accurately read and interpret information about legal boundaries.

- Moreover, the ability of users to interact with the information presented in 2D plans is very limited since the data environment is analogue and static. In complex developments, the ability to mentally conceptualise a full image of all boundaries of an ownership space requires reviewing multiple 2D images of volumetric legal spaces delineated in different floor plans and cross-section diagrams. For interest holders of ownership spaces with complex shapes, joining these various 2D images in their mind to form a 3D image can be a cognitive challenge.

- 2D plans usually include textual notations which are difficult for owners, who have a limited background in understanding subdivision plans, to read and interpret accurately. The notation section of 2D plans is described using technical terms and a comprehensive knowledge of legislations and acts is required to understand these terms.

- Understanding of structural boundaries, which are defined by referencing building elements, could be problematic for inexpert stakeholders. For example, in Victoria, Australia, legal boundaries can be defined by using various spatial relationships with their corresponding building elements. If a person does not have enough knowledge to understand these spatial relationships in the plan, he/she could misunderstand the location of the boundary. For instance, a non-specialist may misinterpret an interior ceiling boundary as a median one.

8.2.2 Research Objective 2

*Discovering limitations of current 3D spatial data models used for the purpose of mapping and registering legal interests.*

In this research, 3D spatial data models are categorized into three main categories, namely pure legal data models, pure physical data models and integrated (legal and physical) data models. In Section 2.3, a thorough review of these spatial data models was presented to meet the second research objective. A synopsis of limitations identified for each category is:

- Pure legal data models: These spatial data models do not provide adequate data elements to semantically differentiate a wide range of legal boundaries defined
within a jurisdiction. Another limitation of legal data models is that they only use multi-surface methods to define geometry of 3D spatial object. This approach does not have specific rules to validate geometric closure of surfaces in terms of forming a valid volumetric object, which sometimes results in dangling faces. These issues could be resolved by solid models; however, legal models currently do not support solid modelling methods.

- Pure physical data models: These models are not specifically developed for modelling legal interests; however, some entities inside these data models could be potentially used and extended for managing legal information. One limitation of physical data models in 3D geospatial domain is that they mainly support B-rep based solid models, not other types of solid models such as CSG. In addition, these models do not provide data elements to semantically define “median” and “other” structural boundaries defined inside building elements.

- Integrated data models: Current integrated data models are conceptual ones. These models are yet to be implemented in complex case studies to prove their viability for modelling complex RRR spaces. Additionally, integration of legal and physical objects is supported at general levels and specifics of relationships between legal space and physical elements are yet to be defined inside existing integrated data models.

Moreover, Chapter 3 provided a relevant literature on BIM and in particular open IFC standard. It was investigated that IFC is currently a pure physical data model and includes a rich amount of entities for modelling geometric and semantic entities over the lifecycle of buildings. In Section 3.3.7, it was also justified why IFC standard was chosen as opposed to other 3D spatial models such as CityGML. Additionally, different degrees of leveraging BIM for supporting land administration functions in relevant studies were reviewed in Section 3.4. None of these studies have investigated the approach to incorporating a wide range of legal data elements into current data structure of the IFC standard, which plays the fundamental role in adapting BIM for the purpose of urban land administration.

8.2.3 Research Objective 3

*Extending IFC data model with a range of required data elements for managing legal interests inside and around multi-storey building developments.*
This research objective has been addressed by conducting two main activities. The first activity was to identify a comprehensive list of data requirements for managing legal information in urban built environments. A primary list of these requirements was identified through reviewing relevant literature in urban land administration. However, this list was complemented and finalized through exploring existing subdivision practices in urban areas of Victoria, Australia. These legal data elements are summarized as:

- **Primary legal interests**: Land lots, volumetric lots, common properties, reserves, and crown parcels
- **Secondary legal interests**: Easements, restrictions, depth limitation, airspace
- **Legal attributes**: Some attributes were common among all legal interests. In addition, each legal interest has its specific and distinct attributes.
- **Legal boundaries**: Interior, median, exterior and other structural boundaries, projected boundaries, ambulatory boundaries, and fixed boundaries.
- **Legal documents**: Title, parent title, mortgage, caveat, encumbrance, planning permit, statement of compliance,
- **Land administration actors**: Owner, developer, city council, land surveyor, referral authorities.
- **Administrative data**: Plan information and geospatial location of developments

The second activity was to propose an extension to IFC standard and incorporate all legal data elements identified in the previous activity. In the proposed extension, relevant IFC entities were extended to model legal information. The summary of this extension is (see Section 6.2):

- “IfcSpatialZone” and “IfcRelReferencedInSpatialStructure” entities were adopted for arranging spatial and physical elements constituting each legal interest.
- Legal attributes were attached to their corresponding legal interest using property sets.
- “IfcRelSpaceBoundary” entity plays a key role in modelling both geometry and semantic of legal boundaries identified in this research. There is currently no enumerator defined for median and other structural boundaries to semantically differentiate them from other types of structural boundaries. Therefore, it is
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suggested that “InternalOrExternalBoundary” should be enriched with “Median” and “UserDefined” values.

- “IfcDocumentInformation” entity was used for referencing and managing metadata about legal documents. “IfcDocumentInformationRelationship” was adapted to model relationships between two legal documents. “IfcApproval” was suggested as the appropriate entity for modelling information about approval of legal documents.

- “IfcActor” and “IfcRelAssignsToActor” were adapted to model roles of land administration actors and define their acting roles associated with legal interests.

- Administrative plan information was suggested to be assigned as property set to “IfcProject” entity.

8.2.4 Research Objective 4

Development of a prototype BIM model to demonstrate feasibility of the extended IFC data model

Research objective 4 was met by implementing a BIM model of a real multi-storey development within an urban built environment. The selected development comprised one multi-storey apartment and three multi-level townhouses. The implementation of the prototype consisted of three main stages. First, an initial BIM model was constructed using a proprietary BIM authoring tool. Subsequently, the BIM model was converted into IFC format and legal information was incorporated into the model according to the proposed extension. Finally, the enriched BIM model was visualized.

In Section 6.3.3, examples of each legal interest, legal boundaries, and metadata about legal documents were presented to showcase the feasibility of managing legal information within 3D digital data environment of BIM. The implemented prototype BIM model provides a proof of concept for the practicality of the proposed IFC extension.

8.2.5 Research Objective 5

Evaluation of the proposed extension:

c) By experts: those specialists involved with building subdivision processes as well as experts involved in the development of the IFC standard

d) By prototype: Comparing the integrated prototype BIM model with pure legal and pure physical models using some objective metrics.
To address the first part of research objective 5, land administration experts involved in building subdivision processes as well IFC specialists were requested to review the proposed IFC extension. Land administration experts evaluated the information completeness of legal data elements in the proposed IFC extension. These data elements comprised legal interests, legal attributes, legal boundaries, metadata of legal documents, land administration actors, and administrative data. IFC experts assessed the logical validity of the proposed IFC extension in terms of correctness, simplicity, understandability, and implementability. The correctness of each legal data element was specifically evaluated, while other aspects were generally rated by IFC experts for the overall structure of the proposed extension. According to the responses of experts, various parts of the proposed IFC extension were revised.

In response to the second part of research objective 5, some objective metrics were utilized to compare the integrated prototype BIM model with its pure legal and pure physical models. The important results of this comparison are summarized as:

- Visualization and querying speed in integrated BIM models is slower than the pure legal and pure physical models.
- Integrated models provide the full capability to model spatial structure of any legal interest, whereas pure legal and pure physical models cannot adequately arrange spatial structure some legal interests.
- Pure physical models are not able to model the projected and fixed boundaries since no physical structure is used to delineate these boundaries. Also, median and other structural boundaries cannot be communicated since these boundaries are virtual surfaces inside physical structure. In contrast, pure legal and integrate models would have the ability to model all types of legal boundaries.
- Pure legal models would not be able to visually communicate the type and position of legal boundaries, while integrated models can facilitate intuitive representation of any legal boundary. In addition, pure physical models can visually communicate interior, exterior, and ambulatory boundaries.

8.3 Response to the Research Problem

To recapitulate from Chapter 1, the research problem identified in this thesis was:

From a land administration perspective, the open BIM data model (IFC) in its
current form is not capable of managing legal information associated with ownership of properties inside and around multi-storey building developments.

In order to address this research problem, design science has been suggested as the appropriate research methodology in comparison with other available methodologies in land administration domain. The application of design science research methodology to this research is summarized as:

- The explicated research problem is firstly transformed into demands expected from the proposed artefact. In the context of this research, these “demands” are the ability of the open BIM data model (IFC) to communicate and manage legal information associated with ownership of properties within urban built environments. More specifically, this requires the new artefact to capably store, manage and represent various types of data requirements in urban land administration.

- Through applying design science research methodology, an existing artefact, which is the current version of IFC standard, was enhanced to a new artefact, in which legal information was logically embedded into data structure of IFC standard. This means that the existing data structure of IFC was first analysed to identify and propose relevant entities suitable for modelling legal information. Subsequently, legal data requirements identified in the previous stage were mapped onto the IFC standard through extending their equivalent entities using suitable extension mechanisms. In this research, the proposed artefact is in the form of a model, which is an extended data model of IFC standard.

- The realization of the proposed IFC extension (the artefact) in a complex multi-storey development within an urban built environment showed that it can potentially convey a solution addressing the research problem in a real world case study. The validity of this solution was confirmed by evaluating it through seeking subjective opinions of experts as well as measuring objective metrics associated with its performance.

8.4 Benefits of the Proposed IFC Extension for Operation and Maintenance of Buildings

Incorporating legal information into BIM products provides benefits over the post-
building phases of buildings since legal information plays an important role throughout the lifecycle management 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 common properties of a building, entitlements and liabilities provide the legal basis for dealing with disputes and dissatisfaction.

Therefore, a BIM product enriched with legal information could support the facility management industry in repairing, operating and maintaining assets within multi-story buildings. The position of boundaries within building elements would assist in determining whether liability for repairs rests with the private owner, the owners corporation, or a combined responsibility. For example, if the ownership boundary is associated with interior faces of the building elements, this would indicate that these building elements, as well as any asset inside them such as conduits and pipes, are part of the common property spatial zone (see Figure 6.33). In this case, the owners corporation would have the responsibility for maintaining those building elements and assets. However, in the case of median boundaries between two private property spatial zones, the ownership of corresponding building elements is halved between owners (see Figure 6.34). For example, if there was damage throughout the whole building element, the BIM model would visually support the fact that both owners would have an equitable and combined responsibility for repairing the damage. For exterior boundaries, the BIM model would show that the building elements are part of the private property spatial zone. This would indicate that the owner of that zone has full rights of use and therefore, responsibility for repairing any damage to the assets within them (see Figure 6.35). Overall, the clear communication of legal boundaries in BIM environment results in saving costs associated with legal issues in determining parties responsible for maintaining assets in complex buildings.

Another benefit of meshing legal information into the BIM environment is the better estimation of costs considered for maintenance plans of buildings. Owners corporations use maintenance plans to set out the major communal assets, such as lifts, air
conditioner or heating plans, expected to require repair or replacement once the building has been commissioned. These plans typically include current conditions or repair states of communal assets, when it is required to repair or replace those assets, the estimated costs of repair and replacement of the major communal components, and the expected functional life of those components once replaced or repaired. Integrating legal information into physical BIM products would help owners corporations to better monitor the conditions of communal assets, which subsequently results in avoiding unnecessary costs associated with maintaining these assets.

The above factors imply that extending the IFC standard with legal information would uncover the camouflaged value of legal information in complex buildings and increase the functionality of BIM in terms of managing costs associated with maintaining the assets over the lifecycle of buildings.

8.5 Comparing the Proposed IFC Extension and Existing 3D Spatial Data Models

Compared to current 3D spatial data models, which were presented in Section 2.4, the proposed IFC extension provides a comprehensive approach for modelling various legal data elements used in urban land administration practices. The following points provide a comparison between the IFC extension proposed in this research and existing implemented models:

1- Modelling spatial arrangements of legal interests: The proposed IFC extension provides an overarching and more flexible approach, which is predicated on concept of spatial zones, to aggregating various constituent physical elements and cognitive spaces of legal interests. In contrast, existing purely legal data models, such as LADM and ePlan, mainly rely on aggregation of only cognitive spaces to arrange parts of a legal interest. This approach adopted by purely legal data models neglects the consideration of physical elements, which would consequently not be able to fully support spatial arrangements of some legal interests such as common properties. This is because physical objects are considered as part of common properties as explained in Chapter 5. CityGML standard provides “CityObjectGroup” entity to aggregate physical elements and
cognitive spaces. However, CityGML includes semantic entities for modelling the surfaces of some building elements (such as walls and ceilings) and there is no semantic entity for the building element itself. This causes difficulties in assigning a building element as part of a legal interest. IndooGML does not provide the capability to model spatial structure of legal interests.

2- Modelling semantic and geometric aspects of legal boundaries: The taxonomy of legal boundaries explicated in this research can be both semantically and geometrically modelled within the proposed IFC extension. The purely implemented legal or physical models have some limitations in modelling legal boundaries. The purely legal models are able to model geometry of legal boundaries; however, semantic entity associated with each legal boundary type is not considered in these models. In purely physical models, CityGML defines geometry of legal boundaries and semantic entities for some boundary types. This mainly includes semantics of interior and exterior boundaries, and there are no semantic entities for median boundaries. IndooGML uses “CellSpaceBoundary” entity for geometric modelling of boundaries, and the semantic information about the boundary is unclear.

3- Modelling land administration actors: The proposed IFC extension provides data elements for managing information about land administration actors as well as their acting roles in various phases of the land administration process. In purely legal data models, semantic entities for land administration actors and their relationships with legal interests are also defined. In contrast, purely physical models do not provide entities for modelling information about actors.

4- Legal documents: The proposed IFC extension also provides mechanisms for modelling information about legal documents and referencing those documents. Similarly, purely legal data models also provide the capability to manage and link information about important legal documents. In contrast, purely physical models have not specified any entity for modelling documents.

5- Administrative information: These legal data elements are also incorporated into the proposed IFC extension. Similar mechanisms can be considered in both
purely legal and purely physical models to integrate administrative information within these models.

### 8.6 Interoperability of the Proposed IFC Extension with Other Land Administration Systems

The proposed IFC extension has been developed in EXPRESS, which is the primary standard data exchange language used for IFC development and enhancing interoperability in BIM domain. However, the proposed extension can be parsed to XML format to promote the interoperability with other domains such as geospatial systems. The existing land administration systems mainly rely on GML, which is developed based on XML, to interoperate and exchange spatial data with each other. Therefore, converting the proposed IFC extension from EXPRESS schema to an XML schema will facilitate the interoperability of the proposed solution with other land administration systems. The adopting approach for mapping the IFC EXPRESS model of the proposed extension into an XML schema should be predicated on the international standard ISO 10303-28ed2 “XML representation of EXPRESS schemas and data”.

The XML-based representation of the proposed IFC extension would facilitate integrating BIM models enriched with legal information into the existing land administration system of a jurisdiction. This would mainly avoid issues in duplications of spatial data, and enhance harmonizing BIM-driven cadastral data with existing cadastral information in land administration systems. This would also mitigate challenges in integrating 3D RRR data with 2D land parcels, which consequently support land administration systems to gradually advance their existing map base from 2D to 3D representations of ownership properties.

### 8.7 Main Findings Contributing to Knowledge

To summarize, this research has succeeded in achieving the below main findings contributing to the current body of knowledge in academic discourse of land administration:

1. Spatial complexity of 3D RRR spaces defined within urban built environments leads to communication challenges in current analogue and 2D-based
representation methods. Additionally, existing spatial data models developed for recording and visualizing 3D RRR information do not include adequate data elements to semantically distinguish a wide range of legal boundaries and manage spatial structure of legal interests.

2. The concept of spatial zones have been extended in open BIM data model to lay the foundation for managing spatial structure and arrangements of complex legal interests defined within urban built environments.

3. This research also responds to the acknowledged communication challenges in 2D-based methods of representing boundaries of legal interests in complex structures. It has been found that BIM environment would enhance the communication of various legal boundaries by improving on the visual representation. In particular, the research has demonstrated that IFC can provide the foundation for managing both geometric and semantic aspects of various types of legal boundaries in a 3D BIM digital environment.

4. 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.

5. An additional strength of BIM-driven approach for urban land administration is the automatic generation of 2D plans from 3D digital environment of BIM. The land administration professionals are used to using the 2D drawings that are presented as examples throughout this research, and in many professions people are resistant to change. Therefore, the big strength of this approach is that it provides the possibility to gradually introduce the 3D digital data environments into the professional workflow of land administration.

6. The other strength of the proposed approach is BIM data is currently being generated but then not used, whereas using BIM for land administration means that there is a better return on investment of time/effort to capture the BIM in the first place.

7. In this research, the integration of legal and physical aspects of urban land administration has moved from a concept to an example implementation, which clearly demonstrates that this can be achieved in practice.
Conclusions and Future Research

8. Pure physical or pure legal models can perform better in terms of visualization and querying speed, whereas integrated (legal and physical) models would provide more intuitive and visual communication of boundaries of legal interests.

8.8 Proposed Guidelines for constructing as-built BIM models for urban land administration

Verification and refinement of the architectural BIM model is required to check its conformance with the as-built model in reality. This stems from the fact that legal boundaries in the real world may be different to those boundaries delineated based on the design model of the building. Therefore, the verified as-built BIM model can precisely represent the reality of legal boundaries delineating spatial extent of vertically stratified properties in complex building developments.

Creating and verifying as-built BIM models in a manual way requires a substantial amount of time and human resources, which may lead to additional costs, lower productivity, and modelling errors. Therefore, it has been suggested that BIM engineers utilize semi-automated indoor mapping approaches to streamline the procedures for creating as-built models in BIM environment. Current indoor mapping practices are widely predicated on 3D laser scanners to accelerate the data acquisition and enhance the accuracy of mapping indoor environments. These scanners are capable of quick collection of the massive point clouds, which would subsequently be used for delineating the as-built indoor structures.

The proposed guidelines for creating as-built BIM model for the purpose of urban land administration are predicated on an efficient semi-automated indoor mapping approach proposed by Hong et al. (2015). This approach includes four main steps, namely pre-processing of point cloud data, vertical modelling, modelling 2D boundaries of floors, and creating the as-built 3D model.

First, point cloud data is pre-processed by eliminating noise data which comes from outside and is resulted from penetrating LiDAR beam into transparent building elements, such as windows. The second step is comprises predicting heights between floors and ceilings as well as eliminating clutter data. In the third step, projection of
Building Information Modelling for Urban Land Administration

Point clouds into the horizontal planes will be done, and 2D boundaries of floors will be created. Subsequently, a 3D wireframe model is constructed through vertical extrusion of 2D floor boundaries and heights obtained from the vertical modelling step. Finally, the 3D wireframe model will be combined with clutter data, which includes details of indoors such as light fixtures, doors and window frames, and imported into the BIM environment to verify the as-built model.

8.9 Proposed Directions for Future Research

The outcomes of this research underpin the basis for future research directions suggested in this section. These future directions would potentially expand the work presented here.

Extending the proposed IFC extension to other jurisdictions in Australia and abroad

Other Australian states and countries can similarly develop an extension of IFC standard for managing legal information in 3D digital data environment of BIM in line with the requirements of their jurisdiction. The methodology described in this research provides an underpinning framework for developing IFC extension for any other jurisdiction since it does not affect current data structure of IFC standard and incorporates legal data elements with as minimums change as possible in IFC standard and it is also in alignment with built-in extension mechanisms in IFC schema.

Appropriate identification of data requirements in the selected jurisdiction plays a key role in development of any cadastral extension of IFC standard. This mainly includes arrangements of legal objects, definition of legal boundaries, possible consideration of physical objects in defining legal objects, roles of key actors, and legal documents. It is important to understand how various parts and boundaries of each legal object are defined. For example, in some jurisdictions, only legal spaces constitute parts of a 3D legal interest and physical objects are not part of a legal interest. In this case, both IfcZone and IfcSpatialZone can be considered as appropriate entities to define spatial arrangements of legal interests. Legal boundaries are defined as only virtual lines without referencing physical elements in some jurisdictions. In this case, “IfcVirtualElement” should be only used to model legal boundaries inside IFC standard. Identifying legal attributes to be assigned to each legal interest is also very important.
Conclusions and Future Research

The concept of property set in IFC provides a good mechanism for incorporating legal attributes of each particular jurisdiction without significant changes in the current data structure of IFC standard. For instance, “Pset_Lot” was used to incorporate legal attributes of a lot to the IFC standard. Likewise, other Australian jurisdictions and countries can develop their own property sets for meshing legal attributes into IFC standard. Another important concept is used defined values which can be used for specializing general concepts for land administration purpose. For example, a spatial zone is a general concept for aggregating physical and space elements. However, its type can be specialized into a specific legal zone by assigning the name of legal interest. In this research, it was shown how various legal zones in Victorian jurisdiction can specialized from general concept of IfcSpatialZone. Similarly, other jurisdictions can develop their own specialized legal zones from general concept of spatial zone in IFC.

Utilizing topological operators for querying structural boundaries from BIM models

In this research, structural boundaries are modelled via defining semantic relationships between legal spaces and building elements. However, if it is assumed that semantic relationships between them are not defined in the stage of constructing BIM model, topological operators can be applied to the geometry of invisible legal spaces as well as building elements, which in turn automatically deduces type of boundary and its corresponding building element. The 9-Intersection model, proposed by Egenhofer and Herring (1990), is the renowned topological formalism in spatial information science. For each spatial object (A), this model subdivides topological space with any dimension, in this case R3, into three regions: 1- Interior of spatial object ($A^o$) 2- Boundary of spatial object ($\partial A$) 3- Exterior of spatial object ($A^e$). According to this decomposition, the following $3 \times 3$ matrix is constituted to determine topological relationships between two spatial objects (A, B):

$$ I = \begin{bmatrix}
A^o \cap B^o & A^o \cap \partial B & A^o \cap B^e \\
\partial A \cap B^o & \partial A \cap \partial B & \partial A \cap B^e \\
A^e \cap B^o & A^e \cap \partial B & A^e \cap B^e 
\end{bmatrix} $$

The values of this matrix can be empty ($\emptyset$) or non-empty ($\neg\emptyset$). If it is assumed that both A and B are solids, then the possible topological relationships between two solids are: Disjoint, Contains, Inside, Equals, Touches, Covers, Covered by, and Overlaps. All
of these relationships and their corresponding intersection matrix are represented in Figure 8.1.

Among these relationships, Touches, Overlaps and Covers are relevant topological configurations for specifying types of structural boundaries. If A is a legal space and B is a building element, the following relationships apply:

\[
\begin{align*}
A \text{ Touches } B & \rightarrow \text{ Interior Boundary} \\
A \text{ Overlaps } B & \rightarrow \text{ Median Boundary} \\
A \text{ Covers } B & \rightarrow \text{ Exterior Boundary}
\end{align*}
\]

A future research investigation could adopt these topological relationships to develop 3D spatial query language for the proposed extension to automate retrieval of various boundaries associated with each legal interest.

**Investigating the role of BIM environment in communication and computation of areal and volumetric rooms defined in property measurement standards**

There are several international property measurement standards which specify the area and volume of buildings and building parts, such as Performance Standards in Building (ISO 9836:2011), International Property Measurement Standards (IPMS), RICS Code of Measuring Practice, and Area and Space Measurement in Facility Management (BS EN 15221-6:2011). The types of volumes and areas specified in these property
measurement standards can be modelled by using one or more instances of “IfcSpace”, which is the entity used for modelling any type of space inside buildings. The boundary types identified in this research were specifically used for defining legal spaces. However, they can be similarly used for defining other types of functional areas or spaces defined in property measurement standards. For instance, in the RICS code of measuring practice, Gross Internal Area (GIA) is considered as the area of a building measured to the internal face of the perimeter walls at each floor. In this case, interior wall boundary type modelled in BIM environment can help communication of GIA area and its correct computation. There are currently some quantity sets in IFC standard but there still remains limited investigation into the subtleties with respect to appropriate modelling of property measurement boundaries and computation of those quantity sets within BIM environment. Consequently, another potential future research direction could be to investigate the role of a BIM environment and the IFC standard in facilitating communication of boundaries of area and volume types used for property measurements.

Exploring the viability of BIM environment for integrated lifecycle management of subdivision processes in built environments

As it was investigated in Section, the process of subdivision in urban built environments is a complex one. This process requires collaboration tasks and data exchanges among various actors. Traditionally, this process was predicated on paper-based exchange of subdivision information, resulting in slow and costly procedures for lodging, certifying, examining and registering subdivision plans. Recently, SPEAR (Streamlined Planning through Electronic Applications and Referrals) system in Victoria has been adopted to reduce the reliance on paper-based modes of information communication. Although this system provides the capability to manage and track activities of subdivision processes in an on-line and digital environment, it still relies on 2D-based methods to record, manage and communicate subdivision information. On the other hand, BIM offers a collaborative, 3D digital, intelligent, and semantically enriched data environment to support the integrated management of multi-dimensional aspects of buildings over their lifecycle. In this research, the main data elements underpinning this process were identified and modelled within IFC schema. The outcomes of this research could be
expanded to explore the potential of using a BIM-enabled SPEAR system to support a 3D digital building subdivision process. Design and implementation of such system can showcase the viability of BIM for managing the entire lifecycle of legal information, from design phase through planning and compliance phases to registration and management phase in building developments within an integrated, 3D digital and collaborative data environment.

**Automatic generalization of BIM models for land administration purposes**

BIM models include 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.

One technical issue identified in this research is information redundancy in architectural BIM models. Not all of the physical building elements are used for modelling spatial structure and boundaries of legal interests. Therefore, another direction for future research could include developing generalization approaches to automatically extract required building elements from BIM models and eliminate unnecessary elements. Considering that A is legal space and B is a building element, the containment topological relationship can be used as one potential solution to eliminate unessential building elements for the purpose of urban land administration:

\[ A \text{ Contains } B \rightarrow \text{ Eliminate } B \text{ from the model} \]
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APPENDICES
Appendices

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Appendix A: EXPRESS-G Notation

IFC standard is primarily developed based on the EXPRESS language (Schenck and Wilson 1994). To facilitate understanding of the proposed entities and their relationships, EXPRESS-G notation, which provides a graphical representation of EXPRESS lexical entities, was used in this research. The main EXPRESS concepts with their graphical notation are described below:

- **Entity**: An entity defines a class for objects having similar characteristics or behaviour. In EXPRESS-G, an entity is represented by a rectangular box, and the name of the entity is written inside the box. In IFC standard, entity boxes are highlighted in yellow (see Figure A.1).

- **Attribute**: Attributes are used to describe the characteristics of an entity. Attributes can be defined as simple data types, such as integer, string, real, Boolean or complex data types such as enumeration, selection or referencing other entities. In EXPRESS-G, the name of simple data type is written within a continuous box having two vertical lines at the right end of the box. Attributes referencing other entities can also be considered as relationships between two entities. In EXPRESS-G, an attribute is represented by a solid or dashed thin line which is terminated by a circular arrowhead. The attribute name is written alongside its corresponding line. A dashed line represents an optional attribute, while a continuous line is used to show a mandatory attribute. In IFC standard, all data types are highlighted in green (see Figure A.2a).

- **Enumeration**: An enumeration data type refers to a range of values belonging to its corresponding attribute. Only, one of the enumerated values can be used in an instance of the entity. In EXPRESS-G, the name of an enumeration data type is written within a dashed box having two vertical lines at the right end of the box (see Figure A.2b).
• Selection: A selection data type indicates that exactly one of the alternatives must be selected in an instance of the entity. In EXPRESS-G, the name of a selection data type is written within a dashed box having two vertical lines at the left end of the box (see Figure A.2c).

![Diagram of selection data types](image)

Figure A.2: Examples of attributes with different data types in EXPRESS-G notation, a) Simple data types b) Enumeration c) Selection

• Relationship: A relationship expresses a dependency or interaction between two entities. In EXPRESS-G, relationships are represented by a solid or dashed thin line which is terminated by a circular arrowhead (a small unfilled circle). The relationship name is written alongside its corresponding line.

• Cardinality: A relationship has cardinality, which indicates the number of objects in each of the entities at either end of the relationship that may be involved in a specific instance of that relationship. Cardinalities can be expressed in terms of sets or lists. A set is an unordered variable length collection of unique items. A list is an ordered variable length collection of not necessarily unique items; to a list of unique items. In EXPRESS-G, A cardinality can be shown as a string in the form C[m:n], where C is one of S(set) or L(list), m is the minimum number of items allowed in any instance of the relationship, and where n is the maximum number of items allowed in any instance of the relationship (see Figure A.3a).
- Inverse relationship: In most cases, an inverse relationship can be inferred directly from the original relationship. In EXPRESS-G, an inverse relationship is indicated by writing (INV) before the name of the relationship (see Figure A.3a).

- Generalization and specialization of entities: Two or more entities which have some characteristics or behaviour in common may be generalised into a supertype. In other words, each subtype entity is a specific specialisation of the supertype entity, inheriting all characteristics and behaviour of the supertype; however, each of them has also its own distinct characteristics or behaviour. In EXPRESS-G, the inheritance relationship between subtypes and supertypes is shown by thick continuous lines with large filled circles touching subtype entities (see Figure A.3b).

![Diagram](image.png)

**Figure A.3:** a) Example of relationships between two entities b) Example of inheritance
Appendix B: Business Process Modelling Notation

Business Process Modelling Notation (BPMN) is a method of illustrating business processes in the form of a diagram. This appendix provides an informative description of those BPMN symbols used in this research (see Figure B.1). These symbols include:

- **Activity (Task):** A task is an atomic activity that is included within a process. A task is used when the work in the process is not broken down to a finer level of process detail.
- **Start Event:** A start event indicates where a process will start.
- **End Event:** An end event indicates where a path of a process will end.
- **Message:** A message symbol can be used to either send or receive a message.
- **Timer:** It indicates the maximum time that an activity should be completed.
- **Exclusive Gateway:** It routes the sequence flow to exactly one of the outgoing branches.
- **Data object:** Data objects provide information about what activities require to be performed and/or what data they produce. Data object elements must be contained within process or sub-process elements.
- **Sequence Flow:** It is used to show the order that activities will be performed in a process and in a choreography.
- **Message Flow:** A message flow is used to show the flow of messages between two participants that are prepared to send and receive them. A message flow must connect two separate pools. They connect either to the pool boundary or to flow objects within the pool boundary. They must not connect two objects within the same pool.
- **Lane:** A lane is the graphical representation of an actor in a collaborative process.
- **Text Annotation:** Text annotations provide additional information for the reader of a BPMN diagram.

![Figure B.1: A subset of BPMN symbols](image-url)
Appendix C: Questionnaires

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**RESEARCH QUESTIONNAIRE**
For Evaluation of IFC Extension

**Questionnaire (1) for Evaluating Information Completeness of Proposed Extension of IFC Standard for Victorian Cadastre**

**Part 1) Interviewee’s details**

1. Name of your organisation:

2. Division/unit and position title:

3. Which of the following alternatives do you specialize in?

   - [ ] Land Surveying
   - [ ] Land Registration
   - [ ] Other (please specify)..............................

4. How much experience do you have in your area of expertise?

   - [ ] Less than a year
   - [ ] Between 1 to 3 years
   - [ ] Between 4 to 8 years
   - [ ] More than 8 years
Appendices

**Part 2) Information completeness of the proposed extension**

In this section, the proposed extension will be assessed in terms of meeting data requirements in land administration domain. Only participants with background in land administration will be asked to provide their feedback about the informational content of the proposed extension.

1.  In your opinion, do you think that each ownership interest, modelled by the proposed extension, includes its required parts? For example, all parts of an individual strata lot can be modelled by the proposed extension.

<table>
<thead>
<tr>
<th>Ownership interest</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Lot</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Volumetric Lot</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Common property</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Reserve</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Crown Parcel</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
2. Is there any ownership interest that has not been considered in the proposed IFC extension?
   If yes, please provide its details below:

3. Do you think that proposed attributes for each ownership interest are comprehensive? For each ownership interest, please provide any missing attribute.

<table>
<thead>
<tr>
<th>Property set</th>
<th>Answer</th>
<th>Missing Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pset_LegalInterestCommon</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_Lot</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
Appendices

<table>
<thead>
<tr>
<th>Pset_CommonProperty</th>
<th>Yes / No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pset_Road</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Pset_RestrictionCommon</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Pset_Easement</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Pset_Restriction</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Pset_DepthLimitationOrAirSpace</td>
<td>Yes / No</td>
</tr>
</tbody>
</table>

5. Almost all types of ownership boundaries are already modelled by current IFC standard. Only, semantic data elements for “median” and “other” physical boundaries are required to be added into current IFC standard. These boundaries were considered in the proposed extension. Do you think that existing and proposed data elements for modelling each ownership boundary are comprehensive?

<table>
<thead>
<tr>
<th>Legal boundary</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior structural boundaries</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
6. Is there any other type of ownership boundary which has not been considered in the proposed IFC extension? If yes, please provide its details below:

7. Do you think that the proposed extension includes the required attributes for managing metadata about all types of legal documents? For each legal document, please provide missing attributes if applicable.
<table>
<thead>
<tr>
<th>Legal document</th>
<th>Answer</th>
<th>Missing Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Parent Title</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Mortgage</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Caveat</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Encumbrance</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Planning Permit</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>

8. Is there any legal document which has been not considered in the proposed IFC extension? If yes, please provide its details below:


9. Is there any land administration actor who has not been considered in the proposed IFC extension? If yes, please provide its details below:


10. Do you think that administrative attributes required in subdivision plans are comprehensively considered in the proposed IFC extension? If any attribute is missing, please provide its details.
<table>
<thead>
<tr>
<th>Administrative data</th>
<th>Answer</th>
<th>Missing Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan information</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Survey header</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
Questionnaire (2) for Evaluating Logical Validity of Proposed Extension of IFC Standard for Victorian Cadastre

Part 1) Interviewee’s details

1. Name of your organisation:

2. Division/unit and position title:

3. Which of the following alternatives do you specialize in?

- Industry Foundation Classes
- EXPRESS data modelling
- Other (please specify)......................

4. How much experience do you have in your area of expertise?

- Less than a year
- Between 1 to 3 years
- Between 4 to 8 years
- More than 8 years
Part 2) Logical validity of the proposed extension

In this part, the proposed IFC extension will be validated and checked against the current logic of the IFC standard. Only participants having knowledge of EXPRESS data modelling language, which is the base language of IFC standard, or being familiar with data schema of IFC standard would be able to provide their feedback on logical validity of the proposed extension. The logical validity of the proposed extension will be evaluated according to the following criteria. These criteria were explicated from existing literature on evaluation of data models.

1) **Correctness:** It refers to the conformance of the proposed IFC extension with the rules for extending IFC standard. This is the most important aspect for assessing logical validity of the proposed extension (Question 5 to Question 13).

2) **Simplicity:** This means that the proposed extension includes as minimum as a possible number of data elements and relationships. In other words, there is no redundant data element in the proposed IFC use and extension. Questions 14 and 15 are dedicated for this aspect.

3) **Understandability:** It refers to as the ease with which the proposed data elements and their relationships can be understood by users and implementers of IFC standard (Questions 16 and 17)

4) **Implementability:** This indicates the feasibility of implementing the proposed IFC use and extension as a prototype BIM model (Questions 17 and 18).

1. In your opinion, do you think that “RelatedElements” attribute of “IfcRelReferencedInSpatialStructure” objectified relationship correctly refers to constituting elements of each ownership interest? For example, “RelatedElements = Set [1:?] of IfcSpace” correctly relates a spatial zone for volumetric lots to its constituent elements.

<table>
<thead>
<tr>
<th>Spatial Zone</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Strata Lot</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td>Option</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Common property</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Reserve</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Crown Parcel</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Easement</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Restriction</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Depth Limitation</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Airspace</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
2. Do you think that each proposed property set were correctly defined and assigned to their corresponding IFC entity?

<table>
<thead>
<tr>
<th>Property set</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pset_OwnershipInterestCommon</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_Lot</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_CommonProperty</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_Road</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_RestrictionCommon</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_Easement</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_Restriction</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Pset_DepthLimitationOrAirSpace</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
3. Given that all boundaries except median and other physical boundaries are defined in current IFC standard, do you think that enriching “IfcInternalOrExternalEnum” with “MEDIAN” and “USERDEFINED” enumeration values is the correct approach to incorporate those boundaries into IFC standard?

<table>
<thead>
<tr>
<th>Ownership boundary</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median physical boundaries</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Other physical boundaries</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>

4. Do you think that “IfcDocumentInformation” can adequately manage metadata associated with the following legal documents?

<table>
<thead>
<tr>
<th>Legal document</th>
<th>Answer</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Parent Title</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Mortgage</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Caveat</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Encumbrance</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>

5. Do you think that “IfcDocumentInformationRelationship” entity was properly used to model relationships among legal documents mentioned in the previous question?

<table>
<thead>
<tr>
<th>Answer</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
6. Do you think that “Planning Permit” document and its actors were properly modelled by within the proposed use and extension of IFC?

<table>
<thead>
<tr>
<th>Answer</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>

7. Do you think that the following actors were correctly assigned to ownership spatial zones?

<table>
<thead>
<tr>
<th>Actor</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land surveyor</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Owner</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Owners Corporation</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Land registry</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>City Council</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Referral Authority</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>Developer</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>

8. Do you think that the following actors were assigned correctly to their corresponding legal documents?

<table>
<thead>
<tr>
<th>Actor</th>
<th>Legal document</th>
<th>Answer</th>
<th>Additional Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>Title</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>
9. In your opinion, do you think that “IfcProject” and “IfcSite” entities are the appropriate data elements to manage administrative information about building subdivision projects?

<table>
<thead>
<tr>
<th>IFC entities</th>
<th>Answer</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>IfcProject</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>IfcSite</td>
<td>Yes / No</td>
<td></td>
</tr>
</tbody>
</table>

10. According to the definition of simplicity, what score do you give to the simplicity of the proposed IFC extension?

<table>
<thead>
<tr>
<th>Poor</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

11. In what part/s of the proposed extension, in your opinion, there are redundant data elements? Please provide your feedback if applicable

12. According to the definition of understandability, do you think that how much the proposed IFC extension is understandable?

<table>
<thead>
<tr>
<th>Poor</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

13. Which parts of the proposed extension are difficult to be understood by its potential users? Please provide your feedback if applicable
14. According to the definition of implementability, to what extent, in your opinion, the proposed extension is implementable?

<table>
<thead>
<tr>
<th>Poor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Excellent</th>
</tr>
</thead>
</table>

15. In your view, which part of the proposed extension is infeasible to be implemented in a real world case study scenario? Please provide your feedback if applicable
Appendices

Appendix D: Plain Language Statement

PROJECT TITLE:
Building Information Modelling for Land Administration

INVESTIGATORS:
Mr. Behnam Atazadeh (Department of Infrastructure Engineering, UoM)
Dr. Mohsen Kalantari (Department of Infrastructure Engineering, UoM)
Dr. Tuan Ngo (Department of Infrastructure Engineering, UoM)
Prof. Abbas Rajabifard (Department of Infrastructure Engineering, UoM)

THE PROJECT:
This research project investigates the feasibility of Building Information Modelling (BIM) approach for managing ownership spaces and boundaries in multi-storey buildings. The main aim of this research is to propose an extension to the BIM standard for 3D digital management of ownership rights in multi-storey buildings. The proposed extension will provide the basis for managing, storing and visualizing ownership of properties within a 3D digital environment.

This project is a minimal risk project, which the only possible inconvenience to the participants is the time spent in the interview. Each interview will take approximately half an hour, which will be conducted at the time convenient to the participant. Each participant will be provided with a documentation of the proposed BIM extension at least a week prior to the conduct time of the interview. Additionally, an audio recorder will also be activated to record participant’s verbal comments. The data collected will be used only for the purpose of this project and will be kept in a safe place. Access to data will be restricted to the named investigators only. The results of this research will likely by presented in form of charts or tables, which will subsequently be published in conference or journal papers.

Participation in this study is completely voluntary. The questions are of a purely informational/factual nature and there will be no direct or indirect financial interest for the researchers in this study. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so without prejudice. Due to the small sample size, you may be identifiable as a participant. However, the confidentiality of the information you provide will be safeguarded, subject to any legal requirements. In addition, please note that if you are in a dependent relationship with any of the researchers, your involvement in the project will not affect ongoing assessment and management. The audio recordings and questionnaires will be stored within the Department of Infrastructure Engineering, The University of Melbourne and will be destroyed securely at least five years after the last publication.

Should you require any further information, or have any concerns, please do not hesitate to contact Dr. Mohsen Kalantari (mohsen.kalantari@unimelb.edu.au). This project has been granted clearance by Human Research Ethics Committee. Should you have any concerns about
the conduct of the project, you can contact the Executive Officer for Human Research Ethics at The University of Melbourne by phone +61 3 8344 2073 or fax +61 3 9347 6739.
Appendices

Appendix E: Consent Form

CONSENT FORM FOR PERSONS PARTICIPATING IN A RESEARCH PROJECT

PROJECT TITLE: Building Information Modelling for Land Administration

Name of participant:

Name of investigator(s): Behnam Atazadeh (Doctoral Candidate); Dr Mohsen Kalantari, Dr Tuan Ngo, Professor Abbas Rajabifard (Supervisors)

1. I consent to voluntarily participate in this project, the details of which have been explained to me, and I have been provided with a written plain language statement to keep.

2. I understand that after I sign and return this consent form it will be retained by the researcher.

3. I understand that my interview will involve an audio recording and one or two questionnaires, and I agree that the researcher may use the results as described in the plain language statement.

4. I acknowledge that:
   a. the possible effects of participating in the testing and the questionnaires have been explained to my satisfaction;
   b. due to small sample size, I might be identified as a participant.

5. I have been informed that:
   a. I am free to withdraw from the project at any time without explanation or prejudice and to withdraw any unprocessed data I have provided;
   b. the tasks and questions are of a purely informational/factual nature, and there will be no direct and indirect financial interest for the researchers in this study.
   c. the confidentiality of the information I provide will be safeguarded subject to any legal requirements.
   d. with my consent the audio recording and the questionnaires will be stored at the University of Melbourne and will be destroyed minimum after five years after last publication.
   e. if I am in a dependent relationship with any of the researchers, my involvement in the project will not affect ongoing assessment and management.
   f. my name and personal details will be kept confidential.
   g. this project is only for research purposes.

Based on the above:

☐ I agree to participate in the research

Participant signature         Date

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Author/s: Atazadeh, Behnam

Title: Building information modelling for urban land administration

Date: 2017

Persistent Link: http://hdl.handle.net/11343/150614

File Description: Building Information Modelling for Urban Land Administration

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