Modelling 3D Legal Boundaries for Urban Infrastructure in a BIM Environment: Case Studies in Queensland, Australia

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Key words: Urban Infrastructure, Volumetric Format Plans, Queensland, BIM, 3D Legal Boundaries

SUMMARY

One of the five goals of the future vision for Australia and New Zealand is to provide a digital representation of the real world that is survey accurate, 3D and dynamic. The 3D element is becoming increasingly important due to the escalating development of buildings and infrastructure below and above the ground that are difficult to visualise on 2D survey plans. In Queensland, Australia, 3D objects in survey plans are represented using Building Format plans and Volumetric Format plans. To enhance the visualisation and useability of these survey plans, legal boundaries have been incorporated into Building Information Models (BIM). Prior research has demonstrated how legal boundaries defined on building format plans can model volumetric spaces based on physical building elements such as floors, walls and ceilings. This project aimed to extend this research by investigating whether more abstract legal boundaries bound by 3-dimensionally located points as depicted on Queensland Volumetric Format plans could be modelled in a BIM and transferred to an alternative BIM program using an international geospatial standard. Industry Foundation Classes (IFC) is the most widely used open data model to facilitate the transfer of information between different proprietary BIM platforms. A BIM prototype model developed in Revit demonstrated how a volumetric lot can be created within a BIM environment together with attributes required for an interactive Land Administration system. Two case studies were conducted for this research using two volumetric survey plans, one representing a volumetric lot underground containing an underground road tunnel and another representing an aboveground lot used for leases of infrastructure above a high-rise building. The volumetric lots in the models were designated as IfcSpace entities in the IFC standardised data structure. The interoperability of the prototype models encoded in an IFC format was demonstrated by successfully importing the files into two alternative information platforms. A BIM/IFC based approach to modelling volumetric boundaries has the potential to be a viable input into the formulation of the 3D land administration for urban infrastructure in Queensland.

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1. INTRODUCTION

1.1 Background

The Australian and New Zealand Spatial Information Council (ANZLIC) is the main intergovernmental organisation assigned with coordinating the collection, use and management of spatial information in Australia and New Zealand. A standing committee of ANZLIC is the Intergovernmental Committee on Surveying and Mapping (ICSM) whose members represent the various Australian and New Zealand commonwealth, state and territory agencies overseeing surveying, mapping, and hydrographic charting activities. A prime function of the ICSM is to provide leadership on land administration reform matters and its strategy to reflect this is addressed in the project "Cadastre 2034" (ICSM 2015).

The vision for Cadastre 2034 is to develop a land administration system that enable users to readily and confidently identify the location and extent of all the rights, restrictions and responsibilities (RRR) related to land and real property (ICSM 2015). One of the five goals of Cadastre 2034 is to provide a digital representation of the real world that is survey accurate, 3D and dynamic. In recent times, there has been a significant increase in road and train tunnels, rooftop gardens, elevated roads, multistorey mixed-use buildings, and other infrastructure that is difficult to visualise on 2D survey plans. Significant advances in digital visualisation technologies have helped address the limitations of paper based 2D plans.

Building Information Models (BIMs) are intelligent 3D models that have become standard across major building projects and help visualise projects in planning, design, construction and operation phases of a project. BIMs can be leveraged to incorporate 3D legal boundaries and provide clear representation of ownership of the different property parcels within a complex (Atazadeh et al. 2021). BIMs have been used in overseas jurisdictions to update the land administration system (Van Oosterom et al. 2014). Further, it has been demonstrated that BIMs can be utilised as one of the building blocks for the establishment of digital twins of a city (Shi et al. 2023).

In Queensland, Australia, 3D objects in survey plans are presented using Building Format plans (BFPs) and Volumetric Format plans (VFPs). The standards and guidelines for undertaking land surveys in Queensland are provided for in the Cadastral Survey Requirements (Surveying Services 2023). The guidelines for the preparation of survey plans are found in the Registrar of Titles Directions for the Preparation of Plans (RTDPP) (Registrar of Titles 2023) which is prepared under the provisions of Section 10 of the Land Title Act 1994. According to Registrar of Titles (2023), BFPs define parcels using structural elements of a building including, for example, floors, walls and ceilings. A BFP is a survey of a building that can be only used when a building exists. VFPs define parcels using 3-dimensionally located points to identify the position, shape and dimension of each bounding surface. A VFP creates a 3D lot and does not require structural elements. All dimensions horizontally and vertically are defined on the plan of the survey using bearings, distances and heights to fully define the 3D shape. VFPs are ideal where different land use ownership is required within or around a building and are extremely flexible in their potential shape which allows a plan to create a title around virtually anything (Registrar of Titles 2023).

Visualisation of 3D structures on a 2D plan can be difficult for spatial science professionals, much less lay person with little spatial training. For a BFP, parcels are defined and limited by a physical building element, typically floors, ceilings, and walls. However, a parcel on a VFP has an added layer of visualisation difficulty as the boundaries are not defined by a physical element such as a wall or a floor but are defined by virtual elements being surveyed bearing, distances and heights that can be above or below ground and are not physically marked on an object (Smart & Priebbenow 2018). A volumetric format parcel can be defined before an associated physical object such as a building or tunnel has been constructed.

The aim of this study is to demonstrate how BIM can be utilised for 3D digital management of vertically stratified legal boundaries in Queensland by modelling volumetric lots created by VFPs.

The project intends to answer the following research question: *Can BIM be used to develop a prototype model to depict legal boundaries on Queensland VFPs and can the BIM model be transferred to alternative programs using an appropriate international 3D geospatial standard?*

1.2 Visualisation difficulties with traditional 2D survey plans

The complexities of visualising 3-dimension objects on 2D survey plans have been the subject of research from many years. Karki, Thompson and McDougall (2013) noted that urban environments have seen the development of buildings and other infrastructure both aboveground and underground as the availability of land in urban areas has become scarce. Different jurisdictions have traditionally depicted legal boundaries as closed polygons with associated property rights known as the 2D land registration. The registration of properties below and above ground level is known as the 3D land registration. 2D plans are usually presented on multiple pages and often struggle to effectively convey the spatial complexity of parcels above and below the ground. Some of these challenges have been identified as follows:

- **Difficulties of visualisation in the spatial context**. 2D plans limit the ability to interact with or visualise objects from various angles, making it difficult to understand the spatial context of the design (Cemellini et al. 2020).
- **Overlapping and hidden features.** When different layers or sections of an object overlap in 2D plans, crucial details may be obscured or distorted, making it difficult to visualise the objects' structure (Larsson, Paasch & Paulsson 2020).
- **Difficulties visualising irregular shapes.** Irregular or curved structures are difficult to visualise on a 2D plan meaning that multiple views are often required to properly understand the design (Hajji et al. 2021).

- **Misunderstanding scale, proportion, and depth.** Accurately perceiving the scale, proportion and depth of objects becomes difficult on 2D plans, particularly when there is no clear reference for height or depth.
- **Uncertainty of spatial boundaries.** Depicting 3D spaces on a 2D surface can lead to confusion or ambiguity, particularly when different layers or levels intersect (Petronijević et al. 2021).

The increased number and complexity of 3D legal spaces below and above the ground in all jurisdictions across the world highlights the need to develop 3D land administration systems to manage the rights, restrictions and responsibilities (RRRs) and interest of land above and below the surface.

1.3 Analysis of Queensland VFPs

Cemellini et al. (2020) identified that visualising land parcels in 3D presents a challenge because legal boundaries are often invisible in the physical world using the example of volumetric boundaries defined by metes, bounds and heights in Queensland VFPs. Atazadeh, Rajabifard and Olfat (2023) devised a questionnaire to develop an understanding of current state of the 3D land administration across all Australian and New Zealand jurisdictions. In their analysis of primary legal parcels, the authors provided a detailed overview of Queensland volumetric format lots. Volumetric format lots are commonly used to reserve an envelope to be later subdivided for building format lots. Alternative uses for volumetric format lots include uses for roads, and for structural, utilities and infrastructure features. The authors note that the purpose of establishing volumetric format lots is to enable the developments of multiple units on the one block. Atazadeh, Rajabifard and Olfat (2023) also analysed the legal requirements of Queensland volumetric format lots noting that the relevant legislation is the Land Title Act 1994 (State Government of Queensland 2024). Section 48D of this Act states that VFPs are defined “using 3 dimensionally located points to identify the position, shape and dimensions of each bounding surface”. Accordingly, 3D points are legally used to define the height dimension of volumetric lots. The ability to register a 3D object as long as it can be defined mathematically meant that Queensland is considered as one of the pioneering and leading jurisdictions in 3D land registration (Van Oosterom et al. 2018; Hajji, El Asri & Ez-Zriouli 2023). The practical considerations for presenting volumetric format lots on a 2D plan are set out in the Registrar of Titles Directions for the Preparation of Plans (Registrar of Titles 2023) discussed in the introduction above. With reference to the ground surface, volumetric lots can be above or under, either partially or fully.

Cemellini (2018) notes that in Queensland, only the footprint of 3D survey plans including VFPs are currently shown on the Digital Cadastral Database (DCDB) and these plans are only stored in scanned Portable Document Format (PDF) or tagged Image Files Format (TIFF). This means than analysis of how volumetric lots are integrated with its surroundings is manual, time consuming and not easily understood by non-spatial professionals as the plans cannot be interactively viewed.

1.4 *Physical land parcels versus legal parcels*

Karki, McDougall and Thompson (2010) examined the 3D land administration systems from a legal property object and physical land parcel perspective and by investigating the differences between the two. The physical land parcel is a defined area of land which is the unique identifiable building block of the land registration process. From a 3D perspective, parcels can encompass a surface parcel with a vertical column of space either above or below it, 3D strata titles for apartments, or parcels spanning many surface parcels (Stoter & van Oosterom 2006).

The legal parcel object was introduced by Kaufman in 1988 where the primary entity is a legal object linked with a corresponding physical parcel. A legal parcel object is an entity comprising of an interest in land with a spatial dimension compared with the traditional model of physical land parcels in which each land parcel is the focal point (Kaufmann & Steudler 1998).

Karki, McDougall and Thompson (2010) concluded that whilst the physical land parcel model has been successful for traditional land administration, it is inflexible for including modern land administration developments including the 3D capability. The legal object parcel model can fulfil the specifications for merging current and future interests as well as developments. The authors suggested that the international standard ISO 19152 LADM Administration model provides a middle ground by integrating physical land parcel models with models which depict rights, restrictions, and responsibilities (RRR) and interest in land.

1.5 *Land Administration Domain Model (LADM)*

In December 2012, the International Organisation for Standardisation (ISO) issued standard ISO 19152 known as the Land Administration Domain Model which provided a standardised framework for representing land administration systems. LADM defines conceptual models and sets out data structures for describing legal, administrative, and spatial aspects of land administration including land tenure, land use and the legal cadastre. The LADM encompasses both the spatial components (primary class LA_SpatialUnit) and the non-spatial elements of land administration (primary class LA_Party, LA_RRR and KA_BAUnit) as shown in Figure 1 (Van Oosterom, Lemmen & Uitermark 2013).

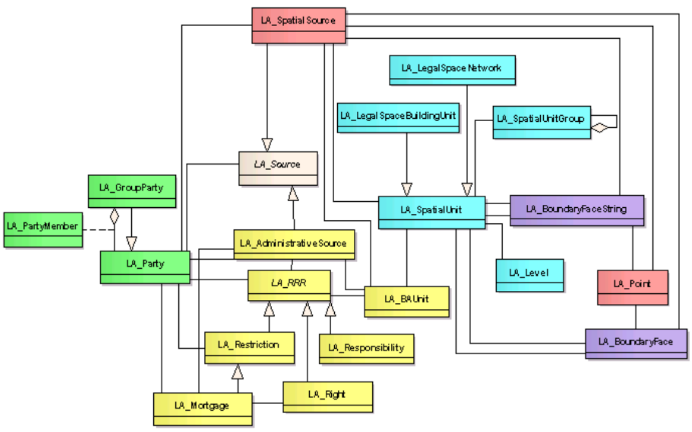

Figure 1. The LADM class diagram (Van Oosterom et al. 2013)

There have been many prototypes of LADM developed across several international jurisdictions. A particular relevant study by Cemellini et al. (2020) designed and developed a LADM-compliant prototype model in Queensland, Australia. They found that the present approach to data capture and conversion for 3D parcels is highly time intensive, laborious, and susceptible to error. It was noted that for newly designed objects, a solution that is both less prone to error and more efficient utilising specific data elements in BIMs is optimal.

LADM II (ISO 19152-2) is being developed as an extension to the original model to address the evolving needs and challenges of the international Land Administration (LA) community that were not provided for in the original iteration. Kara et al. (2024) presented an overview of the revision process, the requirements of the new edition and the package structure and classes of the new edition. There were many motivations for introducing the edition of the model including the desire to integrate LADM with new technologies including 3D land administration systems. The new edition allows for BIM/IFC to be used as a design source to extend the 3D aspects of the LADM.

1.6 ePlan Model

In 2011, an ePlan model was developed across many Australian jurisdictions to manage land and property data exchanges (Aien et al. 2012). This model uses the LandXML standard which is a data exchange format bases on the XML protocol for transferring surveying and civil engineering information. A study was carried out in Victoria, Australia to determine whether different building format plans could be represented using the ePlan model (Shojaei et al. 2016). It was determined that all the necessary components for modelling building subdivisions are supported, however, it identified limitations with modelling curved surfaces and specifically did not address modelling VFPs.

1.7 Open Geospatial Consortium (OGC)

The Open Geospatial Consortium (OGC) was established in 1994 as a not for profit organisation whose aim is to unite the technology industry with the burgeoning geospatial industry (Reichardt & Robida 2019). The OGC established two frameworks for the 3D modelling of the constructed environment: CityGML and IndoorGML

1.7.1 CityGML

CityGML is the international standard for the portrayal and interchange of 3D city models (Gröger & Plümer 2012). The standard identifies the primary topographic features in an urban environment and aims to define the 3D geometry, appearance, semantics, and topology of these features. The standard applies the Geography Markup Language (GML) which offers a standardised geometry model that allows for interoperable data exchange due to its well-defined structures and semantics. The standard uses a scale using increasing Levels of Detail (LOD) to portray a building in a 3D environment (Rajabifard, Atazadeh & Kalantari 2019). The five LODs are depicted in Figure 2 and shows how the semantic and spatial information about urban objects increases when moving along the scale.

Figure 2. Increasing Levels of Detail in CityGML (Rajabifard et. 2019)

Atazadeh et al. (2017b) noted that whilst the CityGML standard did not evolve specifically for land administration purposes, there exist some entities within this building model that could be used to model legal ownership boundaries. The “OuterCeilingSurface” entity could be used to define an external ceiling boundary and the “InteriorWallSurface” could be used to define the internal wall boundary. Further, it has been proposed by several researchers to embed legal information into the City GML models by way of using special extensions using the Application Domain Extension (ADE) system.

A study by Çağdaş (2013) created an ADE extension of CityGML with a more extensive scope to model the legal ownership of condominiums in Turkey. CityGML does not allow for the portrayal of legal property units. The extension developed by Cagdas created 3 new feature classes: an abstract “PropertyUnit” class and two more tangible classes “CadastralParcel” and CondominiumUnit”. A modified version of the ADE extension developed by Cagdas was adopted by the OGC Land and Infrastructure Conceptual Model Standard (Landinfra) (Scarponcini 2016).

Several deficiencies in modelling legal boundaries were identified in CityGML 2.0 and earlier versions. CityGML 3.0 was developed to address these deficiencies and was officially adopted as the OOGC standard in 2021 (Kutzner, Chaturvedi & Kolbe 2020). Nega and Coors (2022) showed how CityGML 3.0 can serve to represent the legal entitlements of individual units of a building format plan using a case study in Addis Abada, Ethiopia. More conceptual boundaries evident in VFPS were not part of the scope of this study. Saeidian et al. (2024) developed a data model to extend CityGML 3.0 to model underground legal boundaries in Victoria, Australia using the application domain extension (ADE) mechanism to provide more detailed information about legal boundaries and RRRs in underground land administration.

1.7.2 IndoorGML

OGC introduced IndoorGML as a standardised data model and XML based structure for indoor spatial representation and to allow for interoperability between indoor spatial information services (Kang & Li 2017). Whereas CityGML addresses indoor space using feature modelling of building structural elements such as ceiling, roof, wall, and floor, IndoorGML defines a minimum data model using the basic space unit called a cell. The depiction of the geometry semantics and topology of the cells in the indoor space is the basis for the IndoorGML standard framework and can be used for navigation within buildings.IndoorGML uses two alternative frameworks being the Structured Space Model (SSM) and the Multi-layered Space Model (MLSM). SSM delineates the spatial arrangements of indoor environments distinct from its semantic interpretation. There are two types of spaces defined by SSM, the primal space and dual spaces. The spatial structure and arrangement subdividing indoor spaces is defined by the primal space. The dual space concept allows for the integration of both geometric and semantic facets of indoor spaces. MLSM integrates multiple space layers from the SSM, each defining a unique semantic understanding of indoor spaces tailored for particular applications (Lee et al. 2014).

Atazadeh et al. (2017b) suggested that there may be two alternative approaches to using IndoorGML to map legal boundaries within 3D environments. Space objects are described by the entity "CellSpace" and the boundaries by the entity "CellSpaceBoundary". These entities could be extended with legal boundary and ownership rights linked to indoor spaces. Alternatively, a different approach could be to define an external connection between an existing 3D land administration standard, for example LADM, and IndoorGML. There have been no studies that have mapped legal boundaries on Queensland VFPs in IndoorGML.

1.8 Industry Foundation Classes (IFC)

The Industry Foundation Classes is a standard data model developed to allow for the exchange of information in the architecture, engineering, and construction (AEC) industries through the Lifecyle of a project or asset. It was first published as a standard by the International Organisation for Standardisation (ISO) in 2007 as ISO 16739 "Industry Foundation Classes (IFC) and is used for data exchange within the construction and facility management sectors (buildingSmart 2024). It has undergone several revisions and updates since inception with the latest version ISO16739-1:2024 published in March 2024 which included necessary information for infrastructure facilities encompassing ports, railways, roads, and bridges. ISO16739 serves as the globally recognised standard for data used in Building Information Modelling (BIM) providing a universal data structure for exchanging information across different 3D information platforms. The IFC data exchange model allows for completing a BIM modelling project in one proprietary software, and then transferring this object to be used as a reference file in different proprietary applications. Only limited editing of an IFC file is allowed meaning that in a IFC based workflow, each discipline remains authorship and ownership of their respective model information. IFC is regarded as an open data specification that operates independently from any specific BIM vendor.

The IFC standard schema is segmented and includes four primary conceptual layers as set out in Figure 3. A schema is a formal description or blueprint of the structure and organisation of a database or data format.

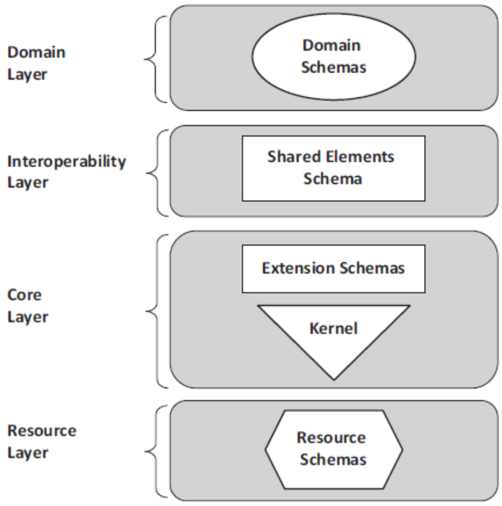

Figure 3. Modular structure of the IFC Standard (Rajabifard, Atazadeh & Kalantari 2019)

Each layer of IFC consists of multiple sub-schemas. The different layers are described by (Rajabifard, Atazadeh & Kalantari 2019) as follows:

Resource Layer

This layer is the lowest layer in the IFC Standard schema and includes subschemas containing basic concepts and generic entities. Entities in this layer cannot exist in isolation and their presence relies on being utilised as value types within attributes of higher-level entities that are made up from the If Root class.

Core Layer

This layer includes the IfcKernel subschema and three core extension subschemas being product, control extension and process. The IfcKernel layer encompasses the most conceptual entity IfcRoot which is specialised into three entities: IfcObjectDefinition entity serves as the conceptual superclass for entities that capture various categories of objects and is the abstract superclass for entities like process (IfcProcess, products (IfcProduct) and control (IfcControl).

Interoperability layer

Interoperability in software means the functionality of various programs to facilitate information exchange, file sharing and adherence to shared protocols. This layer contains IFC entities that can be exchanged across multiple different platforms.

Domain layer

This layer defines the conceptual framework and contains entities used to represent the various elements of building and construction projects.

IfcProduct Class

Atazadeh et al. (2017a) identified that the IfcProduct class within the core layer is most relevant to modelling land and property data in the 3D domain. The IfcProduct superclass is the most conceptual superclass within the IFC Standard spatial structure meaning that specific details are defined by the subclasses. The subclasses are IfcSpatialElement and IfcElement and their underlying entities are set out in Figure 4.

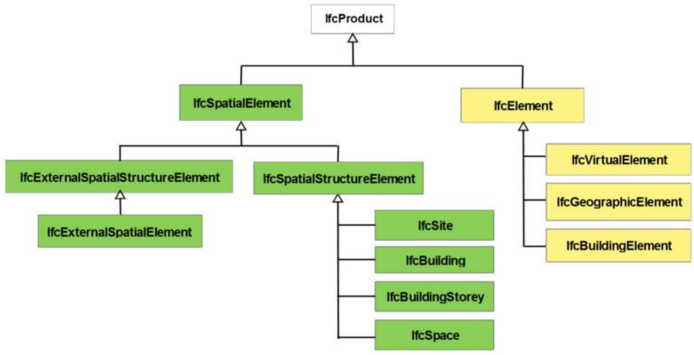

Figure 4. IfcProduct data structure diagram (Atazadeh et al. 2017a)

IfcSpatialElement coloured in green on Figure 4 define the spatial elements of an IFC database and is made up of IfcExternalSpatialstructureElement and IfcSpatialStructureElement. The first class models the outdoor spaces of a building project, whereas the second class models the elements of the project defining the spatial structure of the actual building. IfcElement coloured in yellow on Figure 4 is used to model geographic elements (IfcGeographicElement) and actual physical elements such as building elements.

In the next section, numerous studies that investigate the potential of using BIM in 3D land administration by utilising IFC as the standard data model will be discussed.

1.9 Measuring legal boundaries in BIM using IFC as the standard data model

Clemen and Gründig (2006) was one of the pioneering studies that found that whilst it was not possible to integrate survey data as primary data to an IFC data model, survey measurement and points could be pre-processed and the survey results including thematic information could be imported in IFC files. The authors suggested that additional work could be undertaken to develop an IFC survey domain data model. Plume and Mitchell (2011) in their study on an urban information framework demonstrated that BIM can be extended to include a collection of individual lots. However, the authors did not attempt to model the legal boundaries in the lots using the IFC standard. El-Mekawy, Paasch and Paulsson (2014) presented a conceptual study on how BIM can enhance and augment the 3D land administration. The authors noted that whilst BIM is regarded as the most extensive and detailed object-orientated method for building modelling, it could not at the time be used to model the complete 3D land administration. In a follow-up study El-Mekawy, Paasch and Paulsson (2015) continued their research on the viability of using BIM within the development of the 3D land administration specifically with respect to developing unified building models. It provided a theoretical framework for how 3D legal real property principles could interact with IFC standards in the development of the 3D land administration frameworks. The authors founds that the IFC standards did not currently address legal property aspects like boundaries and RRRs. Oldfield et al. (2016) suggested that whilst the IFC is an extensive model, it would require additional enhancement to meet the demands of legal boundaries. Enhancing the IFC model would facilitate the extraction of data for a 3D land administration for both as-designed and as-built data models. The zone and space ideas in IFC might provide a viable method for creating virtual legal boundaries within BIM. Stoter et al. (2017) demonstrated how 3D legal objects in the Dutch jurisdiction could be registered using a 3D PDF format extracted from a BIM model as the source data. The authors indicated that additional research is required to implement the registration in a standardised and consistent manner. However, it did not specifically look at modelling 3D legal boundaries using the IFC format.

Atazadeh et al. (2017b) argued that BIM lacks the ability to properly record property ownership and legal boundaries through the IFC framework. An extension to the IFC standard was suggested which encompasses legal property objects and legal ownership and secondary interest holder information. This was a theoretical study based on literature review that contended that legal boundaries could be managed in a BIM project within high-rise structures by mapping to their corresponding IFC entities.

Atazadeh et al. (2017a) used a case study in Victoria, Australia to investigate modelling building ownership boundaries within a BIM environment. This study built on prior theoretical research by developing a prototype to demonstrate the ability of BIM to model building ownership boundaries. The authors identified relevant IFC entities appropriate for modelling legal boundaries within buildings and how this applied in the legal jurisdiction of Victoria, Australia. It was suggested by the authors that an avenue for future research could be to explore how a BIM environment in conjunction with the IFC standards could be used to allow communication of volume and area boundaries crucial for property measurement in other jurisdictions in Australia. An application of this would be to investigate whether the IFC standards could be used to model non-physical boundaries present on VFPs in the jurisdiction of Queensland, Australia.

Rajabifard, Atazadeh and Kalantari (2018) examined various 3D spatial models to determine the capacity for modelling legal boundaries and legal interests. The study classified the information models into 3 classes, purely physical, purely legal and an integration of both. Using the Victorian jurisdiction, the authors found that an integrated approach was best suited to meet the data requirements of a 3D spatial information model. The physical parts of the integrated approach could be sourced from both CityGML standards and IFC. CityGML could be used to model external physical components such as roads, tunnels, and bridges. IFC standards could be used to model internal components such as floors, walls, and ceilings. LADM or ePlan could be used to model the legal components of an integrated model. The authors suggested that similar studies in other Australian jurisdictions could be undertaken to contribute towards a national 3D spatial framework for Australia.

Atazadeh et al. (2019) built on prior research on using BIM in creating a 3D land administration system. The focus of this study was to develop techniques to query the identified IFC entities and relationships used for administering 3D legal boundaries and different ownership structures. Again, this study focussed on the 3D legal boundary arrangements in Victoria, Australia. The authors suggested that their method for querying 3D land and property information could be easily adapted in other jurisdictions if their requirements for storage and retrieval of this information is well understood.

Andritsou et al. (2022) explored the potential integration of BIM, IFC standards with the Land Administration Domain Model (LADM) to create a registration and visualisation solution of 3D spatial and semantic information related to the RRRs in modern buildings in the Greek jurisdiction. For their proposed framework, the authors used two multistorey building but did not address non-physical boundaries found in VFPs. Similar studies were also completed in the Chinese, Turkish, Netherlands, Saudi Arabian and Swedish context that also did not examine non-physical boundaries found in VFPS (Sun et al. 2019; Guler et al. 2022; Guler, Van Oosterom & Yomralioglu 2022; Liu et al. 2023) .

Stoter et al. (2024) examined the data requirements for a BIM Legal model designed to support the 3D registration of apartment complexes in the Netherlands using IFC as the open standard model. The authors proposed a 3-phase approach for implementation that is economically, technically, and legally feasible. This paper provides an in-depth analysis of Phase 1 that addresses the technical data requirements. Future research will be required in Phase 2 to enable the registration of the BIM legal Model and in Phase 3 to include the rights to the various building elements identified in Phase 1. This paper focussed on physical components of multi-level buildings when developing the BIM legal Model, however, it did not address more conceptual boundaries found in VFPs.

Kalogianni et al. (2020) used BIM/IFC as the primary source of spatial data for their future vision of a 3D land administration system for an urban environment. The authors chose IFC/BIM over other standardised geospatial administration systems as it is recognised as an ISO standard, its popularity is increasing as more BIM models are becoming available, it is increasingly used in the AEC industry, especially in the design phase, it is starting to be used at the building permit phase, it occurs earlier in the spatial development lifecycle than alternative systems like CityGML and it is regarded as a strategic enabler for enhancing decision-making and the delivery of both buildings and public infrastructure assets through their entire lifecycle.

In early 2024, the buildingSmart organisation announced that IFC version 4.3 was approved as the latest version of the IS160739 standard. The latest update includes extensions that allow for improved data exchange across the lifecycle of infrastructure projects such as tunnels, bridges, ports, roads and railways, whereas earlier versions had a primary focus on buildings. IFC 4.3 helps visualise complex infrastructure objects in 3D and adds the time dimension to enable a project to be visualised in 4D across the various phases of the project. Pszczolka (2023) identified that one of the major benefits of IFC 4.3 is the introduction of a Coordinate Reference System into the schema to allow for a standard method to position and locate different elements within an infrastructure project which is particularly relevant to the analysis of legal boundaries.

1.10 Landinfra

Scarponcini (2016) edited the Open Geospatial Consortium Land and Infrastructure Conceptual Model Standard (Landinfra) which is a standardised data model for the exchange of land and infrastructure data. It aims to provide a framework for sharing information between different proprietary software programs related to infrastructure asses such as railways, roads buildings and utilities by defining common data elements and relationships. The standard is similar to other open standards being IFC/BIM and CityGML(3D GS) and it has been argued that it has potential to close the divide between these areas (Kumar et al. 2019). The standard uses entities from IFC and CityGML for modelling physical objects and uses concepts from LADM and LandXML for modelling legal objects. By integrating GIS and BM, more intricate 3D city models can be created by integrating and reusing existing BIM data.

1.11 What is missing in existing research?

Atazadeh et al. (2017b) showed that integrating legal boundaries of buildings into a 3D digital BIM that incorporates all architectural, engineering and construction elements of a building will help overcome the ambiguities in interpreting the legal boundaries of a complex 3D project.

Atazadeh et al. (2017a) demonstrated how legal boundaries have been modelled in a BIM environment for Victorian Survey plans that are like Queensland's BFPs. Similar studies have been undertaken in overseas jurisdictions to show that BIM can be used in the land registration processes focusing on physical elements in building complexes (Sun et al. 2019; Andritsou et al. 2022; Guler et al. 2022; Guler, Van Oosterom & Yomralioglu 2022; Liu et al. 2023). The intention of this project is to further this research by demonstrating how legal boundaries depicted on Queensland VFPs can be modelled in a BIM environment using a proprietary software program and then exported to alternative software vendors using an appropriate international 3D geospatial standard to demonstrate the interoperability of the standard.

Previous studies have indicated that Industry Foundation Classes (IFC) developed by the international BuildingSMART organisation is the most widely used open data model used to facilitate the transfer of information between various BIM programs (Noardo et al. 2021). The application of IFC standards to legal boundaries has been investigated previously with respect to building format lots (Barzegar et al. 2021). This project will further this research by investigating how the IFC standards can applied to depict legal boundaries on volumetric lots in Queensland.

Incorporating volumetric legal boundaries into BIM projects will further the progress of defining the Rights, Restrictions and Responsibilities (RRRs) regulating ownership of property in a 3D environment (Paulsson & Paasch 2013). The integration of the legal boundaries in BIM projects can be used as a design source for LADM II that can be used to represent the 3D digital data in a land administration system.

2. METHODS AND RESULTS

Çağdaş and Stubkjær (2011) developed a theoretical framework for research on information systems used to present land and property information and their associated legal ownership arrangements. There are two main approaches, behavioural research and design research. The behavioural research framework aims to create and validate theories aimed at understanding human and organisational behaviour. Whereas the design research framework aims to create and assess a prototype developed to solve identified problems with information systems. This research used the design research approach as its objective was to create a prototype to demonstrate how legal boundaries depicted on Queensland Volumetric Plans can be modelled in a BIM environment.

Peffers et al. (2007) proposed a design research methodology consisting of six steps: problem identification and motivation, definition of the objects for the solution, design and development, demonstration, evaluation, and communication. Johanesson and Perjons (2022) refined this design research methodology by basing their approach on these steps but by excluding the communication stage and placing less emphasis on the linear order of the steps but as logically connected through input-output relationships performed in an iterative way by moving back and forward between the steps. This approach is visualised in Figure 5.

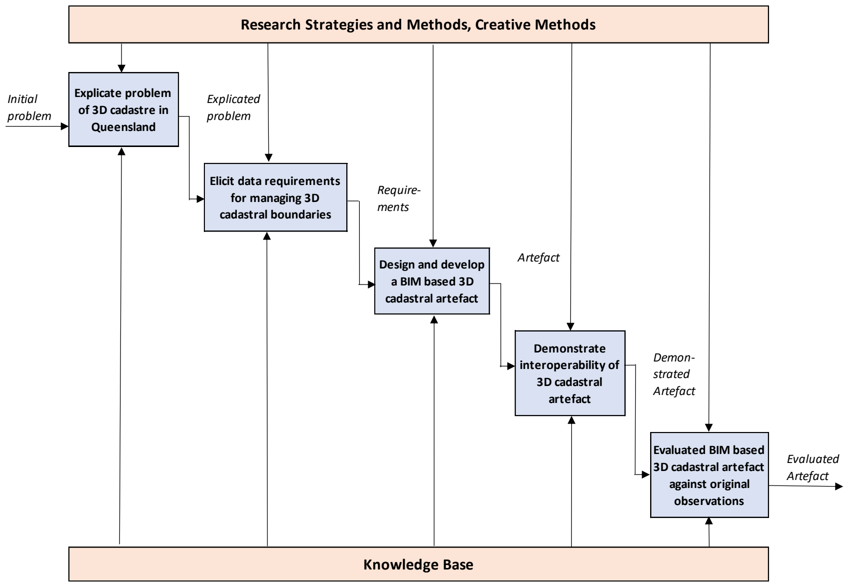

Figure 5. Design science research framework (adapated from Johanesson & Perjons 2022)

The five stages of the design research methodology as applied in this research project will be discussed in the following subsections.

2.1 Explicate problem of 3D land administration for urban infrastructure in Queensland

The problem identified is the difficulty in visualising a 3D object on a 2D survey plan specifically with respect to VFPs in Queensland, Australia as set out in the “Background” section of this paper. The project also aimed to identify an appropriate international geospatial standard to allow for the interoperable transfer of information between competing proprietary 3D visualisation software.

2.2 Elicit data requirements for managing 3D legal boundaries

In this stage the specific visualisation difficulties associated with visualising a 3D object on a 2D plan were set out by examining relevant literature. In Queensland, 3D legal boundaries are depicted using BFPs and VFPs. BFPs use physical building elements such as floors walls and ceilings to define legal boundaries. VFPs and can only be defined when the building has been built. VFPs do not use structural elements to define the volumetric lots but rather all dimensions are defined on the plan using bearings, distances and heights to define the 3D shape of the volumetric lot. The guidelines for the preparation of volumetric survey plans in Queensland were examined to understand how a prototype model could address the legal boundary requirements. These guidelines are set out in the RTDPP (Registrar of Titles 2023).

Volumetric plans define parcels that:

- Are fully enclosed by bounding surfaces, which may be other that vertical or horizontal.
- All bounding surfaces, where not vertical or horizontal must be capable of a precise mathematical definition.
- Are above or below or partly above and partly below the surface of the ground.

The footprint of the volumetric lot must be shown on the plan and at least two corners of the footprint must each be independently connected (by bearing and distance) to at least one corner of the base lot by direct connection. Attributes such as the areas of footprints of the volumetric lot to the nearest square metres must be shown on the plan together with the volume of the volumetric lot to the nearest cubic metre. The ground levels of the footprint and the heights of the bounding surfaces must be shown with reference to Australian Height Datum (AHD) or another pre-approved height datum. The lot number of the volumetric lot must be shown following the word lot in the case of a primary legal volumetric parcel. Where the volumetric lot is a secondary legal tenure, the lot must be described as an easement, lease or common property as appropriate (Registrar of Titles 2023).

The various standardised information models used for legal boundary representation were examined in the background review. It was identified that BIM models using IFC standards is the most appropriate information framework to use to present VFPs to easily visualise the 3D objects depicted in the plans. By incorporating the legal boundaries including volumetric lots into a 3D digital BIM that incorporates all architectural, engineering and construction elements of a building, it will help overcome the ambiguities in interpreting the legal boundaries of the project (Atazadeh et al. 2017a).

The authors suggested that the IfcProduct class within the core layer is the most applicable to modelling land and property data in a 3D environment. IfcProduct data structure diagram can be seen in figure 5. Within the IfcProduct hierarchy, it is contended that IfcSpace is the most appropriate IFC class to use for volumetric format lots. The IFC entity definition of IfcSpace is "A space represents an area or volume bounded actually or theoretically. Spaces are area or volumes that provides for certain functions within a building" (buildingSmart 2024). Section 48D of the Land Title Act 1994 states that "a volumetric format plan of survey defines land using 3 dimensionally located points to identify the position shape, and dimensions of each bounding surface" (State Government of Queensland 2024). The legislated definition of the volumetric format lot satisfies the IFC definition as it is a volume bounded theoretically by a mathematical definition using bearings, distance and heights. IfcSpace has another level of classification known as an object predefined type which is further used to differentiate objects without the need for additional sub types (buildingSmart 2024). The predefined type options for IfcSpace are space, parking, GFA, internal, external, user defined or not defined. The most appropriate option selected for this for the volumetric format lot is “space”.

2.3 Design and develop a BIM based 3D land administration artefact

In this stage of the project, a prototype was designed to model the legal survey requirements of VFPs. As the 3D land registration is defined as the registration of properties below and above ground level, one underground plan and one above ground plan was selected so both scenarios were addressed.

Two volumetric survey plans were selected for this project, one representing a volumetric lot underground and another representing above ground lots. Extracts from the Survey plans are presented in Figure 6 for the underground volumetric lot and Figure 7 for the above ground volumetric lots.

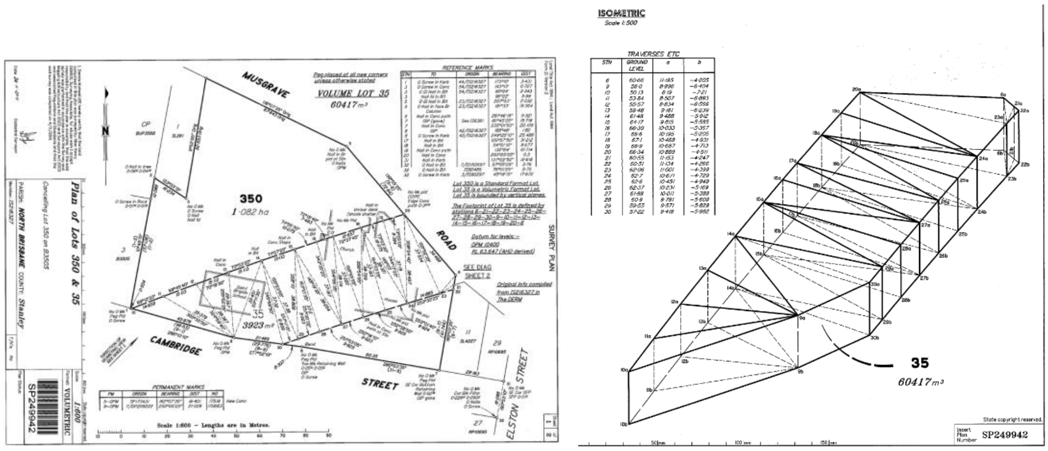

Figure 6. Underground volumetric lot (Lee 2011)

The underground volumetric lot depicted in Figure 6 contains part of the underground “Clem 7” road tunnel passing through the inner-western suburbs of Brisbane. The location of the volumetric lot in context to the topology of the base lot is not easily visualised on the 2D plan. Further, how the volumetric lots integrate with the architectural, engineering and construction elements of the tunnel design and as-constructed plans cannot be easily visualised on the 2D survey plan. Whilst it is evident that format lot is bounded by planes, it is not easily identified the volumetric lot rise from west to east.

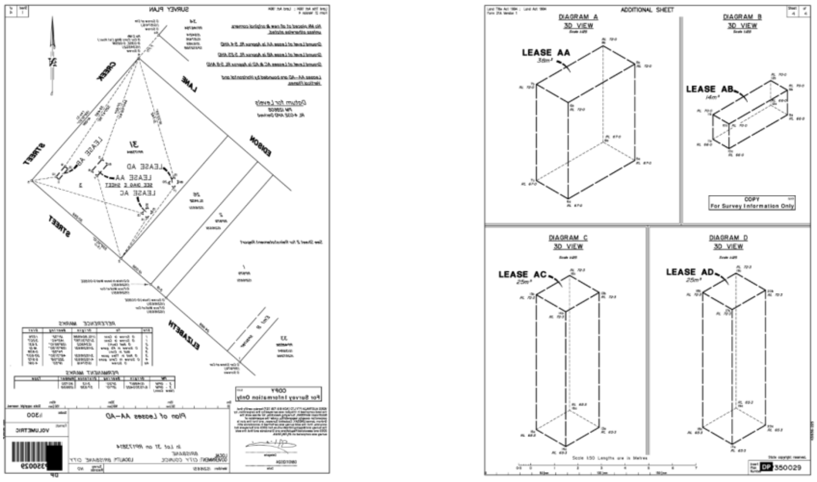

Figure 7. Above ground volumetric lots (Lindsay 2024)

The aboveground volumetric lots depicted in Figure 7 are used for leases of infrastructure above a high-rise building in inner city Brisbane. The location of the volumetric lot in context to the ground level footprint of the base lot is not easily visualised on the 2D plan. Further, how the volumetric lots integrate with the associated building format plan and the architectural, engineering and construction elements of the building design and as-constructed plans cannot be easily visualised on the 2D survey plan.

The surveyed legal boundaries of the selected VFPs including their relationships between the volumetric format lots and the base parcels was firstly created in Listech Neo, a leading survey software program, using the bearings, distances and heights depicted on the original 2D based survey plan and are considered a record of the survey data. The underground volumetric lot and above ground volumetric lot as recreated in Listech Neo are presented in Figures 8 & 9 respectively.

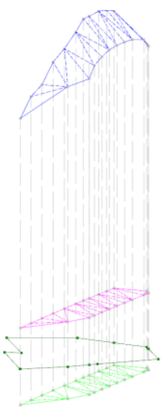

Figure 8. Recreation of underground volumetric lot in surveying software

Figure 9. Recreation of aboveground volumetric lot in surveying software

The survey data representing the bearings, bearings distances and height of the volumetric lots, together with the survey dimensions of the underlying base lots were exported from Listech Neo as standard CAD DWG files. The dimensions of the volumetric lots contained heights or Reduced Levels (RLs) for each of the vertices of the lots together with corresponding ground level RLs to give an indication of where the lots are positioned vertically with respect to ground level of the lots. The RLs are based on Australian Height Datum and were derived from nearby permanent survey marks.

The 3D legal boundary information was then modelled within Autodesk Revit, which is a widely used proprietary BIM software, to create the legal volumetric spaces. The DWG files containing the underlying survey data of the volumetric lots, and their base parcels were imported into Revit using the "Link CAD" function. The points, lines and polygons comprising the survey data was considered one block of information and could not be individually interrogated or manipulated. The purpose of Revit is for designing buildings and creating 3D building models for use in the architectural, engineering and construction industries and is not inherently designed to facilitate the analysis and presentation of survey information so other functionality was adapted for this purpose. The boundaries of the underlying base parcels were created using the "Property Line" function within the Massing & Site menu. The topography of the ground levels was created using the "Toposolid" function within the Massing and Site menu. The volumetric lots were created using the "In-Place Mass" function also within the Massing and Site menu. The volumetric lots, base parcel boundaries, and ground level topography as modelled in Revit are presented in Figures 10 and 11. If there is a common datum and base point, this information could be integrated with any existing BIMs modelling the original design, as-constructed data, or future designs stages. Sourcing and integration of existing BIMs is outside the scope of this project.

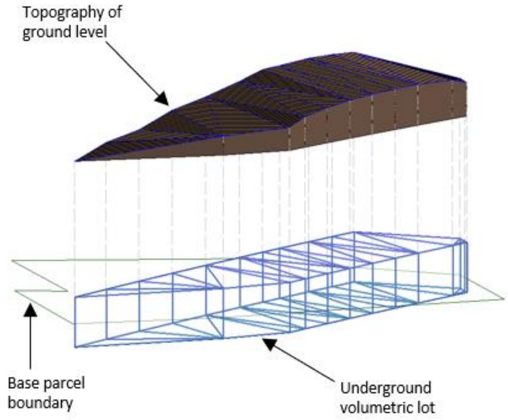

Figure 10. Underground volumetric lot created in Revit

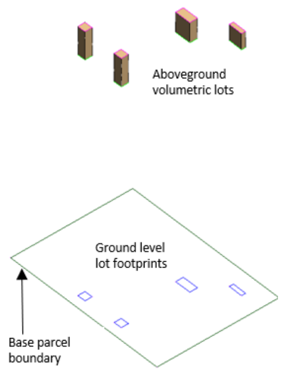

Figure 11. Aboveground volumetric lots created in Revit

Revit automatically calculates the gross surface area and volume of the various BIM components where applicable and has functionality for project descriptors/attributes. These attributes are integrated into the IFC file when the project is exported using the IFC standards. Further attributes can be added to the Revit objects as required that are similarly integrated into the IFC file when exported. Such attributes could include lot name, lot owner, legal tenure (for example, primary, secondary, common property, road or reserve), secondary interest descriptor (for example, lease, easement, profit a prendre or covenants) or any other attributes required in a land administration system.

The prototype volumetric format models built in Autodesk Revit were then mapped to appropriate IFC entities using specified mapping tables embedded in the software. The Revit projects containing the volumetric format lots, topography of the ground levels, the base parcel boundaries and their related project and object attributes were exported from Revit in the UFC format as IFC 2x3 files.

2.4 Demonstrate interoperability of 3D land administration artefact

To demonstrate that IFC format lots are interoperable with competing proprietary BIM software, Solibri Model Viewer was used to visualise the BIM model and used to demonstrate the legal zones, legal attributes, and legal spaces/boundaries with the prototype volumetric format plan. Solibri Model Viewer is an open- sourced windows program that can be used to open and edit standard IFC files.

The IFC 2x3 files were opened successfully in Solibri Model Viewer, and the volumetric lots as depicted in Solibri Model Viewer are presented in Figures 12 & 13. The project and object attributes were also able to be successfully accessed in Solibri Model Viewer.

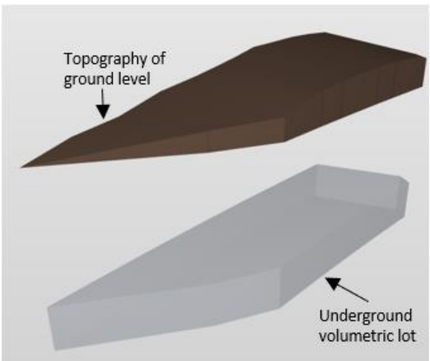

Figure 12. Underground IFC standard volumetric lot displayed in Solibri

Figure 13. Aboveground IFC standard volumetric lot displayed in Solibri

2.5 Evaluate BIM-based 3D land administration artefact against original observations

This stage of the project was intended to determine the extent the prototype VFPs fulfil the specifications. The volumetric format lots were examined in Autodesk Revit by using the 3D pan function to help assess visualisation effectiveness of the plans in a 3D environment compared with the original 2D plans. To further evaluate the interoperability of the protypes using the IFC standardised data model, the prototypes were successfully imported back into the Listech Neo file as IFC 2x3 files. The IFC volumetric lots were evaluated in Listech NEO to assess whether they were accurately bound by the survey observation recreated in Listech Neo from the bearings, distances, and heights on the original 2D survey plans.

By importing the IFC files into Listech Neo, the legal spaces depicting the volumetric format lots were displayed alongside the survey observation as shown in Figures 14 & 15. The relationships between legal volumetric spaces and the survey observations were examined to assess whether the spaces were accurately bound by the survey observations and no discrepancies were observed.

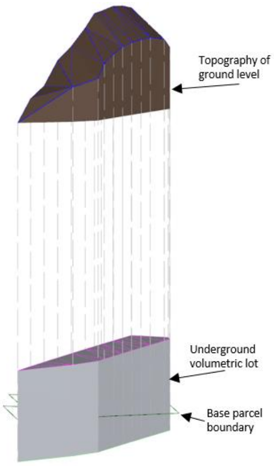

Figure 14. Underground IFC-standard volumetric format lot displayed in surveying software

Figure 15. Aboveground IFC-standard volumetric format lot displayed in surveying software

3. DISCUSSION AND CONCLUSION

The BIM prototype developed in Revit for this research has demonstrated how a volumetric lot can be created within a BIM environment, together with attributes required to legally define the ownership parcel, the size of the parcel, and any other attribute required for an interactive land administration system. The legal volumetric lot was assigned the IfcSpace entity in the IFC standardised data structure which can be shared and exchanged together with its project and object attributes between IFC compliant BIM tools. The interoperability of the volumetric lot encoded in an IFC format was proven by importing the files into two alterative information modelling platforms, Solibri Model View and Listech Neo surveying software. The volumetric lots are unique to the Queensland jurisdiction and use bearings, distance and heights to define the 3D shape of the lot as opposed to using structural elements such as floors, walls and ceilings found in building format lots in Queensland and other jurisdictions. The modelling of the volumetric lot in BIM using the IfcSpace entity in the standardised IFC data structure is a major contribution to the knowledge of the 3D land administration. Other jurisdictions across Australia and internationally could adopt a similar approach to defining the volumetric lots using 3D located points to identify the position, shape and dimensions that do not require physical building elements. This could similarly allow other jurisdiction the ability to reserve an envelope using a volumetric format lot prior to construction that could be later be subdivided into building format lots defined by structural elements.

Whilst difficult to demonstrate in a paper based academic report, the volumetric format lots were easier to visualize in a 3D environment in relation to the topography and base parcels by being able to scroll, pan in 3-dimensions, zoom in/out and by turning on/off different layers compared with the 2D plan. Data validation tools such as survey close programs could be incorporated into the 3D digital programs to ensure data integrity. Storing the plans as digital data allows for the querying of data and analysis of property ownership and how the different primary and secondary legal boundaries of parcels interact with each other. It allows different stakeholders to view and interpret legal boundaries with greater clarity helping to prevent misunderstandings and resolve land and property disputes.

It was outside of the scope of this project to source and integrate existing BIMs modelling the tunnels, buildings and infrastructure associated with the volumetric lot to develop the prototypes in this project. However, if there is a common datum and base point, any existing BIMs could be integrated with this project to further demonstrate the benefits of visualising 3D volumetric environment by identifying any overlapping and hidden features, determine how different layers or levels intersect and how different architectural or engineering plans fit with the legal boundaries and how future design elements could be incorporated. Revit has a clash detection tool that would be able to easily locate and examine any clashes with other models or elements in a BIM project.

Like other BIM software, the functionality of Revit was primarily designed to create 3D building models for use in the architectural, engineering and construction industries. It was not designed to easily create or integrate survey information, like those required to define volumetric format lots. The volumetric format lots were created in this prototype by adapting other Revit functionality. This was a clunky process that was relatively time consuming and would benefit from future automation. Presently, the legal spaces defining the volumetric lots can only be seen alongside the related survey observations by importing the legal spaces back into a surveying or drafting software. As BIMs are increasingly used to present 3D land and property information in the future, Revit and other BIM developers are encouraged to incorporate functionality that import or input survey observations that could be easily used to define legal boundaries specified by bearings, distances and heights in the BIM software. Oldfield et al. (2017) proposed that boundaries of legal spaces could be modelled in IFC by IfcRelSpaceBoundary. The survey observations within BIM could be mapped to this IFC entity meaning that the legal space and survey observations could be viewed alongside each other in an IFC format.

The eight Australian and New Zealand jurisdictions that make up the ICSM are formulating digital strategies that will eventually require survey plans to be submitted electronically and include 3D elements to formulate the 3D land administration systems (Haanen et al. 2023). Whilst the data standard for the 3D Survey Data Model and Exchange have not been finalised, jurisdictions will require surveyors to be capable of submitting 3-dimensionally defined parcels that maintain precise relationships with the traditional 2D underlying element. There is potential for 3D legal boundaries depicted in BIM/IFC to be a viable input into the formulation of the 3D land administration in Queensland using a LADM II based approach.

The benefits of a 3D land administration system extend beyond registration and surveying profession to broader activities such as urban planning, facility management and infrastructure development to support better governance and planning of ever-expanding cities both laterally and below/above the ground.

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