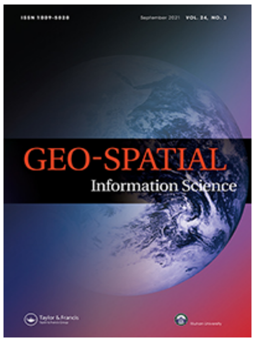

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Integration of cadastral survey data into building information models

Behnam Atazadeh [a,b], Leila Halalkhor Mirkalaei[a], Hamed Olfat [a,b], Abbas Rajabifard [a] and Davood Shojaei[a]

[a]Centre for Spatial Data Infrastructures and Land Administration, Department of Infrastructure Engineering, The University of Melbourne, Parkville, Victoria, Australia; [b]Land Use Victoria, Department of Environment, Land, Water and Planning (DELWP), Melbourne, Victoria, Australia

ABSTRACT

Cadastral surveying plays an important role in defining legal boundaries of land and property. The current practice for recording cadastral survey data mainly relies on 2D digital or analog documents. This practice is efficient for simple land parcels but can be challenged in complex building developments. To address the issues stemmed from 2D methods of representing cadastral survey data, 3D spatial information models can be considered as a viable solution for managing cadastral survey data. Building Information Modeling (BIM) enables colsslaborative 3D management of the design, construction, and operation of buildings. There have been extensive studies conducted to investigate the connectivity between BIM and 3D cadaster. Most of these studies focus on managing legal information, such as ownership boundaries and attributes, in BIM-based environments. However, there is limited investigation on how surveying measurements can be mapped into BIM. In this study, the proposed method for integrating the cadastral survey data into the BIM environment includes identifying cadastral survey requirements, using BIM entities relevant to cadastral survey data, enrichment of a BIM prototype, and evaluation of the prototype. The major contribution of this study is to demonstrate the storage of cadastral survey data such as survey marks and traverse lines in the BIM environment. Therefore, this research contributes to the further enrichment of BIM with incorporating data elements related to cadastral surveying practices. It is confirmed that current BIM-based tools provide restricted capabilities for explicit management and visualization of cadastral survey data. This limitation can be addressed in the future enhancements of BIM in terms of supporting important elements for cadastral survey data.

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1. Introduction

Cadastral data are an essential component of the land administration system and plays an underpinning role in securing land and property rights. Cadastral surveying measurements provide the basis for demarcating the legal boundaries of land parcels. While the traditional 2D representation approach can be used in simple land parcels with single ownership right, this method of representation has some constraints when describing complex buildings with overlapping ownership rights. Additionally, validation, examination, and query of cadastral survey data from 2D plans describing overlapping ownership rights is a laborious and error-prone task which can be performed only by experts. To address these issues, 3D data models have been considered as potentially effective approach for managing complex overlapping ownership rights in various countries (Van Oosterom et al. 2012; Vučić et al. 2017; Janecka and Karki 2016; Stoter, Van Oosterom, and Ploeger 2012; Rajabifard, Atazadeh, and Kalantari 2019). Some 3D data models were specifically developed for land administration purposes such as Land Administration Domain Model (LADM) (Lemmen, Van Oosterom, and Bennett 2015) and ePlan model (ICSM 2010; Shojaei et al. 2016; Olfat, Shojaei, and Briffa 2016). There are also other data models which define physical reality of the world such as CityGML (Kolbe, Nagel, and Stadler 2009) and Industry Foundation Classes (IFC) (ISO16739 2013) standards. There is also a new 3D data model that integrate land and infrastructure information, known as LandInfra (Scarponcini et al. 2016).

The Land Administration Domain Model (LADM) has a major role in reforming cadastral systems. More specifically, LADM can be used in developing countries to enable an effective framework for modern land administration. Therefore, this international land administration standard is utilized for modernization of cadastral systems, especially in developing countries. Pilot projects in different countries were conducted to showcase the feasibility of LADM for enabling modern cadaster (Janečka et al. 2018). Some of these countries are Malaysia (Jamil et al. 2017; Rajabifard et al. 2018; Zulkifli et al. 2014; Zulkifli, Rahman, and Van Oosterom 2014; Zulkifli et al. 2015), China (Ying et al. 2018; Yu et al. 2017; Zhuo et al. 2015), Netherlands

CONTACT Behnam Atazadeh behnam.atazadeh@unimelb.edu.au

(Góźdź and Van Oosterom 2016), Greece (Gkeli, Potsiou, and Ioannidis 2018; Kalogianni 2015; Kitsakis, Apostolou, and Dimopoulou 2018), Czech (Janečka and Petr 2017, 2016), Turkey (Alkan and Polat 2018; Aydinoglu and Bovkir 2017; Polat and Alkan 2018), Croatia (Mađer, Matijević, and Roić 2015; Mader et al. 2018; Vučić et al. 2017; Vučić, Roić, and Zdravko 2013), Korea (Kim et al. 2015; Lee et al. 2015), Serbia (Radulović, Sladić, and Govedarica 2017a, 2017b; Sladić, Radulović, and Govedarica 2018; Radulovic et al. 2018), Russia (Vandysheva et al. 2011a, 2011b), Trinidad and Tobago (Griffith-Charles, Sutherland, and Davis 2016).

In addition to the widespread adoption of LADM worldwide, some Australian jurisdictions and New Zealand are currently using "ePlan" as the core data model to implement smart cadastral systems. ePlan is encoded in LandXML format. LandXML can record civil engineering and survey data and it was selected to implement the ePlan model in Australia. The ePlan data model was developed in Australia in 2011 to exchange digital cadastral survey data between the government agencies and Australian surveying industry. Currently, 2D ePlan is the operative and acceptable format in Victoria and New South Wales for submitting cadastral plans to land registry organizations (Shojaei et al. 2017). Although the ePlan data model has addressed the limitations of 2D paper plans, it is limited in terms of managing 3D cadastral data (Shojaei et al. 2016). In recent years, there has been an increasing interest in 3D digital cadaster to enable inexpert owners to understand their Rights, Restrictions, and Responsibilities (RRRs) in complex urban areas in an interactive 3D environment and accelerate the process of registration alongside saving time and cost (Shojaei et al. 2018).

Recent developments in the field of 3D digital modeling have created a significant momentum in producing 3D physical models for buildings and complex infrastructures (Becker, Nagel, and Kolbe 2013; Dangermond and Goodchild 2020). A widely used approach is Building Information Model (BIM) which creates a rich repository of 3D spatial and semantic datasets and facilitates multidisciplinary cooperation among various actors involved in the development of a building during its lifecycle (Eastman et al. 2011). In comparison with the traditional 2D-based processes, BIM demonstrates many long-term profits such as saving resources in all phases of a building lifecycle (Forbes and Ahmed 2010). IFC is an open data format for BIM which comprises both spatial and semantic features of a building and enables data interoperability (Liebich 2013).

Over the last few years, there have been various investigations related to the integration of cadastral information and BIM. These studies mainly looked at the integration of legal information, such as legal boundaries and attributes (El-Mekawy, Paasch, and Paulsson 2014; Stoter et al. 2017; Rajabifard, Atazadeh, and Kalantari 2019); however, they are limited in terms of exploring the integration of cadastral survey data into BIM. In addition, the lack of appropriate tools to define cadastral survey data and observations within the existing BIM authoring software packages constrain using the BIM environment as an acceptable platform among land surveyors. In the previous research, cadastral survey observations, which are required in cadastral examination and registration, have not been modeled in the object-based environment of BIM. Therefore, this study aims to assess the feasibility of a suitable approach for capturing and visualizing cadastral survey data in BIM.

The Abstract of Field Records (AFR) is prepared during a cadastral survey typically includes the important surveying measurements. The first part of this research is to investigate how cadastral survey data elicited from AFR can be modeled and stored in the BIM environment using the IFC format. In the second part, appropriate approaches for visualizing the cadastral survey data in the BIM environment will be examined.

Integration of cadastral survey data and BIM model preserves the spatial integrity of the 3D components of the cadastral observations. This integration will also enable connection to geodetic network, which would subsequently support adjustment and positioning of 3D parcels in cadastral fabric. A BIM model for 3D cadaster should include legal, physical and survey information. There is a knowledge gap in the integration of survey information, which will be addressed in this paper. This integration will improve the use of the BIM models for a 3D digital registration of stratified ownership spaces with accurate cadastral survey data.

In the next section, a review of the current literature relevant to challenges in cadastral plans and survey information for multi-story building subdivisions, BIM for 3D cadaster purpose, and IFC format will be provided. Section 3 is dedicated to the methodology used for this study. Remaining parts of the paper proceed as follows: identification of cadastral survey data requirements, identification of relevant IFC classes considered for the enriched model, implementation and evaluation of BIM prototype model, discussions of the results. Finally, the conclusion section presents a summary of findings and future research areas.

2. Literature review

The literature review comprises two parts. First, a number of challenges in the current approach adopted for managing cadastral plans and survey information will be identified. The focus is on the issues that happen in multi-story building subdivisions. The second part of the literature review describes relevant studies related to BIM and its uses in cadaster.

2.1. An overview of challenges in cadastral plans and survey information with a focus on multi-story building subdivisions

As a key response to the urbanization and intensive building developments, overlapping property ownership was proposed to facilitate taxation procedure and demarcate ownership boundaries in the vertical dimension. Cadastral plans for multi-story building subdivisions contain two types of information in Victoria: 1) spatial information which is mainly described by floor plans and cross-section diagrams representing geometric extent and boundaries of property units above or below the ground 2) semantic information that includes a wide range of attributes describing rights, restrictions and responsibilities (El-Mekawy, Paasch, and Paulsson 2014). In the current practice in Australia, 2D paper or PDF cadastral plans are the accepted format for lodging and registering cadastral plans in the land registry organizations (Shojaei et al. 2017). In addition to cadastral plans, survey information is also recorded for fixing a multi-story building subdivision to a survey network. In Victoria, a state in southeast Australia, survey observations are recorded in the AFR document. According to Shojaei et al. (Shojaei et al. 2017), the data captured and presented by surveyors cannot be validated, authenticated and updated automatically due to the analog method of representing cadastral data in paper and PDF formats. This stems from the fact that cadastral plans and survey documents are managed separately, which causes some challenges for managing cadastral and survey information in complex developments. These challenges are listed in the following.

2.1.1. Data management issues

Managing cadastral and survey information related to multi-storey building subdivisions is a challenging task. In complex multi-story properties, spatial arrangements of cadastral spaces typically dispersed in various parts of these developments (Rajabifard, Atazadeh, and Kalantari 2019). Using multiple pages of cadastral and survey documents is a hard task to manage and ensure the spatial integrity of cadastral and survey information. Information related to survey measurements and cadastral information, such as legal boundaries, are recorded in two different documents, namely subdivision plan and AFR document. It is very hard to search, query and retrieve cadastral and survey information from 2D documents even if these documents are stored digitally. Therefore, the cadastral and survey information is visually represented on 2D pages and the further use of this information is difficult for future cadastral survey jobs.

2.1.2. Communication problems

The static environment of subdivision plans and AFR documents make the communication of information embedded inside these documents very difficult. This is particularly relevant for stakeholders with limited background in building subdivision and surveying profession. Therefore, the value of cadastral and survey information cannot be unlocked due to poor communication resulting from annotations. The survey annotations are normally understandable for land surveyors and other stakeholders may find it difficult to use them.

In response to data management and communication challenges, there has been significant research in using 3D digital solutions for cadastral survey purposes. In Australia, the Intergovernmental Committee on Surveying and Mapping (ICSM) has developed a strategy for Cadaster 2034 (Intergovernmental Committee on Surveying and Mapping 2015), to enable the community to understand RRRs in a 3D environment. Storing multi-level building subdivisions in a 3D spatial environment is proposed, but this approach requires a change in the existing subdivision procedures (Olfat et al. 2019). The change from 2D to 3D could not only include technical aspects. Legislative and institutional frameworks play crucial roles too. In terms of the technical aspects, BIM is considered as one of the enabling 3D spatial environments to manage spatial and semantic data requirements in realizing a 3D digital cadaster. BIM provides a significant opportunity to develop a wide range of 3D spatial analysis and query methods for many cadastral and urban applications (Emamgholian, Taleai, and Shojaei 2020; Barzegar et al. 2021a, 2021b). In the next subsection, the relevant BIM research and its potential uses in cadaster will be reviewed.

2.2. BIM and its application in cadaster

The BIM abbreviation is attributed to two specific concepts: product and process. BIM process includes creating, managing, deriving and sharing information among various experts involved in the architecture, engineering and construction (AEC) and facilities management (FM), simplifying communication and teamwork (Eastman et al. 2011). The outcome of the BIM process is a 3D digital product that consists of functional elements, semantic information, and relationships between building elements such as architectural and structural elements inside complex buildings (Atazadeh et al. 2017b; Atazadeh, Rajabifard, and Kalantari 2018). While BIM has significantly addressed fixing 2D or 3D CAD problems and brought various advantages for efficiency in the AEC industry (Arayici 2008), it turns into a dynamic research field for settling difficulties associated with interoperability and information integration (Isikdag et al. 2007). An open data model can provide a good response to the interoperability problem and facilitate data transmission among various BIM tools (Eastman et al. 2011). Hence, the IFC standard has been developed by the international BuildingSMART organization to promote communications, efficiency, and interoperability of BIM tools throughout the design, construction and maintenance stages over a building lifecycle (ISO16739 2013). IFC is an open BIM format which adopts a universal information model to manage physical objects of buildings and improve interoperability among different BIM tools. The IFC schema consists of four underlying layers: resource, core, interoperability, and domain layer (Iso 2013; Atazadeh et al. 2017a). Resource layer includes basic elements used in all other layers such as time and date, length and area as well as basic topologic elements such as vertex, edge and face. "IfcKernel", which comprises object definitions, relationships, and property definitions, is the essential subschema in the core layer. The interoperability layer is used for the shared data among different AEC areas. Finally, for each AEC area, the specific sub-schemas are defined under the domain layer.

The application of BIM environment and IFC standard in cadaster has been investigated in different countries such as Australia (Barton et al. 2010; Rajabifard, Atazadeh, and Kalantari 2019; Atazadeh et al. 2019), the Netherlands (Stoter et al. 2017; Oldfield et al. 2016), China and Sweden (El-Mekawy, Paasch, and Paulsson 2014; Andrée et al. 2018). In Australia, researchers in Victoria and New South Wales states have developed approaches for extending BIM with cadastral information.

In Victoria, the IFC standard is extended with various data requirements in urban cadaster including legal ownership spaces, boundaries, attributes, and administrative plan information. According to (Atazadeh et al. 2017a), two major classes in the IFC standard related to 3D RRRs are "IfcSpatialElement" and "IfcElement". Physical boundaries and legal restrictions are defined in the "IfcSpace", and a group of spaces is assembled into the "IfcSpatialZone" as a nonhierarchical division under "IfcSpatialElement" class (Atazadeh et al. 2017b). "IfcSite", "IfcBuilding", "IfcBuildingStorey" and "IfcSpace", and also "IfcExternalSpatialStructureElement", which is the element for the exterior area around the building, are the hierarchical spatial decompositions. "IfcElement" is the supercategory for physical objects such as walls, windows, columns (in general building components) "IfcBuildingElement", and geographic elements "IfcGeographicElement" like trees or roads (Atazadeh et al. 2017a). Studies in the New South Wales jurisdiction considered the use of BIM for cadaster as the core part of a major project called UrbanIT (Barton et al. 2010). More specifically, the IFC standard was extended to manage legal ownership spaces in buildings. "IfcSpace" and "IfcZone" entities are in particular considered for modeling ownership rights in buildings (Atazadeh et al. 2021). In addition, the "IfcSite" entity was also considered for modeling legal boundaries of 2D land parcels on a construction site. To model ownership attributes, the "IfcSite" entity was enriched with a new set of attributes or properties (Pset_CadastreCommon).

In China, a conceptual model of easements based on the IFC standard has been developed and analyzed (Ying et al. 2019). It was shown that the BIM environment can optimize representation of 3D cadastral objects. More specifically, the study focused on the easement modeling method using BIM environment. The case studies demonstrated that IFC standard is an effective data model for easement spatialization. The combination of legal and physical (spatial) information in BIM was identified as an effective approach for managing and operating buildings as well as planning and developing compact cities in China (Ying et al. 2019).

In the Netherlands, BIM is considered a major source of 3D digital data for enabling 3D cadaster. The registration process for multi-owned properties was exemplified in two complex cases (Stoter et al. 2017). The first one is a subway station that is architecturally combined with the city hall in Delft. The second case study is a multi-use complex which includes a hotel, a residential building, and an underground parking in north of Amsterdam. Implementation of BIM for 3D cadaster in these case studies was based on a new workflow to enable 3D cadastral registration using 3D PDF. Two sources of 3D digital data considered in this workflow: 3D surveying data sources, e.g. laser scanner data, or 3D architectural BIM data. 3D surveying data is appropriate for capturing existing buildings while architectural BIM data is created for new buildings.

In Sweden, Smart Built Environment has been developed as a strategic program for innovation to identify potential approaches for effective use of 3D BIM data during the building development processes including planning, building permits, property formation and management. More specifically, three important aspects have been considered for enabling a BIM-based cadaster: legal issues, financial aspects, and technical matters (Andrée et al. 2018). A more recent study has proposed a generic framework for 3D cadaster by integrating BIM/IFC and CityGML data. The integrated BIM-GIS data is connected to LADM data to provide fully-integrated legal and physical views of indoor and outdoor ownership spaces in a complex urban built environment (Sun et al. 2019).

The above-mentioned studies indicate different approaches for integrating BIM to 3D cadaster processes. The differences stem from the fact that each jurisdiction has its unique requirements for managing cadastral information. However, these investigations have not considered how cadastral survey measurements and observations can be embedded in the BIM environment and IFC standard. Therefore, the aim of this study to develop a methodology for integrating cadastral survey data into BIM models. In the next, the research methodology will be explained in further details.

3. Research methodology

A case study approach was used as the basis for developing the research methodology. The case study area was Melbourne, Victoria. Cadastral plans and survey documents for different developments were investigated. The methodology of this study comprises four steps (Figure 1). The logic of the four methodology steps is based on different stages of data modeling techniques. The aim of this methodology is to enrich the current open BIM data model, which is the IFC standard, with cadastral survey data elements. Therefore, the first step is identifying the requirements for managing cadastral survey data. In the next step, since the IFC standard includes some relevant entities for managing cadastral data, these entities are enriched by considering the requirements identified in the first step. The third step is about demonstrating the viability of the enriched IFC standard for managing cadastral information by constructing a BIM model of a multi-story building as a case study. In the final step, the created BIM model is evaluated in terms of representing and managing different cadastral survey data elements. There is a detailed explanation of these four steps.

3.1. Identifying cadastral survey requirements

The previous investigations on 3D digital cadaster in Victoria only focused on converting 2D floor plans to 3D building models and modeling legal rights in BIM. Modeling the survey observations in BIM was out of the research scope. Therefore, we will firstly identify the requirements for managing cadastral survey data. An industry internship in Land Use Victoria (LUV), which is the state government agency for land administration and property information, has been undertaken to understand the survey data elements required for managing cadastral plans. For this study, four main categories were identified: data preparation, survey data, legal data and physical data requirements (see Section 4).

3.2. Using relevant entities in the IFC standard

To address the identified data requirements, the IFC standard is put forward as the possible solution for managing cadastral survey elements in the BIM environment. A comprehensive study was conducted on the IFC entities to consider the relevant ones for managing cadastral survey elements and observations. For managing legal and physical data requirements, previous studies have identified relevant IFC entities and this research will rely on the outcomes of those studies (Atazadeh et al. 2017b; Shojaei et al. 2018). IfcGeographicElement was selected by our study as the appropriate entity for managing survey data elements (see Section 5).

3.3. Enrichment of a BIM prototype

A BIM model of a building developed in the previous study (Shojaei et al. 2017) was used for this research. This BIM model includes necessary spatial and semantic elements that meet physical and legal data requirements. However, the BIM model includes no data element that describes the survey aspects. Therefore, the model was enriched with survey data elements. Data preparation requirements, such as georeferencing the BIM model, were also addressed. In this context, a comparison between 11 BIM tools was conducted during the implementation to respond to all the requirements (see Section 6).

3.4. Evaluation of the prototype

To evaluate the BIM-based cadastral survey data, the prototype was compared with the current 2D-based approach that relies on the AFR document. An assessment was conducted to show if cadastral surveying elements in 2D plans and documents are mapped into the IFC standard correctly (see Section 6).

Figure 1. The research methodology steps.

4. Identification of cadastral plan and survey data requirements

The cadastral survey data requirements were elicited through an industry internship undertaken in the land registry organization. During the internship, a wide range of experts, including ePlan project officers and plan examiners, were consulted to identify the requirements. The identified requirements are:

4.1. Data preparation requirements

The data preparation requirements refer to necessary steps for creating a BIM-based survey data for cadastral purposes. These steps include geo-referencing, merging 3D BIM model with survey data, visual representation of survey data in a BIM environment, and measurement tools. These requirements will be addressed during the prototype implementation phase of this study (see Section 6).

4.2. Survey data requirements

A survey network is the cornerstone for the geospatial coordination of a cadastral plan. In cadastral surveying, the survey network includes various elements including traverse lines, radiation lines, permanent survey marks, monuments, and occupation. Traverse lines are defined based on traversing between survey marks and reference marks/traverse points. A radiation line is measured between survey/reference marks/traverse points and boundary corners. In other words, the radiation line connects the survey network to the land parcels. Figure 2 shows examples of the traverse and radiation lines.

Survey marks provide reliable points for performing a cadastral survey. There are five types of survey marks in Victoria: permanent marks (PM), primary cadastral marks (PCM), reference marks, traverse points, and boundary points. PM and PCM are control points in a cadastral survey network. The Land Surveyors Regulations, Part 2 1947, made provision for the use of a standard survey mark to be used as reference mark. They are no longer used. These are still to be found in some areas, but are not permanent marks, unless registered as such (Land Use Victoria 2000). Traverse points are new survey points that are defined during a cadastral survey and represented in the AFR. The boundary points define the legal boundaries of land parcels. Survey marks define the monuments at the survey points. A monument is an object, such as pin or peg, that is placed in the ground for the purpose of being surveyed. A monument must be placed for each survey point. However, a survey point could have more than one monument. For instance, there may be a nail in concrete for the corner and a reference to a brick wall at the same survey point. References to occupation are the occupation or improvements (e.g. fence posts, walls, buildings, poles, manholes, gully traps or any such immovable objects) that are connected in the course of the survey. These references are in addition to the monument denoting the corner and marks referencing the corner (reference marks).

4.3. Legal and physical data requirements

These requirements are defined based on the legal information embedded in the subdivision plans as

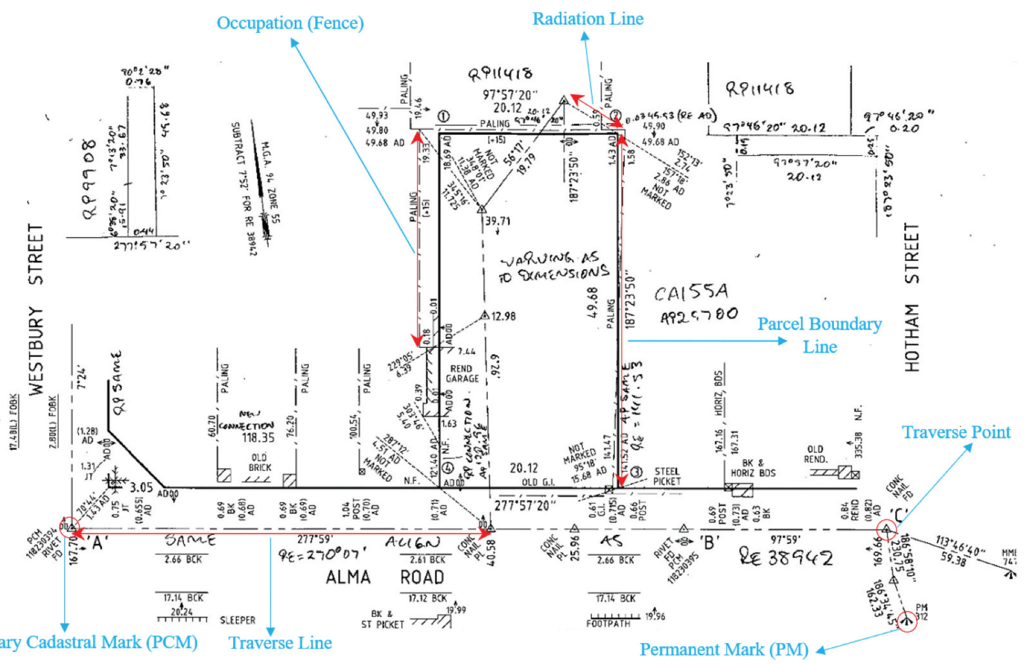


Figure 2. Survey data elements in the AFR document.

well as physical structures required to communicate ownership rights in multi-owned buildings. Previous studies have investigated legal and physical data requirements comprehensively (Shojaei et al. 2017; Atazadeh et al. 2017a, 2017b). In summary, the legal data requirements include primary legal interests (such as lot, common property, and road), secondary legal interests (easement, restriction, and depth limitation) and legal boundaries. The legal boundaries can be defined based on either precisely fixed survey measurements or physically existent objects. The physical data requirements typically refer to basic architectural elements that are used to define a legal boundary or they can be a constituent part of a legal interest. For example, the interior face of a wall can be used to define a legal boundary while the wall itself can be a constituent part of a common property legal interest.

Figure 3 presents a summary of four main categories of cadastral plan and survey data requirements identified in this research.

5. Identification of relevant IFC classes

Significant research has been conducted to accommodate 3D cadastral data within the IFC standard. These investigations have only considered legal and physical data requirements for using BIM in a 3D cadaster. However, survey data requirements should be incorporated into the BIM environment to provide a complete solution for using BIM in the current cadastral surveying practices. In this section, the study conducted by Atazadeh et al. (Atazadeh et al. 2017a) was used as the basis for mapping cadastral survey data requirements in the IFC schema.

"IfcProduct" is the super class for all spatial entities in IFC data model. The geometric shape of spatial elements is defined by "IfcProductRepresentation" attribute which refers to a wide range of point, line, surface, and volumetric representations. Besides, the "IfcObjectPlacement" attribute defines coordinate-based placement of spatial entities based on various approaches such as absolute placement relative to the world coordinate system, relative placement to the other spatial entities, and grid reference relative to the grid axes. Associated context information of these entities in "IfcProduct", such as measurement units, coordinate system and direction of true north is gathered in the "IfcProject". "IfcBuildingElement" and "IfcSpatialStructureElement" are two major super classes for physical data. All fundamental parts of the building such as walls "IfcWall", doors "IfcDoor", and slabs "IfcSlab" are placed under "IfcBuildingElement". "IfcSpatialStructureElement" defines the spatial structure for organizing a building project. "IfcSite", "IfcBuilding", "IfcBuildingStorey", and "IfcSpace" constitute the spatial project structure of an IFC file.

"IfcSite" consists of complementary information, such as parcel address, and can represent the topography of a building site. In each IFC project, there might be a complex site, which can comprise a collection of 'IfcSite's connected or disconnected to each other. "IfcBuilding" includes information about the entire building, such as elevation relative to sea level, elevation above the terrain around the building footprint, and the building postal address. Elevation of each level of the building is stored in "IfcBuildingStorey" class. Most building elements, such as walls and columns existing in "IfcBuildingElement", are linked with "IfcBuilding Storey" by "IfcRelContainedInSpatialStructure". "Ifc Space" is used for abstract spaces correlated to the

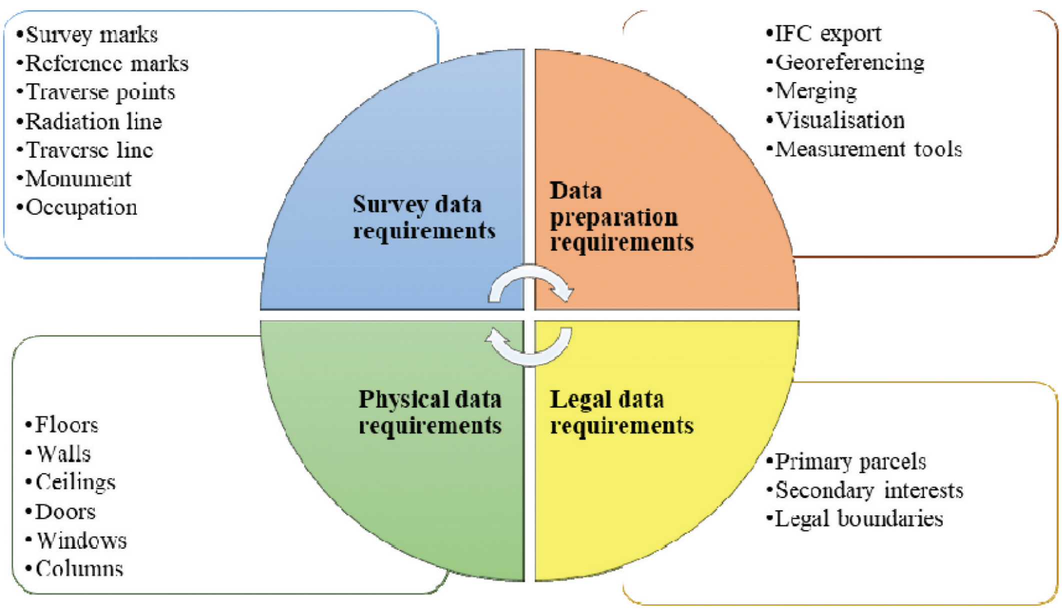


Figure 3. Cadastral plan and survey data requirements.

building story, which contains space area and volume. It can also hold information about name, description and object type, and this feature makes it a suitable class for dealing with 3D legal rights, restriction and responsibilities inside buildings. Common properties, 3D ownership spaces for lots, and easements are examples of legal information in this class. However, for outdoor spaces, "IfcGeographicElement" as a subclass of "IfcElement" must be used.

Legal data requirements are met by entities shown in yellow in Figure 4. According to legal entities characteristic, they can be modeled in suggested classes within the IFC schema. For example, "IfcLegalPropertyObject" in Figure 4 is a proposed conceptual class symbolizing the 3D legal spaces so that it can be embedded within "IfcSpace".

"IfcGeographicElement" class (highlighted in blue in Figure 4) is defined for geographical features such as lines. It is a subtype of "IfcElement" and spatially associated with "IfcSite" that comprises all geometry of components (Rajabifard, Atazadeh, and Kalantari 2019). Attribute definition for this entity has predefined types. For each type, there might be specific property sets. To meet survey data requirements, our research confirmed that "IfcGeographicElement" is the appropriate class for capturing various survey features such as points, lines and polygons. Table 1 shows different survey elements that are modeled using "IfcGeographicElement" in this study.

6. Enrichment and evaluation of a BIM prototype

To show the capability of the proposed IFC-based approach for modeling cadastral survey data requirements, a BIM of a multi-story building with the purpose of integrating physical elements, legal spaces, and survey observations was developed. The developed BIM was used to demonstrate various cadastral survey data requirements identified in this study can be managed in a BIM environment. More specifically, visualization and identification of each survey data element inside the BIM can be compared against the subdivision plan and AFR.

Once it was confirmed that "IfcGeographicElement" can be used for modeling the survey elements, the first step of prototype development was dedicated to investigating all potential BIM tools, which might be able to support the requirements identified in Section 4 and adopt the IFC data model proposed in Section 5.

The data preparation requirements played a significant role in selecting the BIM software packages. These requirements include exporting data to the IFC data format, georeferencing IFC files, merging multiple IFC files, and visualizing the enriched IFC model. The results of comparing all investigated BIM tools are presented in Table 2. From this comparison, LISTECH Neo and Simplebim have been chosen as the suitable tools for modeling cadastral survey data in IFC-based BIM models. Additionally, Simplebim

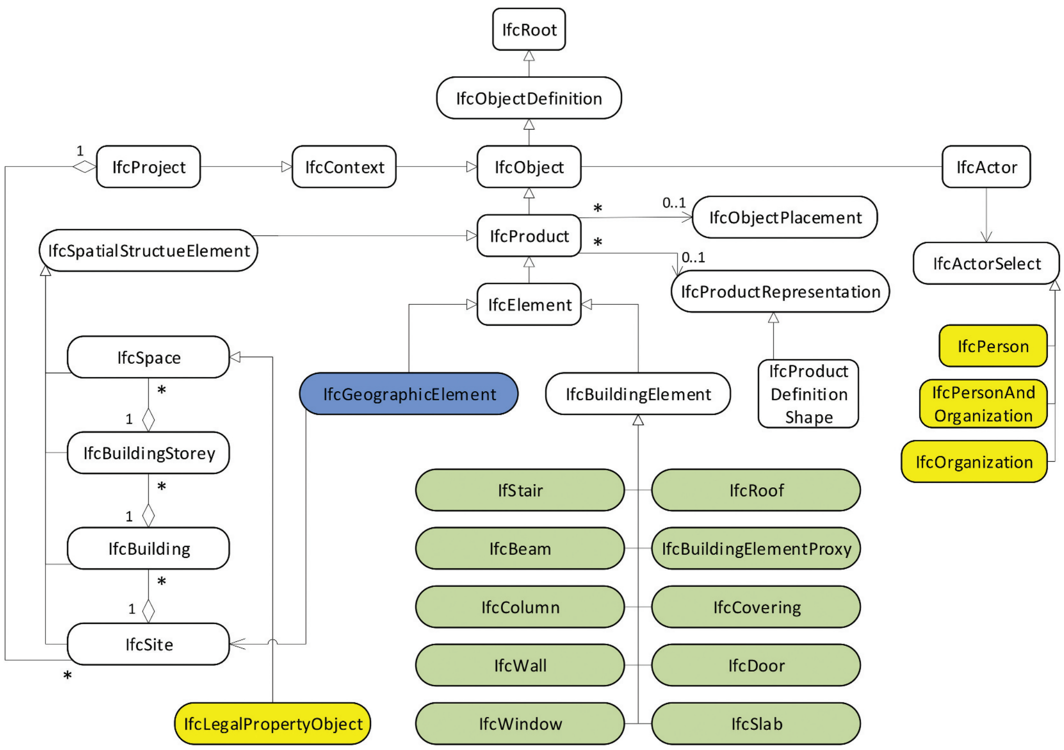


Figure 4. Hierarchy of physical, legal and survey data modeling in IFC schema, adopted from (Atazadeh et al. 2017a).

Table 1. The proposed representation and properties of survey elements within the IFC schema.

Survey element	Representation	Predefined type	Properties
Survey marks	IfcCartesianPoint	SURVEY MARK	OID, Coordinates, Monument Type, Monument State, Monument Condition
Reference marks	IfcCartesianPoint	REFERENCE MARK	Coordinates, Monument Type, Monument State, Monument Condition
Traverse points	IfcCartesianPoint	TRAVERSE MARK	Coordinates, Monument Type, Monument State, Monument Condition
Traverse line	IfcPolyline	TRAVERSE LINE	Equipment, Bearing, Distance
Radiation line	IfcPolyline	RADIATION LINE	Equipment, Bearing, Distance
Occupation	IfcPolyline	OCCUPATION	Type, Description

has shown the remarkable ability to modify existing IFC files.

The integrated 2D/3D environment of LISTECH Neo was used to capture the survey observations such as permanent marks and traverse points, traverse and radiation lines, and occupation based on the existing AFR document of the sample cadastral plan used in this study (see Figure 5). Once the survey data was created and attributes for the project and components were defined, the survey data was exported to IFC version 4.0.

Figure 6 shows an example of a survey mark modeled inside the BIM model. The attributes of this survey mark are also shown in Figure 6. In addition to coordinate and appearance attributes, the new attributes defined in this study were also incorporated to survey marks. These attributes are Name, OID (object ID), monument, status and order.

Although 3D BIM model of the apartment can be imported into LISTEH Neo and be visualized with the survey data at the same time, there were some limitations in terms of exporting and visualization of legal spaces. These limitations were explained in detail in Section 8 (Discussion). Therefore, Simplebim application was used for georeferencing, merging, and editing IFC data. Subsequently, both 2D and 3D IFC files were imported into the Simplebim environment. The location of the imported 3D BIM model that was previously created in Autodesk Revit and exported into IFC format was not matched with the 2D survey data. Therefore, the apartment with all its attachment was georeferenced manually by using the Placement Editor Tool in Simplebim. Besides, the Property Value Editor is another functional tool that provides the ability to edit or add attributes. Next, the integrated IFC file was exported and then imported again into the selected BIM tools. Figure 7 shows the integrated BIM model that includes survey, legal and physical information, which is visualized in Simplebim, usBIM. viewer+, and LISTECH Neo.

In the last stage of this research, to evaluate the enriched BIM prototype, modeling of cadastral survey observations in IFC was examined and compared with the traditional 2D format. The first set of analysis observed how and which data elements in AFR are recorded into IFC. As a result, various survey elements selected from AFR were assembled in IfcGeographicElement.

Further analysis revealed that the accuracy of all components is bound up inextricably with the drawing phase. For example, if the unit for drawing is set to meter, all dimensions will be calculated in the same format by using existing tools in the software. Moreover, in LISTECH Neo measuring bearing in sexagesimal format is also available, which can help cadastral plan examiners to check the precision of surveying performance in a quicker way. For the representation aspect, even though all elements were stored in IFC, only lines and polygons could be symbolized in applications, and points were embodied as attributes in an object table.

Table 2. A comparison of BIM tools based on data preparation requirements.

Software	Export IFC	Geo-reference IFC	Merge IFC	Visualize enriched IFC model	Description
Autodesk Revit	√	√	×	×	It cannot support and visualize the enriched model. It cannot also export the enriched model.
usBIM.viewer+	√	√	×	√	It can modify objects in view mode but cannot merge and export them into a single file
Autodesk InfraWorks	×	×	×	×	It can only visualize typical building IFC files
LISTECH Neo	√	√	√	√	It can export survey data in both IfcGeographicElement and IfcBuildingElementProxy
Autodesk Civil 3D	√	×	×	×	It cannot export survey points in IFC format
Simplebim	√	√	√	√	It cannot create elements. It is an effective tool for editing IFC data
Solibri Viewer	×	×	×	×	It can only visualize IFC files
Autodesk Navisworks	×	×	×	×	-
ARCHICAD	√	×	×	×	It cannot support and visualize the enriched model
ArcGIS Pro	√	√	×	×	Georeferencing should be undertaken layer by layer cannot export the enriched model
XbimXplorer	√	×	√	×	-

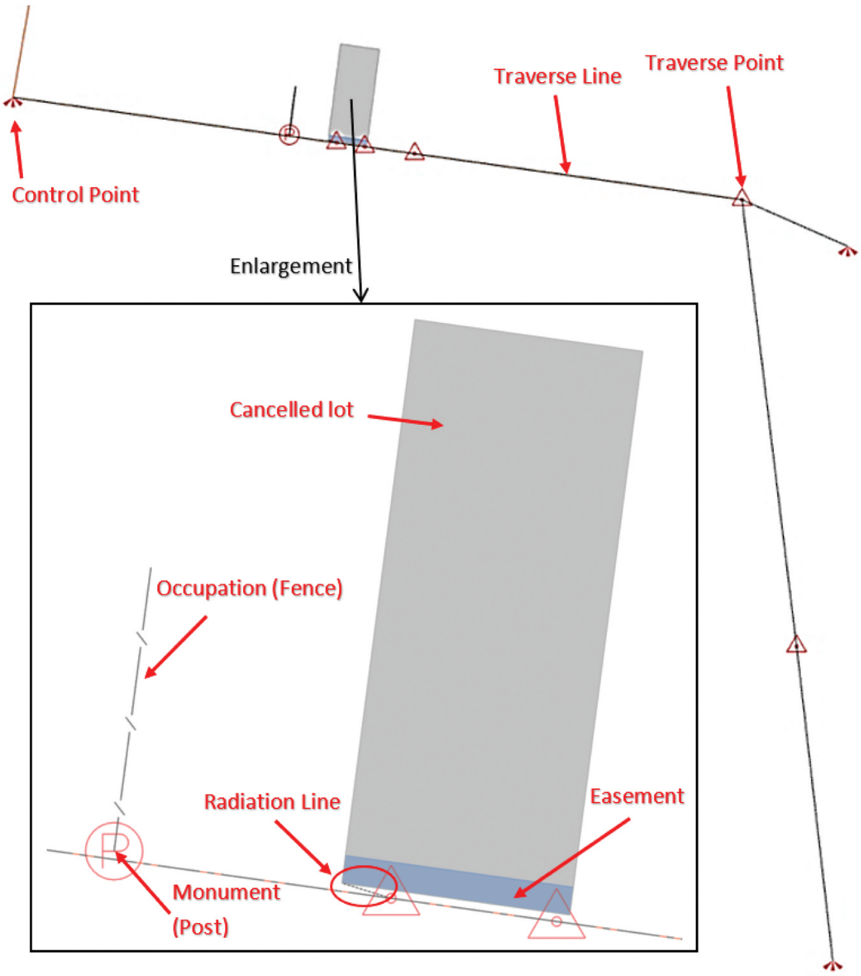


Figure 5. The floor plan of the 2D model based on AFR document.

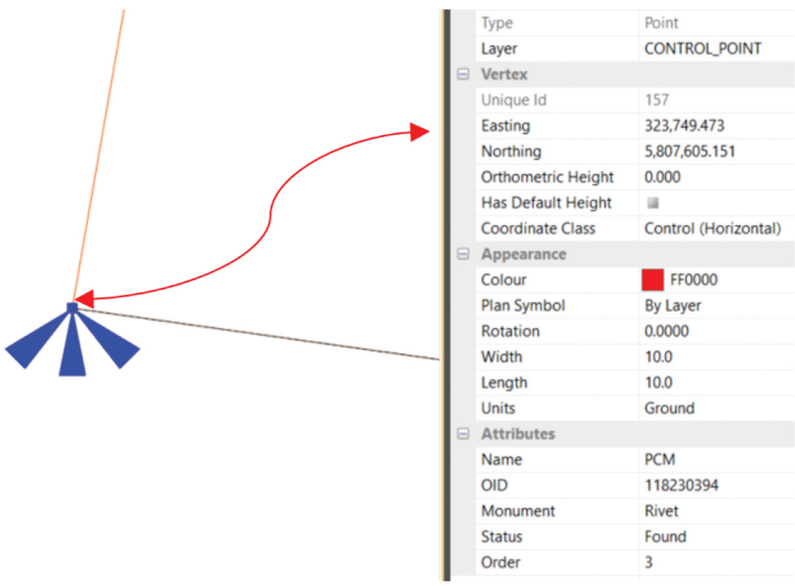
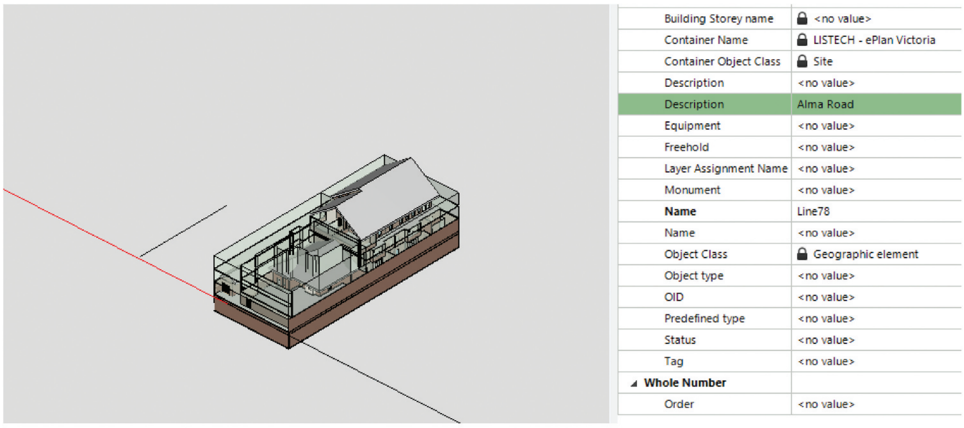
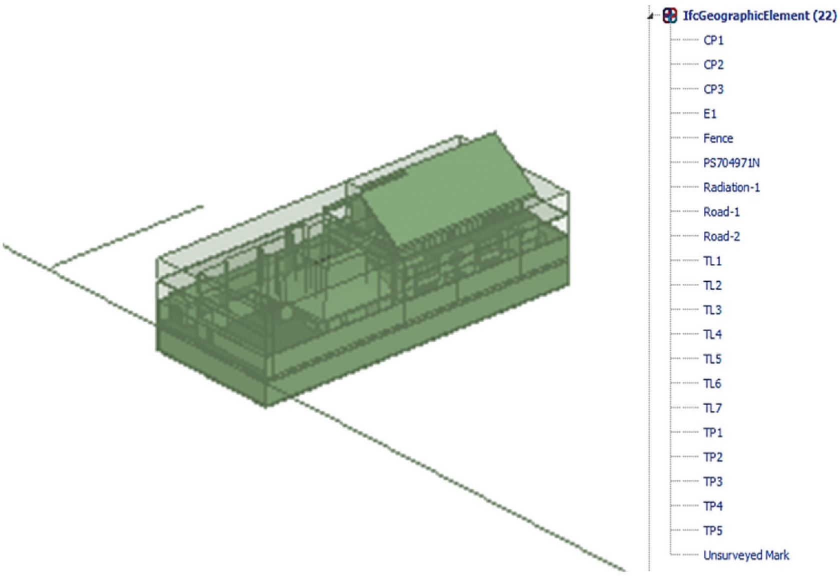


Figure 6. Demonstration of a control point with its attached semantic information in LISTECH Neo before exporting to IFC.

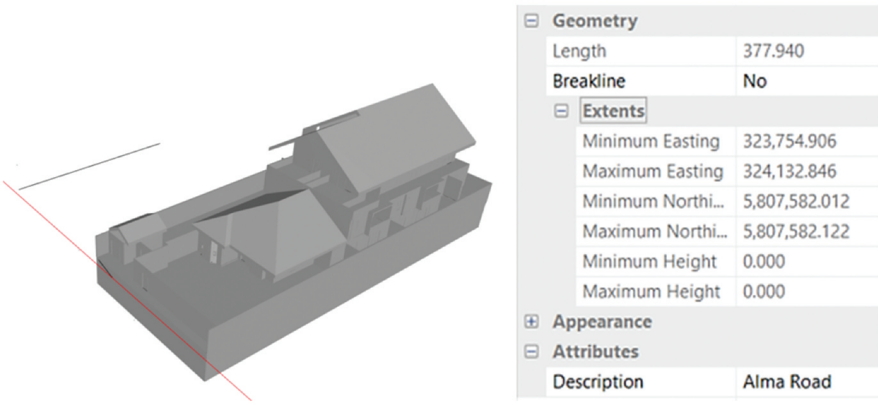
Overall, the comparison of the outcomes provides an important insight into the feasibility of utilizing IFC for capturing survey data elements in the cadastral surveying. The results obtained from the analysis of the developed IFC file are summarized in Table 3.



(a) Simplebim



(b) usBIM.viewer+



(c) LISTECH Neo

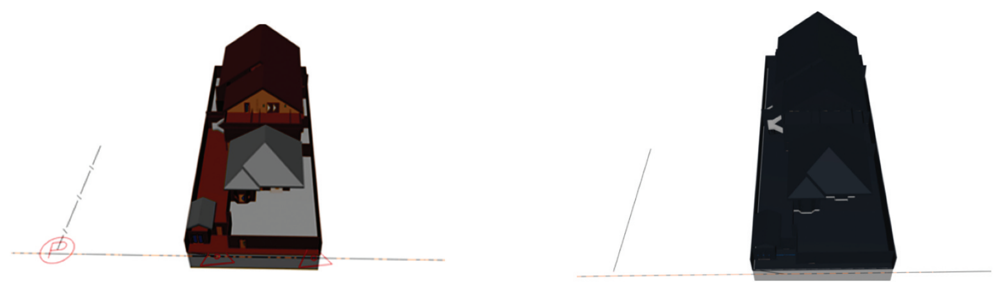
Figure 7. Snapshots of the integrated model in various BIM tools (a) Simplebim. (b) usBIM.viewer+. (c) LISTECH Neo.

Table 3. Evaluation of the prototype BIM model.

Evaluation criteria	AFR	IFC	Description
Data elements	Traverse line	√	All elements were stored in IfcGeographicElement
	Radiation line	√	
	Occupation	√	
	Survey marks	√	
Accuracy	Distance in meter	√	It can be calculated for enriched IFC by using measurement tools in the software
	Bearing in sexagesimal	√	
Representation	Point Line Polygon	Point Line Polygon	Points cannot be visualized in the investigated BIM tools with IFC format and represented as attributes in the object table

7. Discussion

The absence of survey information and observations in the current BIM applications has led us to investigate the feasibility of the BIM, in particular the open IFC standard, to manage cadastral survey data based on a review of various BIM tools and develop an integrated BIM prototype. In the current study, comparing the developed prototype with AFR showed some distinct advantages in overcoming this gap. However, the survey marks were



(a) Inside LISTECH Neo before exporting (b) After exporting from LISTECH Neo

Figure 8. The BIM model enriched with survey data. (a) Inside LISTECH Neo before exporting. (b) After exporting from LISTECH Neo.

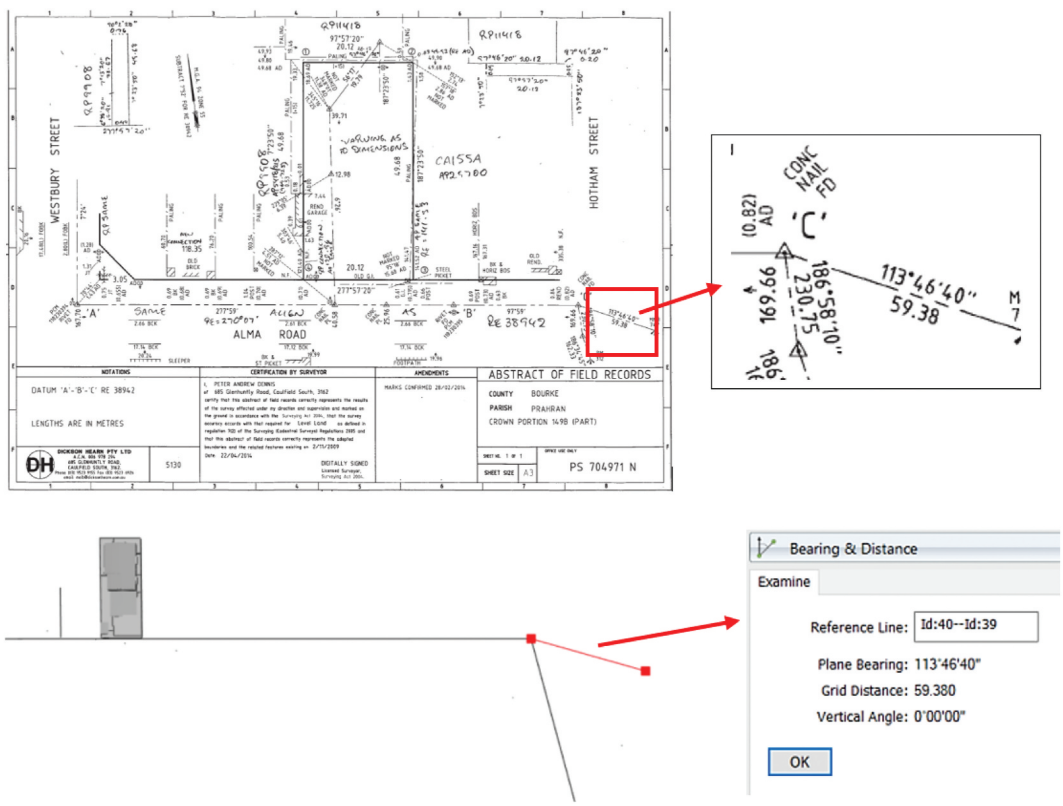


Figure 9. Comparing AFR and enriched BIM model for a traverse line.

stored as semantic information without geometry and thus cannot be visualized. This inconsistency creates concerns related to the accuracy of the initial drawing, examination of the plan and its corresponding 2D components. Technical and non-technical matters identified when implementing a BIM prototype for managing survey data are discussed in this section.

In LISTECH Neo, IfcSpace cannot be shown, and only the geometry of the building and real objects is displayed. Furthermore, exporting a combined IFC file from LISTECH Neo results in all elements, including doors, window, points, etc., being classified in IfcGeographicElement. Thus, the original shape of the building would be smashed, and all spaces would be lost (see Figure 8). Hence, instead of unifying all data in LISTECH Neo, Simplebim has been utilized for modifying and merging IFC files, which can maintain both IfcGeographicElement and IfcBuilding.

In the AFR, all lines are stored with attached bearings and distances while in IFC all objects are correlated together with a survey point and a project point defined in the IfcSite entity. Though, measuring these parameters are possible in LISTECH Neo and can be added as attributes for each line. Figure 9 provides an example of measured distance and bearing for a traverse line in the BIM environment compared to the AFR document. The land surveyor can find the survey information about a survey element in the BIM environment more interactively. However, in the AFR document, identifying survey information should be undertaken by interpreting annotations used in this document and this makes it difficult to use the AFR document for retrieving the survey information.

The scale of the IFC file is 1:1 while the AFR is not to scale. The scale of IFC data is consistent throughout the entire model; however, the AFR may exaggerate the representation of survey details in various parts to show very small or clashing measurement labels. This may create inconsistent scale throughout the AFR.

One of the applications of the proposed method is enabling adjustment of 3D cadastral observations in BIM environment since integration of BIM and cadastral survey data enables connectivity of BIM data to the geodetic network. This would significantly contribute to the examination and registration of 3D land parcels and 3D ownership spaces when implementing a 3D digital cadastral system. In other words, integration of survey data (e.g. traverses, survey connections, and survey marks), legal data (e.g. ownership RRR, easements, and legal boundaries) and physical data (e.g. building footprints, walls, ceilings, doors, and windows) would provide a complete dataset for a 3D digital cadaster.

8. Conclusions and future work

The aim of this study was to explore the possibility of storing survey observations into the BIM environment for cadastral purposes. This study has shown that how survey requirements with the abstract modality can be modeled in the IFC data model. The findings suggest that IfcGeographicElement can act as an appropriate candidate entity to support the storage of cadastral survey data such as survey marks and traverse lines in the BIM environment. Furthermore, various BIM applications in the market for merging, georeferencing, and visualizing the survey data in BIM models were examined. Among these application, LISTECH Neo and Simplebim are found to be effective for integrating cadastral survey data into the BIM models. The fundamental limitation was that no BIM software could visualize survey points and these points are typically presented as attributes in BIM models. This limitation can be addressed in the future enhancements of the IFC schema to support various types of survey marks such as control points, traverse points, and boundary points. Another finding was that surveyors may find it easier to capture all legal, physical, and survey information in the same data environment. This can also facilitate the process of checking the integrity of 3D cadastral data by plan examiners. Therefore, further research is also required to evaluate the practicability of replacing 2D cadastral plans with BIM during the plan lodgment process, which includes 3D data storage, visualization, validation, and examination.

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Notes on contributors

Behnam Atazadeh is a research fellow in the Centre for Spatial Data Infrastructures and Land Administration at the University of Melbourne. He is a leading researcher in the field of 3D land administration. His research leverages advanced scientific approaches driven from building information modeling and 3D urban modeling

Leila Halalkhor Mirkalaei received her masters degree from the University of Melbourne. She currently works as a research assistant at the University of Melbourne.

Hamed Olfat is a Senior Research Fellow and Team Leader in the Centre for SDIs and Land Administration (CSDILA), The University of Melbourne, who is responsible for coordinating the ePlan project in Victoria. Hamed has over 16-

years of involvement in many projects with research interests in "Smart Land Administration", "3D Digital Cadaster", "Spatial Data Infrastructure (SDI)", "GIS", and "Open Data Platforms".

Abbas Rajabifard is Discipline Leader of Geomatics, Director of Smart Sustainable Development and Leader of the Future Infrastructure Research Program at the University of Melbourne. He has a strong track record in research and teaching, and academic leadership, and is internationally recognized scholar and engineer. His academic background is in Surveying and Mapping, Land Administration and Urban Systems, and has continued to maintain a high level of performance across the areas of research, teaching, supervision, and service to the surveying and spatial sciences.

Davood Shojaei is a lecturer within the Department of Infrastructure Engineering at the University of Melbourne. He is also a member of Surveyors Registration Board of Victoria. Davood has extensive experience over the last 15 years in designing and implementing a variety of research and industry projects, ranging from GIS, cadaster and BIM, to 3D visualization.

ORCID

Behnam Atazadeh http://orcid.org/0000-0001-9295-4220
Hamed Olfat http://orcid.org/0000-0003-1888-007X
Abbas Rajabifard http://orcid.org/0000-0002-4256-3173

Data Availability Statement

Due to the nature of this research, the third party providing the data for this study did not agree for their data to be shared publicly, so supporting data is not available.

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