# 3D-Cadastre, a Multifaceted Challenge

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**Key words**: 3D, Cadastre, BIM, CityGML, Land development

## SUMMARY

These days, there is much talk about 3D: 3D cadastres, Building Information Models (BIM), 3D GIS and 3D visualisation platforms – technical initiatives that are driven largely by a recognition of the physical complexity of our built urban environment, the growing use of high-rise as the functional residential model in urban settings, the increasing number of stakeholders involved and the corresponding streams of information outputs. All of which demand better tools to facilitate analysis, understanding and ongoing management of the built urban environment.

An ongoing research project titled 'Land and Property Management in 3D' at the Centre for SDIs and Land Administration at the University of Melbourne is currently investigating the use of 3D technologies for land administration purposes, with a key aim of modelling legal and administrative cadastral information for complex multi-storey buildings in an urban context and linking this with a building's physical information. The project adopts two key themes of inquiry to support a move to 3D: institutional challenges, and technical issues such as data visualisation.

The paper seeks to provide an overview of the project as well as key findings to date in terms of articulating the relevant opportunities and challenges and potential areas of change in relation to 3D-cadastres.

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## 1. INTRODUCTION

People increasingly live in high density urban, often high rise and multi-functional buildings (Williamson 2001). To support this, cities require significant infrastructure above and below the ground in unique titles and arrangements. Notwithstanding this situation, the 3D software applications in engineering, architecture and geographic information systems do not have the integrity demanded in land administration. The 2D plans comprising multiple pages which are commonly used by land registries cannot be easily understood or visualised outside the domain of highly specialised professional surveyors. 3D engineering and architecture drawings do not deliver legal authority for rights, restrictions and responsibilities in land and property registration. The lack of an efficient and effective 3D solution for land administration purposes limits the ability of the resident community to visualise and understand the rights, restrictions and responsibilities of their buildings; the ability of local government and developers to visualise multi-level developments for regulatory and registration purposes; and the ability of the government to administer a title registration system that can accommodate these increasingly complex multi-level developments.

Furthermore in the Australian context, disputes arising from high density living in buildings with owners corporations is likely to increase as the public brings their expectations developed while living in detached houses into the village atmosphere of projects. Disputes among owners, owners and their corporations, and owners and third parties, could increase in numbers and complexity, and associated with this, the efforts of institutions such as courts, administrative tribunals and informal dispute settlement centres, and bureaucracies to service them. 2D plans are no longer able to represent the reality of these inter-related titles and land uses with their complex rights, restrictions and responsibilities.

Achieving changes for the betterment of the community is not without its challenges. Land development is a multi-disciplinary process involving a wide range of expertise. This includes investors, engineers, builders, architectures, town planners, planning and development authorities, land surveyors, utilities/service provision authorities, lawyers, land registry, banks, real estate agents, and potential buyers.

Depending on the size of the development, the level of involvement of each stakeholder might be different. In high-rise land developments where multi-level construction takes place, significant time and resources will be spent on the coordination between stakeholders and fulfilment of their requirements. The high-rise land development process generally includes the following phases: acquiring planning permit, obtaining building permits, marketing and advertisement for pre-sale, building and construction, registration of subdivided land and properties and final sale.

In this paper, we present an update on an ongoing research project at the Centre for SDIs and Land Administration at the University of Melbourne on ‘Land and Property Information in 3D’ with a particular emphasis on Building Information Models and the role of the surveying industry in collecting land and property information in 3D. We first present the technical and institutional context in which we operate with regards to 3D information and then we present the findings and developments of the project.

## 2. CURRENT CONTEXT

There is little doubt that with the current rate of urbanisation, the positive link between cities and economic wealth will strengthen, inexorably cementing the role of cities as lynchpins of development (UN-HABITAT, 2011). This role is staggering: the top ten urban regions of the world in which only 2.6 percent of the world’s population resides, generates more than 20 percent of the world’s economic activity (Florida et al, 2009). These high levels of productivity are predicated on the agglomerating effects of cities. Infrastructure and services are provided through the exploitation of above and underground spaces in the ongoing bid to do more with less. This however comes at a high cost: cities notoriously metabolise vast quantities of resources, with high-rise buildings identified as one of the key consumers of energy (UN-HABITAT, 2008). With high-rise buildings becoming synonymous with cityscapes, there is increasing recognition and emphasis on cultivating sustainable cities through better building design, urban planning and ongoing management – all of which are driving demands for improved building information (National Science and Technology Council, 2008; National Institute of Building Science, 2011).

### 2.1 Physical aspects

The realisation of high-rise buildings is the product of a long process that begins from conception to construction involving multiple stakeholders. Development is contingent on higher than normal levels of collaboration to underpin decision-making. For example, Rahman (2010) used the example of the involvement of at least 18 different disciplines across eight organisations as a fairly typical example of the level of stakeholder participation involved in the development of complex structures. Such diversity inevitably results in heterogeneous data outputs arising from different professional practices and methodologies amongst different disciplines, different work processes amongst different organisations and different formats of information representation (eg. digital, electronic, paper-based) – resulting in clashes, conflict, communication gaps and collaboration issues (Eastman et al, 2011).

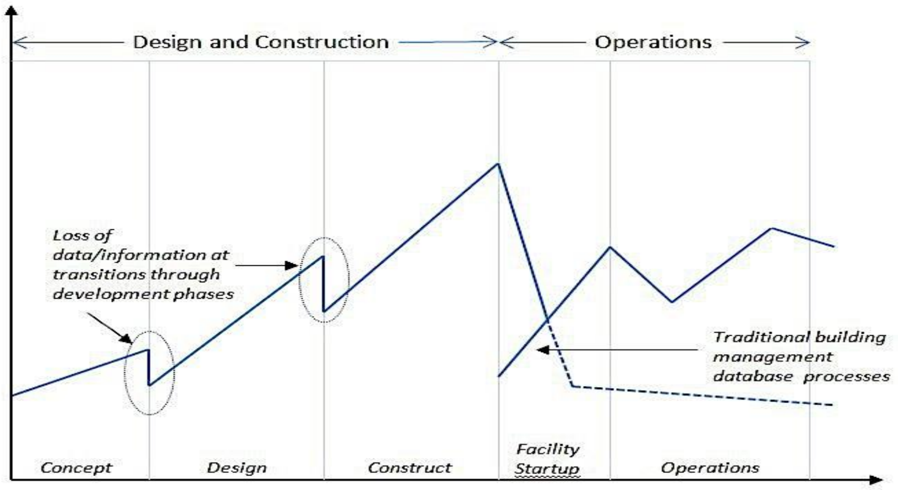


**Figure 1.** Graphical representation of the data issues associated with the traditional 2D paradigm to support information processes of the land development process for high-rise buildings (adapted from Eastman et al, 2011).

Data loss from lack of interoperability amongst stakeholders has been estimated to cost the Architecture, Engineering and Construction (AEC) industry almost $16 billion annually in the United States (Gallagher et al, 2004) and around $12 billion annually within Australia (Engineers Australia (Queensland Division), 2005). Figure 1 above shows a common graphical representation of the information and data issues associated with the use of the traditional 2D paradigm for high-rise development, and consequently, building operations and management (Eastman et al, 2011).

### 2.2 Legal and administrative aspects

Structural complexity has post-construction implications in terms of the ongoing management of the building, estimated to comprise around 85 percent of total costs over the lifecycle of the building (Haviland, 1978). These are significant costs, but they are still contained to the building – most of the literature does not even take into account the long-term costs on the community.

Curves, planes, mezzanines, intersecting elements, protrusions… along with a range of other architectural and structural articulations, and a trend towards mixed use of space, all impact on the design and layout of private, public and communal ownership spaces within the limits of a high-rise development, which ultimately affects the management and ongoing amenity for a building's resident community. These spaces are formalised through the process of subdivision, which enables a high-rise development to be divided into multiple individual apartments or units, and for these to be individually traded as commodities through the process of registration. These spaces are currently represented as 2D plans, mostly defined by the structural elements of buildings, but can also be wholly cognitive concepts.

In recent years, there has been increasing awareness within the land administration industry regarding the limitations of 2D survey plans and the use of 2D-based concepts to both define and represent boundary and ownership information of high-rise buildings. Figure 2 below shows the complexity of information representing boundary definitions in a block of high-rise residential units in Melbourne, Australia, as well as the volume of documents required to reflect the legal aspect of this building. In particular, focus has been on the effectiveness of 2D-based representations of ownership spaces for supporting the security of ensuing property rights, responsibilities and restrictions (RRRs) given the difficulties in understanding complex drawings. (e.g. Osskó, 2001; Stoter and Zevenbergen, 2001).

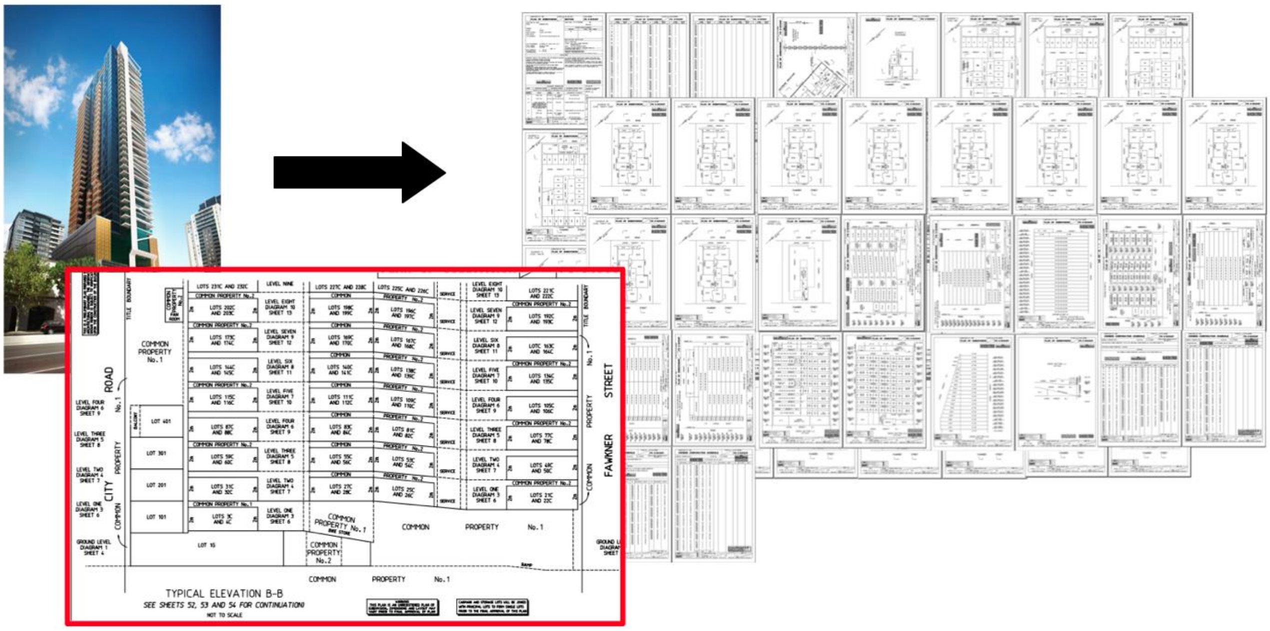


**Figure 2.** Over 50 pages of 2D plan drawings required to represent overall parcel and individual unit (lot) boundaries for a 40-storey apartment building in urban Melbourne (AAM VEKTA, 2012).

In terms of producing and managing legal information pertaining to high-rise buildings, much of the same arguments regarding information loss cited above also applies, perhaps even to a more drastic degree – most residents would not have access to the physical information (such as building or architectural plans, engineering schematics, etc) relevant to the building. In such buildings, the only authoritative set of information that carries through from the development process through to the management stage is the plan of building subdivision, which records the various units or ownership lots (including accessory lots such as parking spaces and storage) and common property.

### 2.3 3D innovations in support of information processes

To address these issues, the industry has increasingly moved towards a technological response, and indeed has been doing so since the 1980s when the use of digital building models as a viable basis of representing the physical aspects of building information first emerged amongst AEC industry (Eastman, 1999). Within the individual sectors, uptake of technological innovations that move towards 3D representation of building information have been significant, with architects and engineers using computer-aided design (CAD) successfully in their own information production processes. Most recently, a global trend in building information modelling (BIM) processes that leverages the use of 3D digital parametric building models has become widespread. The mandated use of BIM in countries such as the United States, the United Kingdom, the Scandinavian countries of Finland and Denmark, and recently Singapore, all point to BIM as the future of collaboration and information interoperability for the development process (see Figure 3 below). Importantly, this wave of innovation is not only technological, but critically encompasses social and cultural change.

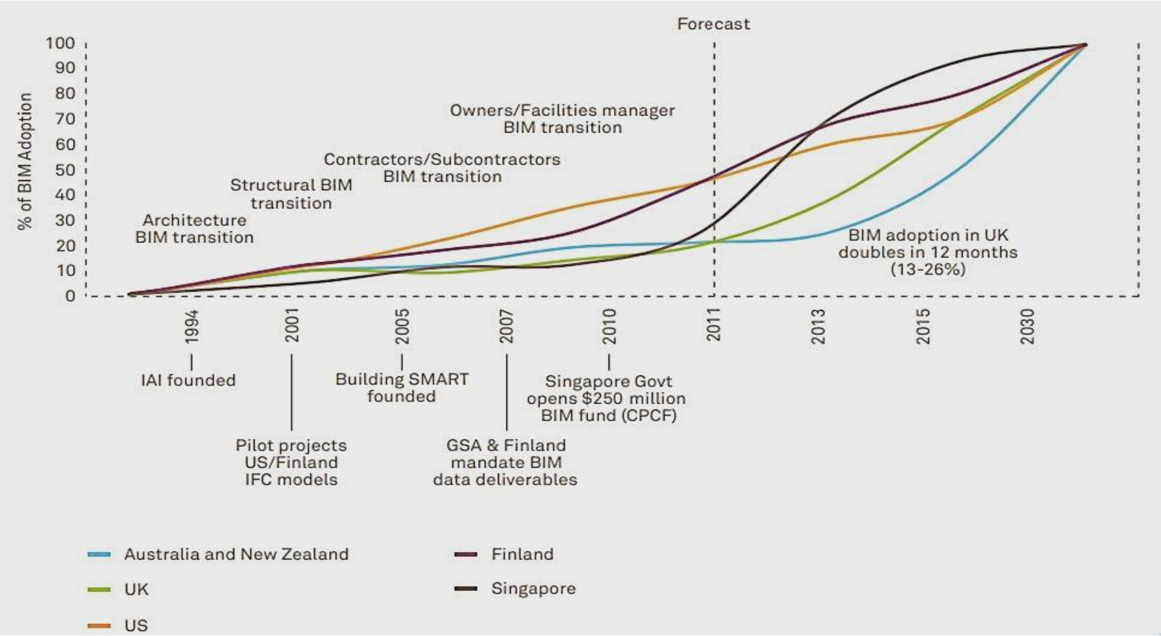


**Figure 3.** International trends in mandated BIM use (Davis Langdon, 2012: 67).

BIM as both product and process innovation has delivered significant improvements in productivity across the AEC industry, primarily in planning, coordinating and analysing building design across multiple stakeholders. Within Australia, the Co-operative Research Centre for Construction Innovation (CRC-CI) noted that improving design and project documentation can save up to 17% in constructions costs; in turn, a 10% improvement in efficiency in the construction industry could boost GDP by up to 2.5% over the next five years (CRC-CI in Engineers Australia (Queensland Division), 2005).

Despite the evident benefits that emergent 3D technologies are delivering, their applications remain almost wholly relevant to the physical aspects of development. The literature on land and property development rarely includes legal aspects of development, most notably planning and development assessment, compliance and registration (including easements, encumbrances and common property for vertically delimited property). This is despite the fact that structurally complex structures undoubtedly produce complexity in the rights, restrictions and responsibilities (RRRs) associated with owning and using these spaces – be it individual ownership, common property regimes or facilities management. There is no through-flow process for managing the information that is produced through the land development process about buildings (i.e. high-rise land development), with the corollary being a dearth of information that can be used by the community to manage these structures transparently, efficiently and sustainably.

## 3. SURVEYING AND BIM

The acronym BIM can be viewed from two perspectives, namely product or process. From a product point of view (Building Information Model), it is defined as a 3D digital representation of physical (or spatial) as well as functional (or semantic) information about elements of a facility from its conception to its destruction (NBIMS, 2006). As a process (Building Information Modelling), it is used to create, manage, derive and share building information among different stakeholders involved in various phases of the construction process in order to facilitate collaboration and communication between them (Eastman et al., 2011) (Figure 4).

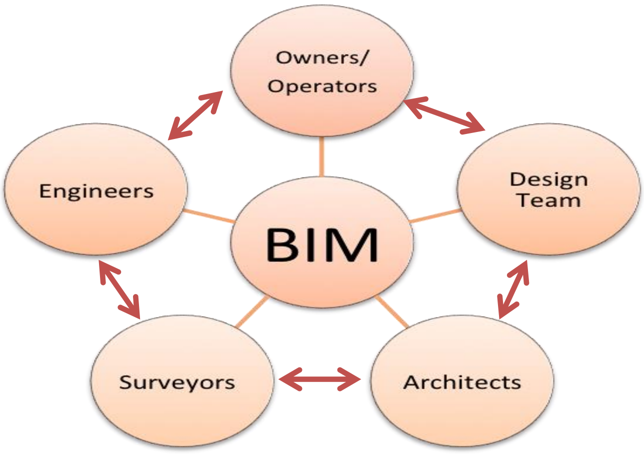


**Figure 4:** Different stakeholders contributing to BIM (Eastman 2011)

The most prominent standard for BIM is the Industry Foundation Classes (IFC). IFC was developed by International Alliance for Interoperability (IAI), recently renamed to buildingSMART, and it enables sharing and exchange of building information among various BIM software and applications (buildingSMART, 2013).

Besides BIM, there are other standards and formats developed for 3D modelling purposes. Some of these standards/formats such as VRML (ISO, 2004), 3D Studio Max and X3D (ISO, 2005) are used in the field of 3D computer graphics and some of them, such as COLLADA (Barnes and Finch, 2008) and KML (Wilson, 2008), are developed for geo-visualisation purposes. Although the aforementioned standards and formats are powerful in terms of visualising the geometry of buildings, they are inefficient in providing semantic information about buildings. In contrast to these models, the CityGML standard, which was developed by Open Geospatial Consortium (OGC) for the management of 3D city models, concentrates on the management and representation of semantic information about buildings (Gröger and Plümer, 2012).

Both IFC and CityGML standards provide detailed geometric and semantic information about buildings and its interior structures. Nevertheless, considerable differences exist between these standards (Nagel et al., 2009). The first one is that semantic objects are defined differently in both standards (Gröger and Plümer, 2012). The second difference is that since CityGML concentrates on usage and observation of buildings, the geometrical representation approach is Boundary Representation in this standard. However, IFC standard additionally uses Constructive Solid Geometry (CSG) or sweeping methods (Mäntylä, 1988). The third difference is that IFC objects are represented in only one Level of Detail (LoD), while the CityGML ones can be represented in five various LoDs (Gröger et al., 2012). The last difference is that the IFC standard only models buildings, but CityGML additionally addresses other objects like water bodies, terrain and transportation (Gröger and Plümer, 2012).

BIM models usually exist for newly constructed facilities since engineers or architects manually create them in the design stage. Recently, surveying technologies such as terrestrial/airborne laser scanner or total stations and photogrammetric techniques are being utilised to reconstruct 3D geometrical models of already built-up constructions in BIM. However, these geometrical models need to be enriched with semantic information to become fully functional BIM models. Also, the interaction between the land development industry and land surveying profession in the development lifecycle of high-rise complex developments is restricted to 2D plans prepared by the land surveyors. Based on the research undertaken as part of this project, land registries and land surveyors are not ready to adopt BIM for the modelling and registration of 3D rights, restrictions and responsibilities. At the same time, BIM standards do not consider property rights, restriction and responsibilities information for the lifecycle of buildings and infrastructures.

## 4. FINDINGS OF THE PROJECT

The 'Land and Property Information in 3D' research project aims to develop innovative methodologies which will help to address the problem of modelling and managing complex 3D property rights, restrictions and responsibilities (RRR) in multi-level developments in our rapidly growing cities. This research moves multiple two dimensional drawings that now identify buildings and infrastructure objects and their separate parcels into authentic visual 3D images of the building and objects that meet the exacting legal standards of ground surveys. Property information systems based on 2D maps have served land administration and property management well for hundreds of years based on the cadastral concept of an inventory of property parcels in two dimensions (FIG 1995). However, most of the developed world (including Australia) and many developing countries now give ownership titles in buildings in three dimensions (3D) using the same 2D maps developed for traditional broad acre development on vacant land (Williamson 2002). It is the technical, institutional problems surrounding the move to 3D-enabled representation of property rights, restrictions and responsibilities that are the focus of this project.

### 4.1 Institutional findings

Significant literature exists which underscore the importance of understanding social and cultural factors in technological change within the AEC industry (e.g. Mitropolous and Tatum, 2000; O'Brien, 2000; Davis and Songer, 2002). To support the move towards 3D-enabled land administration processes, a case study on the city of Melbourne was undertaken to explore similar factors underpinning the current land administration environment for high-rise buildings. A total of 27 interviews were conducted.

Institutional theory, which focuses on the regulative, normative and cultural-cognitive elements that constitute social structures (Scott, 1995; 2001) was used as an analytical framework for elucidating the 'invisible' constraints that may prove to be barriers to innovation. Essentially, institutionalisation serves to preserve the actions that historically, have produced the best economic outcome. Overtime, the outcome may no longer be favourable, but social structures have developed to 'lock in' these actions, often at an unconscious level – hence becoming 'invisible'. Identifying these 'invisible' structures is the first step towards developing a better understanding of the options available to an organisation for the purposes of developing and deliberating strategic responses to facilitate change. A forthcoming paper discusses the case study and its findings in greater detail (Ho et al, forthcoming). However, the key findings are summarised and presented here.

#### 4.1.1 Institutional Environment and 'Invisible' Constraints

A range of 'invisible' constraints were identified through the interview process. Primarily, the regulatory environment that underpins subdivision in general was perceived to work well for most buildings – to the extent that participants could not foresee the possibility that the process could, or would, change to accommodate high-rise developments, which only constitute less than five percent of subdivisions processed at the land registry annually.

The current approach towards subdivision was established in the late 1980s with the introduction of the Subdivision Act 1988. This approach was not intended for the complex superstructures that proliferate today. Comments reveal the increasing level of resources invested in producing these plans, only to be subjected to further change and modification via the regulated plan examination process. Information production is wholly reliant on the skills and experiences of individual surveyors, which were shown to be increasingly varied through comments such as the following made by participants from the land registry: 'two-thirds (of subdivision plans) need amendment from surveyor, one in 10 to 20 will require significant amount of change'.

The skill level is compounded by the fact that only a small pool of surveyors consistently engage with high-rise developments, followed by a long tail of surveyors who are involved every now and again: in the last year alone, surveyors from just four firms were responsible for more than half of the plans lodged in the city of Melbourne.

The variable skills amongst surveyors produces inconsistency in plan information that is challenging for other end-users in the community, such as strata managers. The use of profession-specific codes and symbols for encoding information also emerged as an issue, with the following comment made by an experienced surveyor about the plan of subdivision:

> "that's unintelligible to anybody except for Titles (Office)… nobody outside (of) Titles Office and surveyors understands vinculums (a symbol used to show a change in level along the same boundary plane)".

In attempting to provide clarity, the land registry developed the 2011 Subdivision (Registrar's Requirements) Regulations. This however, is still based on current ways of thinking and acting, and serves only to further constrain users to the current 2D-based approach.

Overlaying these constraints is the conflation of several trends at a broader level that serve as both normative and cultural barriers to change. Firstly, high-density high-rise living is a fairly recent phenomenon in Australia. Many apartment owners are new to strata living and do not appreciate the interdependent nuances of owning 'space' as opposed to the independence of owning a free-standing dwelling. Secondly, there has been a growing trend in the use of multiple owners corporations to manage mixed-use properties: a lawyer who was interviewed commented on his current 'record': 71 owners corporations for 75 lots in an inner-city development in Melbourne. Thirdly, the proliferation of multi-storey developments and the increasing need to regulate its management also led to the introduction of the Owners Corporation Act 2006 and the formalisation of an industry around strata management that leverages the plan of subdivision for management purposes. All these factors are putting pressure on the institutional structures that support subdivision – it is evident that the institutional environment must shift or change to acknowledge the different requirements of high-rise developments.

Perhaps the most important constraint that surfaced from the interviews was the lack of a key strategic actor who has the power to drive change. Due to the primacy of the land registry in the subdivision and registration process, many participants associate them with a leadership role. However, it appears that the institutionalised environment that the land registry operates within, including the mandates of a statutory framework and historical legacies, constrains their ability to take up such a role.

### 4.2 Technical findings – 3D Cadastral Visualisation Requirements

A preliminary set of visualisation requirements was identified as a result of the literature review. This was then extended by conducting a comprehensive questionnaire among the land development industry. These requirements are classified according to the following categories:

- ***Data Requirements*** are considered as inputs and define the types of data that are important for the users and represented on 3D cadastral visualisation applications.
- ***External Interface Requirements*** describe the interface of the program and the components of the interface.
- ***Visualisation Requirements*** define the visualisation requirements which are significant for 3D cadastral visualisation.
- ***Functional Requirements*** explain the required functions which are expected from the software.

- ***Non-functional Requirements*** define some constraints such as usability, performance and interoperability to determine the overall quality or attributes of the application.

In order to validate these requirements, a 3D cadastral visualisation prototype was developed and presented to the users. Feedback was elicited via a questionnaire and considered for improving the utility of the prototype. Figure 5 represents a snapshot of the prototype.

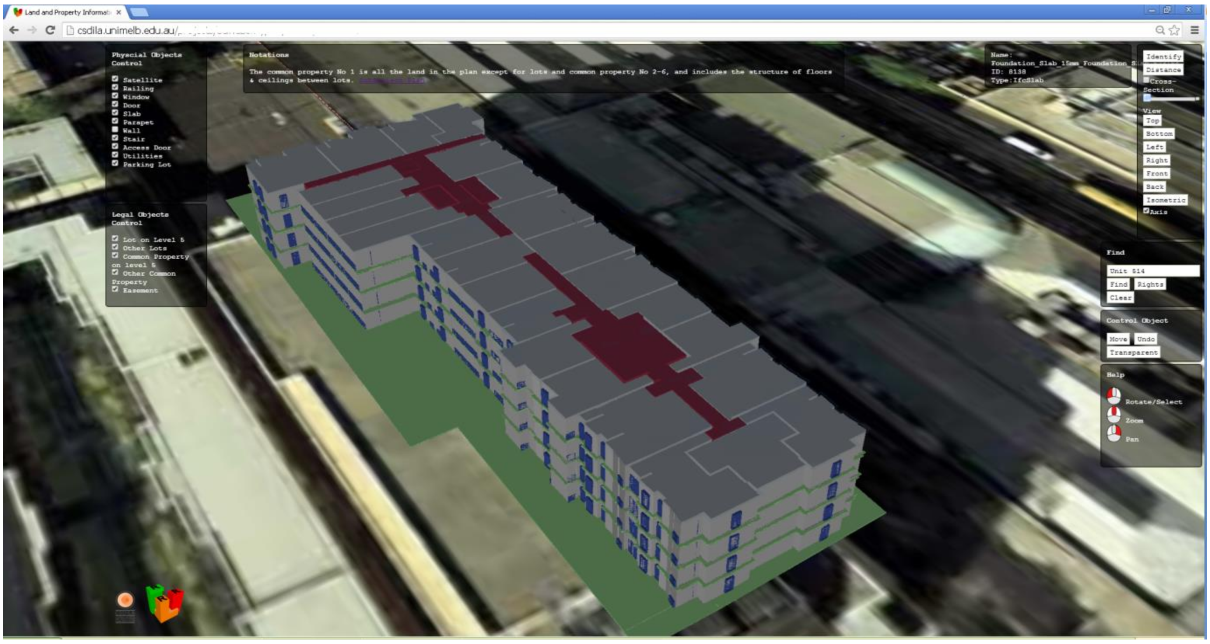

**Figure 5:** 3D cadastral visualisation prototype.

This prototype is based on WebGL, which is an open-source technology for representing 3D objects on the web. WebGL is a royalty-free web standard based on OpenGL and provides users with 3D models using canvas elements and container for graphics in HTML 5. WebGL brings plug-in-free 3D to the web and major browsers.

The IFC format was utilised for storage of 3D objects. IFC is one of the formats which support BIM, but as mentioned earlier in the paper, it does not support legal objects (e.g. lots, easements, common property). Therefore, one of the existing components of IFC, "Space", was utilised for representing legal objects. Using this approach, the prototype was able to visualise both physical and legal objects in an integrated approach to minimise the ambiguity in representing ownership rights.

## 4.3 Technical findings – 3D printing technology

3D printing is a rapid prototyping process that enables the construction of physical objects based on 3D virtual models. This industry is a relatively new one, having only been around in the last 30 years. The first commercially successful 3D-printed object appeared in 1994 with printed wax material. Since the start of the 21st century, the technology has progressed rapidly and printers are now widely available. At present, 3D printing is used in the architecture, construction, industrial design, automotive, dental and medical industries and many other fields (Knill and Slavkovsky, 2013). In this project, 3D printing technology is used to demonstrate physical and legal aspects of buildings by producing tangible 3D models. The models have been prepared in 3D design applications such as Revit and SketchUp and then were processed in specific 3D printing applications (MakerWare and Makerbot Replicator 2) and transmitted to a 3D printer.

A high-rise building in Melbourne, Australia, was chosen as a case study for 3D printing. A 3D model of three neighbouring units was generated. Two 3D models, namely physical and legal models, were printed (Figure 6 and 7). The physical model shows the apartment boundaries and the legal objects represents the lots. These two models can then be integrated (Figure 8) to represent both physical and legal objects.

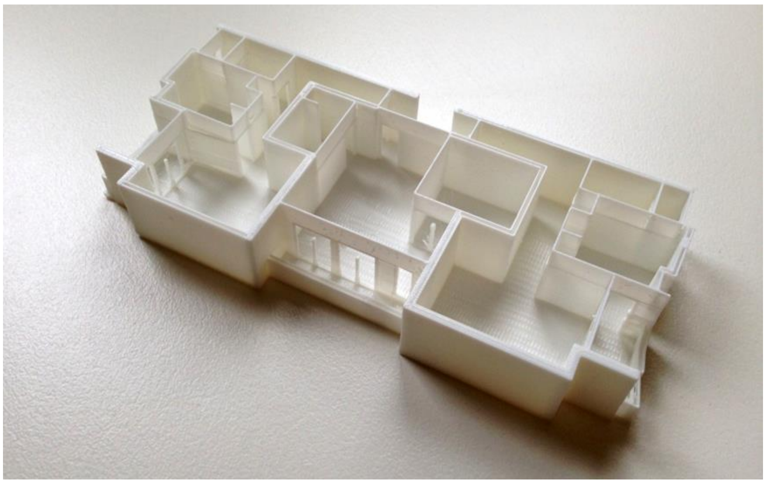

**Figure 6.** Physical model of the 3 apartment units

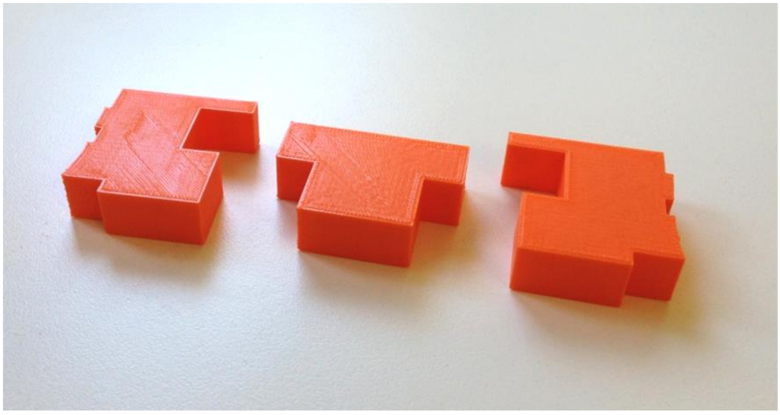

**Figure 7.** Legal model of the 3 apartment units

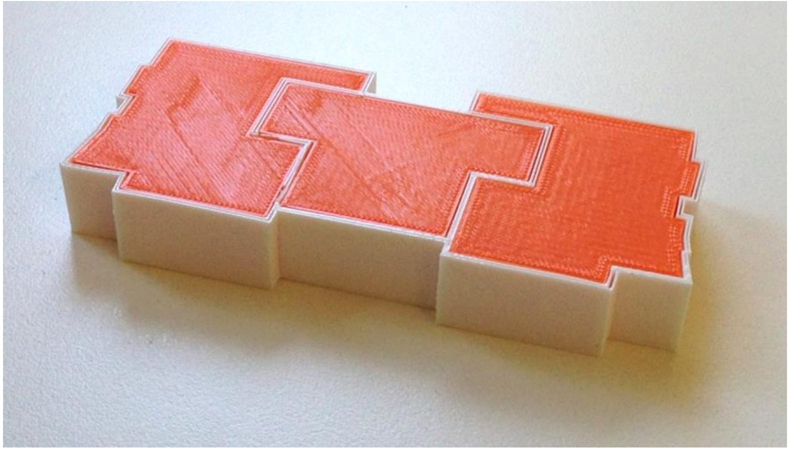

**Figure 8.** Integrated 3D model of the 3 apartment units

3D printers can be used for generating 3D models of buildings and also the ownership boundaries of each lot. Other types of legal objects such as common property areas and easements can also be printed to show other legal objects. However, there are still some technical limitations in printing complex objects.

### 4.4 Technical findings – 3D modeling for disaster management

Buildings may be affected by a range of natural or man-made hazards (e.g. earthquake, floods and storms) which may result in their partial or total damage (e.g. destruction of buildings by 2011 Earthquake in Christchurch). The enriched physical information about buildings stored in BIM, as discussed earlier, has been highlighted as a potential way of facilitating the modelling, identification and visualisation of such damages to different building aspects such as structural elements, cosmetics, or the utilities (Isikdag & Zlatanova, 2009; Christodoulou et al., 2010). While such physical aspects are critical for the recovery and reconstruction of the affected buildings, legal objects such as ownership are also required for better identification and management of legal boundaries and protecting the owners' rights in this process. Aien et al. (2013) proposed a paradigm for an integrated management of 3D physical and legal information. Such integrated information management approach can be utilised for further identification of the legal objects associated with the damaged building components by emphasising on BIM as the overlapping concept between legal and damage information. Without such an integrated approach, reconstruction and recovery can be cumbersome, particularly in extreme cases (total destruction of building) where none or limited real world physical benchmarks exist to indicate the owners' rights and entitlements.

As part of this project, information from BIM and 3D virtual city models were integrated. Damage to a typical residential building as a result of an urban flooding case was identified in a 3D prototype system. Legal objects associated with physical aspects of this building were also considered in identifying the RRRs for the recovery of the building after the disaster. The initial findings show that such a system can be beneficial in disaster management and particularly the recovery process. The use of 3D building information in this approach can be applied to more complex building types where such analysis and visualisation is a difficult task using the traditional 2D methods.

## 5. CONCLUSION

The research to date through this project has clearly demonstrated the complexities of changing the land development processes to accommodate a true 3D representation of cadastral information. It involves not only the technological aspects but also many deeply engrained institutional issues, which are compounded by the involvement of many disciplines in the land development process

The ability to maintain 3D information relating to property interests, and make it available through the land administration systems will provide important benefits to community. Its greater benefits lie with the surveying profession where it will assist management of the economy of 3D land development, security of tenure and community engagement. Implementation of a 3D land and property information system potentially provides significant long-term benefits and savings for the community in the land development processes where land surveyors play important roles.

A clear understanding of complex developments through computer visualisation or 3D printing will help reduce misunderstandings and disputes between developers, owners and managers, and the public. At the same time this will improve the ability of authorities, such as local government and utility companies, to effectively plan large multi-unit developments, as well as large-scale infrastructure such as shopping centres, bridges and tunnels.

With the mandating of BIM in a number of countries to improve the productivity of the AEC industry, and as such the availability of detailed 3D building models, the use of this information for broader land administration purposes appears to have considerable merit. The focus of BIM encompasses the entire life cycle of a building, which further supports the case to leverage its use for land administration applications.

The challenge for the surveying profession is to consider the many facets of the 3D challenge and to assist in bringing about changes which will have long term benefits to the community and to the profession.

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