Assessment of the Australian Digital Cadastre Protocol (ePlan) in terms of Supporting 3D Building Subdivisions

Shojaei, D., Olfat, H., Rajabifard, A., Darvill, A. & Briffa, M.

Abstract

Population growth and lack of available land in urban areas have resulted in intensive property development both above and below ground. According to the 'Cadastre 2034 Strategy' published by the Intergovernmental Committee on Surveying and Mapping (ICSM) for Australia in 2014, the current digital cadastres have limitations in positional accuracy and do not adequately represent the three-dimensional nature of real property. This strategy highlights the fact that land parcels that are limited in vertical dimension are not adequately represented in the current digital cadastre. This makes it difficult to visualise security of tenure as it relates to a building or an apartment within a building.

Since 2011, a national cadastral data model (ePlan Protocol) is being implemented in different Australian jurisdictions including Victoria, New South Wales and Queensland for 2D (non-building) plans of subdivision. Following the ICSM's strategy, the ePlan Working Group has started to investigate the requirements for supporting 3D building subdivisions in ePlan. As part of this investigation and to assess the potential of the ePlan Protocol in terms of supporting 3D spatial units associated with land and property management, a research project was recently undertaken in Victoria, Australia.

In this research, various building subdivision plans were investigated and modelled in ePlan and a number of technical and non-technical challenges were identified. Overall, the study confirmed that the ePlan Protocol is able to support 3D building subdivision plans, however curved shapes are not well handled. This paper also proposes future investigations for implementing a 3D digital cadastre in Victoria.

Keywords: 3D Cadastre, ePlan, Land Administration, LandXML, BIM, Australia

1 Introduction

A growing population and lack of available land in urban areas leads to intensive property development above and below ground. The Singapore Land Authority's vision statement, ‘Limited Land - Unlimited Space’, has highlighted this fact (Soon 2012b). In these developments, overlapped ownership rights are created and registered in paper/PDF-based plans. This method of registration is not efficient as it does not record ownership boundaries in a digital format and as a result, spatial queries (e.g. finding the car park and storage associated with an apartment) are not supported.

In order to address the issues of paper/PDF-based plans, an ePlan Working Group (eWG) was formed by the Intergovernmental Committee on Surveying and Mapping (ICSM) in 2003 to develop a national model to transfer digital cadastral survey data between the Australian surveying industry and government agencies. In 2009, the ICSM endorsed the national ePlan as an agreed conceptual data model of a cadastral survey that meets the needs of the jurisdictions in Australia (Aien et al. 2012). In 2011, an ePlan Protocol was developed to map the components of the ePlan data model to LandXML, a specialised XML data file format containing civil engineering and survey measurement data commonly used in the land development and transportation industries[1]. Two dimensional ePlan is currently operational in Queensland, New South Wales and Victoria. The Singapore Land Authority also joined the eWG in 2013 and have adopted the ePlan Protocol for their 2D cadastral surveying modelling and electronic lodgements (Soon 2012a).

Following the considerable progress of 2D ePlan implementation in Victoria over the past few years and with a major focus of the ‘ICSM Cadastre 2034 Strategy’[2] being a 3D digital cadastre for Australia, the land registry in Victoria (Land Victoria) has recently begun to investigate the legal, institutional and technical requirements for developing a 3D digital cadastre for Victoria. A 3D digital cadastre is expected to facilitate the registration process (Aien et al. 2015), save time and cost, increase transparency in land and property transactions, and improve land use and management. For example, in a 3D digital cadastre, overlapped spatial units can be validated and geometries can be checked to ensure rights are protected and disputes are minimised.

On the technical aspect of the 3D digital cadastre investigation in Victoria, 3D modelling of building subdivision plans has been a challenge. At the moment, building subdivision plans are created in PDF-based plans including floor plans and cross-sections, as illustrated in Figure 1. Floor plans and cross-sections assist to define and understand the overlapped ownership rights in building subdivision plans.

[1] www.landxml.org
[2] www.icsm.gov.au/cadastral/Cadastre2034.pdf

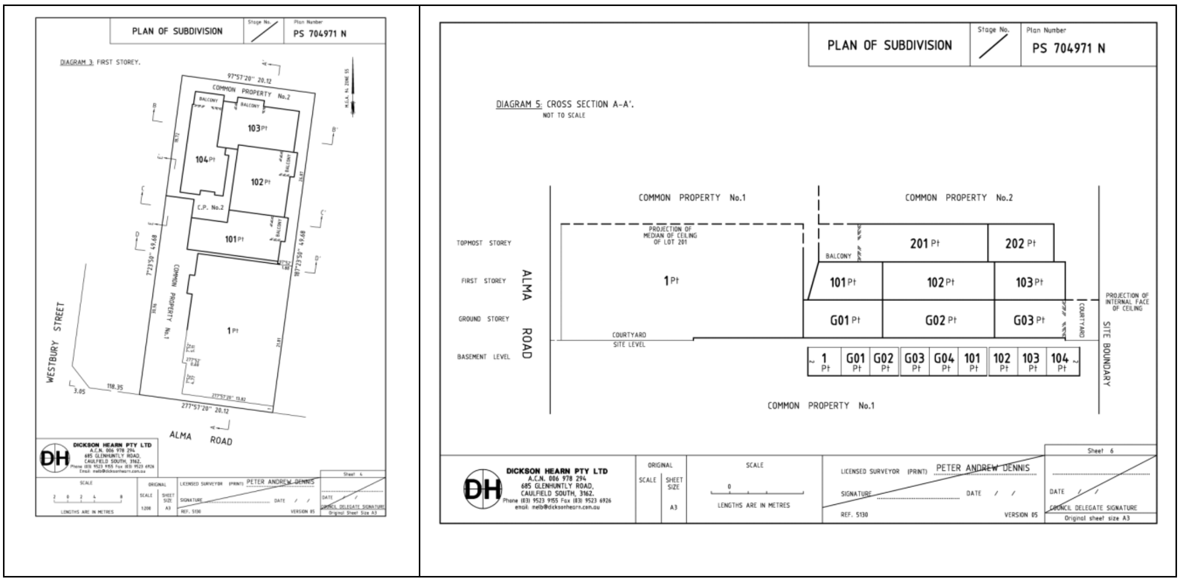


Figure 1. A building subdivision plan in Victoria including floor plans and cross-sections

However, as shown in Figure 1, building boundaries in subdivision plans in Victoria do not include dimensions (bearing, distance and height) to show the extent of building structures (Victorian Consolidated Regulations 2011). Due to this, converting the existing building subdivision plans to a 3D digital format is not simple (Aien et al. 2014). On the other hand, the feasibility and potential challenges of supporting 3D objects in ePlan have not been explored in detail. Therefore, a research project was defined and undertaken in Victoria to investigate the feasibility and possible methods of defining 3D spatial units in the ePlan Protocol.

This paper discusses the results of this research project. The scope of this paper has been limited to the electronic lodgement of future building subdivision plans in ePlan, as the existing building subdivision plans do not include bearings and distances to accurately represent the interior geometry of buildings. Ownership rights which are defined only by measurement and have no physical boundary (e.g. car parks) are considered as 3D spatial units in this research.

The paper is structured as follows with five main sections. In Section 2, the previous studies relevant to 3D ePlan are explored. Section 3 reviews the phases designed and implemented for this research. The technical and non-technical results are discussed in Section 4. Finally, the paper concludes with a summary and directions for future research.

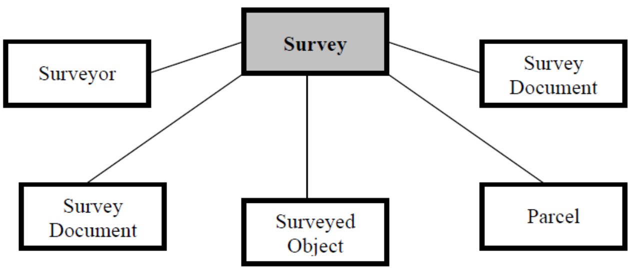
2 An Overview of Previous Relevant Studies

3D modelling in ePlan has been previously investigated to some extent. Cumerford (2010) identified that the ePlan model has been designed to support 3D surveys, which include volumetric and strata (building) surveys. He has also highlighted the challenges in the validation of 3D objects. Karki et al. (2011) investigated supporting 3D objects in the ePlan Protocol for building format plans and volumetric format plans. Shojaei et al. (2012) tested the feasibility of modelling 3D legal objects in the ePlan Protocol and developed a web-based visualisation service to visualise 3D ePlans. Soon (2014) used the same approach as Cumerford (2010) to reference the faces and create 3D objects. This method avoids duplication in parcel creation, as a face can be defined once and used multiple times.

However, in these studies the 3D modelling approaches in ePlan are not completely discussed and evaluated and various building scenarios are not tested. As a result, this research focuses on assessing the potential of the ePlan Protocol in modelling different types of building subdivision plans. The next section explores the investigation phases.

3 Investigating the Support of Building Subdivision Plans in the ePlan Protocol

The ePlan data model was implemented using the LandXML 1.2 standard. LandXML is an XML-based data format used for exchanging civil engineering and surveying data[3]. As the LandXML format has a wide schema covering various components for land administration purposes, ePlan uses a subset of LandXML schema specifically for cadastral purposes (see Figure 2). The ePlan data model is common to all jurisdictions in Australia. However, there are some differences in enumeration schemas to support different regulations in each jurisdiction.



[3] www.landxml.org

Figure 2. Overview of the ePlan data model diagram (Karki et al. 2011)

The Parcel class in Figure 2 is responsible for defining spatial units such as lots, stage lots, easements, common properties, restrictions, roads and reserves.

The Parcels element contains individual Parcel elements (see Figure 3). Parcels containers can be defined within Parcel elements to capture parcel relationships. However, there is only one LandXML/Parcels element allowed and this contains the collection of all parcels defined in LandXML. For each //LandXML/Parcels/Parcel element, a number of nested Parcels elements are also allowed (ICSM 2011).

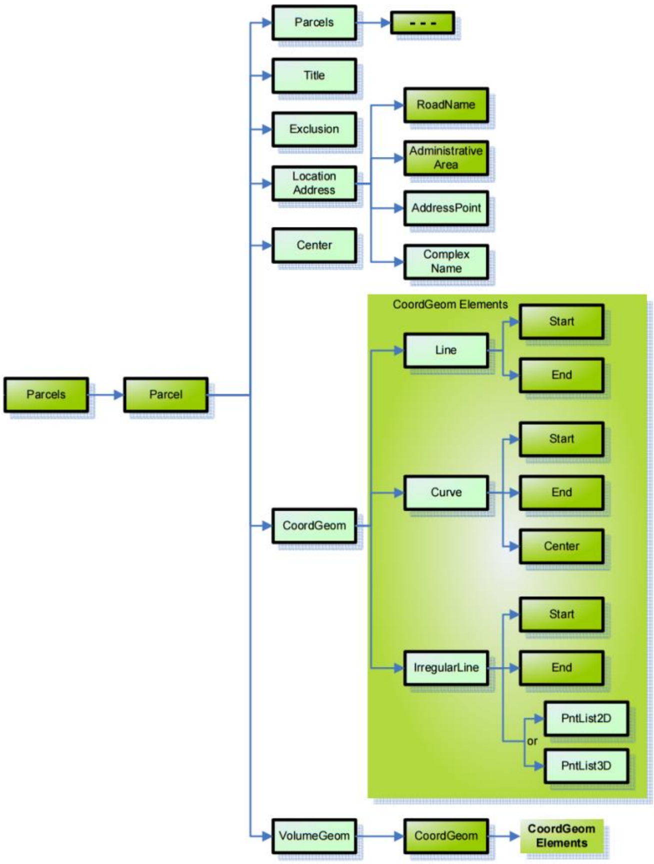


Figure 3. Parcel logical diagram in ePlan schema (ICSM 2011)

Based on Figure 3, in the parcel class, CoordGeom and VolumeGeom elements have several primitive objects such as lines, curves and irregularLines. To investigate the potential of 3D object definition in the ePlan Protocol, a study in three phases was undertaken, as follows:

3.1 Phase 1: modelling a simple building subdivision plan

The possibility of defining 3D spatial units in ePlan was already investigated by a number of researchers (see Section 2), however this phase was designed to understand the appropriate approach for modelling 3D objects in ePlan based on initial work carried out by Shojaei et al. (2012).

Various approaches, such as boundary representation (Karki, Thompson and McDougall 2010), constructive solid geometry (Jarroush and Even-Tzur 2004), extrusion (Pouliot et al. 2010), and sweeping (Pouliot et al. 2010) exist for defining geometry of 3D objects. However, the ePlan Protocol only supports boundary representation. In boundary representation, a solid object is represented using a collection of connected faces (see Figure 4).

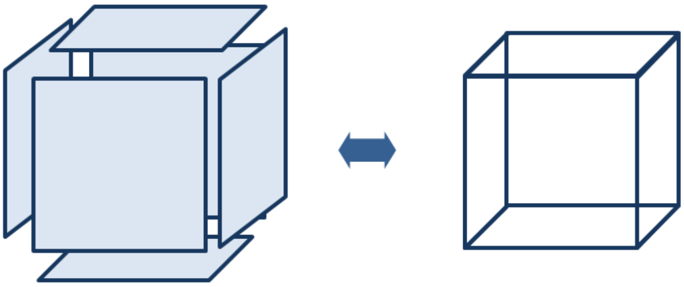


Figure 4. A cube is defined by 6 connected faces

Faces in ePlan are defined by CoordGeom element and six CoordGeom elements create a cube in 3D. Figure 5 shows the main steps of this phase.

Figure 5. The main steps in the first phase

Firstly, a simple building subdivision plan including three lots, one common property and one easement was selected as the case study (Figure 6).

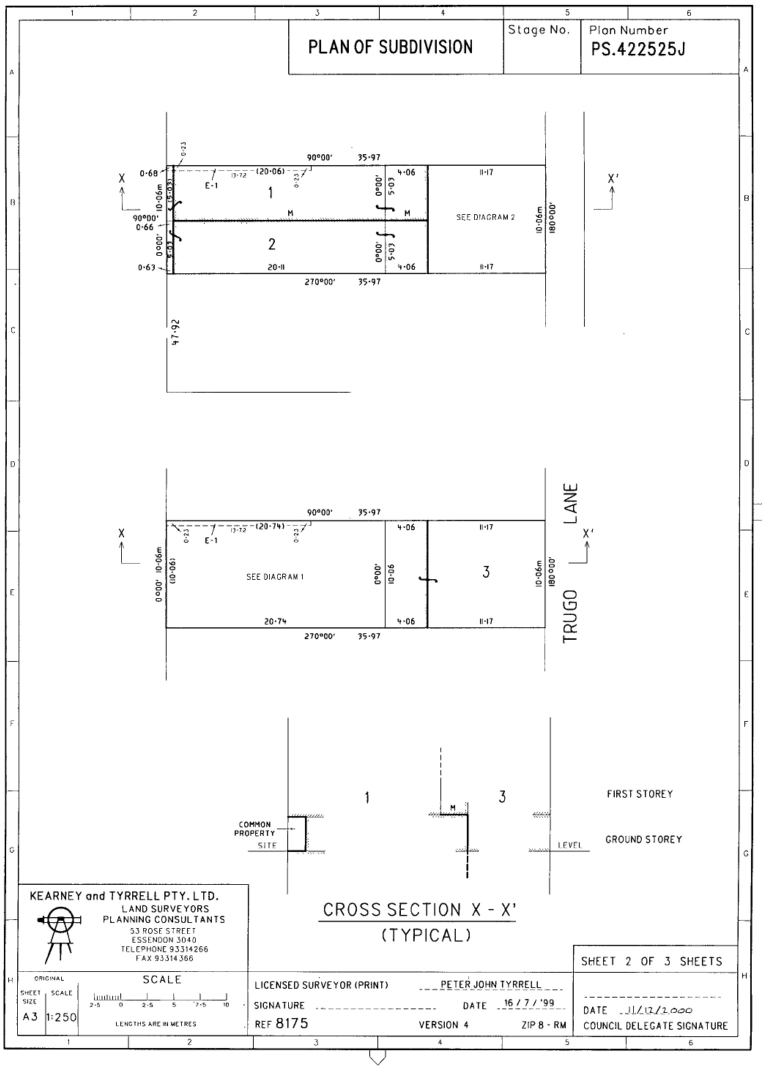


Figure 6. A simple building subdivision plan is selected for the first phase

The Parcel class in the ePlan Protocol was studied in this phase and three possible approaches for modelling 3D objects, CoordGeom, VolumeGeom, and Referencing, were identified and evaluated. These approaches are discussed below in more detail.

3.1.1 CoordGeom approach

In the ePlan data model, the CoordGeom element is a container for the spatial component of 'Parcel' elements which defines a face using Lines, Curves and IrregularLines, named based on the CoordGeom element utilised here. Figure 7 shows a single CoordGeom element structure and how several CoordGeom elements are linked together to make a 3D object (e.g. Lot 1).

```xml
<Parcels>
 <Parcel name="Lot1">
          <CoordGeom name="FLOOR1">
                    <Line>
                              <Start pntRef="CGPNT-1"/>
                              <End pntRef="CGPNT-2"/>
                    </Line>
                    <Line>
                              <Start pntRef="CGPNT-2"/>
                              <End pntRef="CGPNT-3"/>
                    </Line>
                    <Line>
                              <Start pntRef="CGPNT-3"/>
                              <End pntRef="CGPNT-4"/>
                    </Line>
                    <Line>
                              <Start pntRef="CGPNT-4"/>
                              <End pntRef="CGPNT-1"/>
                    </Line>
          </CoordGeom>
          <CoordGeom name="ROOF"/>
          <CoordGeom name="RIGHT"/>
          <CoordGeom name="LEFT"/>
          <CoordGeom name="FRONT1"/>
          <CoordGeom name="FLOOR2"/>
          <CoordGeom name="FRONT2"/>
          <CoordGeom name="SIDE1"/>
          <CoordGeom name="SIDE2"/>
 </Parcel>
 <Parcel name="Lot2"/>
 <Parcel name="Lot3"/>
 <Parcel name="Easement"/>
 <Parcel name="Common Property"/>
 ...
</Parcels>
<CgPoints>
 <CgPoint name="CGPNT-1">5814105.597 315084.99 0</CgPoint>
 <CgPoint name="CGPNT-2">5814110.596 315085.552 0</CgPoint>
 ...
</CgPoints>
```

Figure 7. Modelling a 3D object in ePlan using CoordGeom element (CGPNT-# refers to the identifier of a point which has X, Y and Z coordinates)

In Figure 7, CgPoints store 3D coordinates of points, each having a unique identifier (e.g. CGPNT-1). The simple building subdivision plan was modelled in ePlan by manually editing the LandXML file and defining five 3D objects. Due to lack of a 3D LandXML visualiser, this file was converted to KML and visualised in Google Earth (see Figure 11). Different colour and transparency levels were assigned to the 3D objects to differentiate them. In this approach, common faces between two adjacent objects are recorded twice which causes data redundancy.

The CoordGeom element can be defined as planar or non-planar faces in the ePlan data model. However, for a given boundary, there are many possible permutations when complicated objects are created with non-planar faces. For example, in Figure 8, two different scenarios are possible in the rendering process of a non-planar face on the top. These two scenarios might give different answers when the volume is calculated. In addition, an encroachment into the region of ambiguity could cause an un-resolvable dispute.

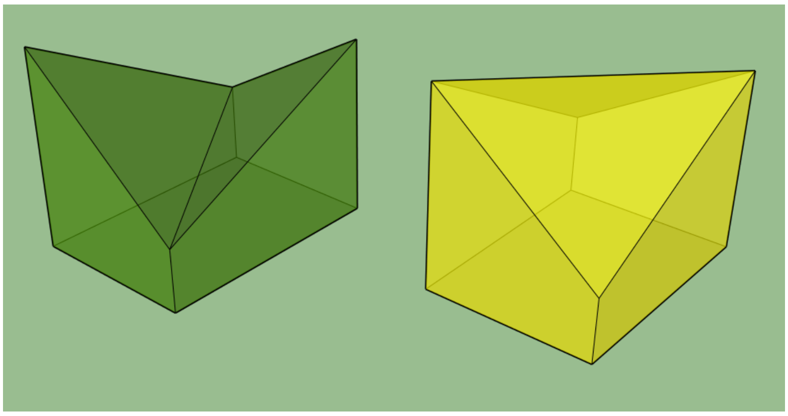


Figure 8. Two possible scenarios of creating a 3D object with a non-planar face using CoordGeom element

To avoid this undefined behaviour, non-planar faces can be split to match what is expected. In general, planar faces on polygon meshes are preferred. Non-planar faces may render incorrectly in the final images or when exported to an interactive visualisation application (Autodesk Maya 2014).

3.1.2 VolumeGeom approach

The VolumeGeom element is the other element for modelling 3D objects in the ePlan Protocol. In this approach, CoordGeom elements are connected to create a VolumeGeom element (Figure 9).

```xml
<Parcels>
 <Parcel>
        <VolumeGeom name="Lot 1">
                <CoordGeom name="FLOOR1">
                        <Line>
                                <Start pntRef="CGPNT-1"/>
                                <End pntRef="CGPNT-2"/>
                        </Line>
                        <Line>
                                <Start pntRef="CGPNT-2"/>
                                <End pntRef="CGPNT-3"/>
                        </Line>
                        <Line>
                                <Start pntRef="CGPNT-3"/>
                                <End pntRef="CGPNT-4"/>
                        </Line>
                        <Line>
                                <Start pntRef="CGPNT-4"/>
                                <End pntRef="CGPNT-1"/>
                        </Line>
                </CoordGeom>
                <CoordGeom name="ROOF"/>
                <CoordGeom name="RIGHT"/>
                <CoordGeom name="LEFT"/>
                <CoordGeom name="FRONT1"/>
                <CoordGeom name="FLOOR2"/>
                <CoordGeom name="FRONT2"/>
                <CoordGeom name="SIDE1"/>
                <CoordGeom name="SIDE2"/>
        </VolumeGeom>
        <VolumeGeom name="Lot 2"/>
        <VolumeGeom name="Lot 3"/>
        <VolumeGeom name="Common Property"/>
        <VolumeGeom name="Easement"/>
 </Parcel>
 ...
</Parcels>
<CgPoints>
 <CgPoint name="CGPNT-1">5814105.597 315084.99 0</CgPoint>
 <CgPoint name="CGPNT-2">5814110.596 315085.552 0</CgPoint>
 ...
</CgPoints>
```

Figure 9. Modelling a 3D object in ePlan using VolumeGeom approach. It shows a single VolumeGeom element has several CoordGeom elements to make a 3D object

In this approach, similar to the CoordGeom approach, faces (CoordGeom) are defined and connected to make 3D objects. Similar to the CoordGeom approach, common faces are recorded twice which causes data redundancy. Figure 11 shows the case study's 3D model generated using the VolumeGeom approach.

3.1.3 Referencing approach

In the Referencing approach, firstly, all faces are defined as parcels. Due to this, common faces are not defined multiple times. Secondly, these defined parcels are referenced to a parent parcel to form a 3D object. In this approach, a face (parcel) can be used multiple times as part of different 3D objects (Figure 10).

```xml
<Parcels>
 <Parcel name="Lot1-1">
        <CoordGeom name="Lot1-1">
                <Line>
                        <Start pntRef="AI"/>
                        <End pntRef="C"/>
                </Line>
                <Line>
                        <Start pntRef="C"/>
                        <End pntRef="E"/>
                </Line>
                <Line>
                        <Start pntRef="E"/>
                        <End pntRef="AD"/>
                </Line>
                <Line>
                        <Start pntRef="AD"/>
                        <End pntRef="AI"/>
                </Line>
        </CoordGeom>
 </Parcel>
 <Parcel name="Lot1-2">
 <Parcel name="Lot1-3">
 <Parcel name="Lot1-4">
 <Parcel name="Lot1-5">
 <Parcel name="Lot1-6">
 <Parcel name="Lot1">
        <Parcels>
                <Parcel name="Face1" pclRef="Lot1-1"/>
                <Parcel name="Face2" pclRef="Lot1-2"/>
                <Parcel name="Face3" pclRef="Lot1-3"/>
                <Parcel name="Face4" pclRef="Lot1-4"/>
                <Parcel name="Face5" pclRef="Lot1-5"/>
                <Parcel name="Face6" pclRef="Lot1-6"/>
        </Parcels>
 </Parcel>
 <Parcel name="Lot 2"/>
 <Parcel name="Lot 3"/>
 <Parcel name="Common Property"/>
 <Parcel name="Easement"/>
</Parcels>
<CgPoints>
 <CgPoint name="AI">5814105.597 315084.99 0</CgPoint>
 <CgPoint name="C">5814110.596 315085.552 0</CgPoint>
 ...
</CgPoints>
```

Figure 10. Modelling a 3D object using the Referencing approach. Each face is defined as a parcel and related faces (parcels) form a 3D parcel.

Table 1 illustrates the results of comparison between 3D modelling approaches in the ePlan protocol discussed above.

Table 1. Comparing the three possible approaches for 3D object modelling in ePlan Protocol.

Approach	Redundancy	Topology
CoordGeom	Redundant faces	Not supported
VolumeGeom	Redundant faces	Not supported
Referencing	No redundancy	Supported

Following Table 1, the advantages of Referencing approach with respect to other approaches are as follows:

- Avoid redundant faces;
- Recognised as one object in other CAD/GIS applications (Soon 2012);
- Supporting topology as it defines topological relationships among 3D objects; and
- When a common boundary between two volumes is composed of more than one face, the surface composed of those faces could be defined as a parcel, with a CoordGeom for each face, and the surface could be shared between 3D objects. This would be more efficient if facetted "curved" surfaces separate 3D objects.

According to the above advantages, the Referencing approach was selected by the eWG as an efficient method for modelling 3D objects in the ePlan Protocol (eWG Minutes, 2014).

Although these three data modelling approaches are different, their output ePlan LandXML files look similar in the visualisation software packages (Figure 11).

Figure 11. A simple building subdivision plan modelled in ePlan

In addition to LandXML elements used in the above modelling approaches, the ePlan Protocol (ICSM 2011) has defined 'Surfaces' and 'Surface' elements for 3D plans. The specification of these elements has not been finalised yet. The first phase of study also confirmed that these elements are useful for defining a surface (e.g. terrain model) and not spatial units in LandXML. Therefore, this may be unnecessary information in the context of the subdivision plan, unless defining a terrain model is required.

3.2 Phase 2: modelling a complex building subdivision plan

In phase 2, a complex building subdivision plan was selected as the case study and modelled in ePlan based on the Referencing approach. The main steps of this phase are shown in Figure 12.

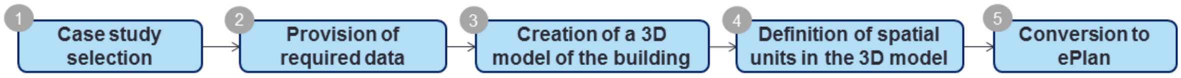


Figure 12. The main steps in the second phase

3.2.1 Case study selection

In this step, a plan with 12 lots and 2 common properties in a 3 storey building in Melbourne was selected. This building subdivision plan is presented in Figure 13. This plan was selected because it has above and below ground interests.

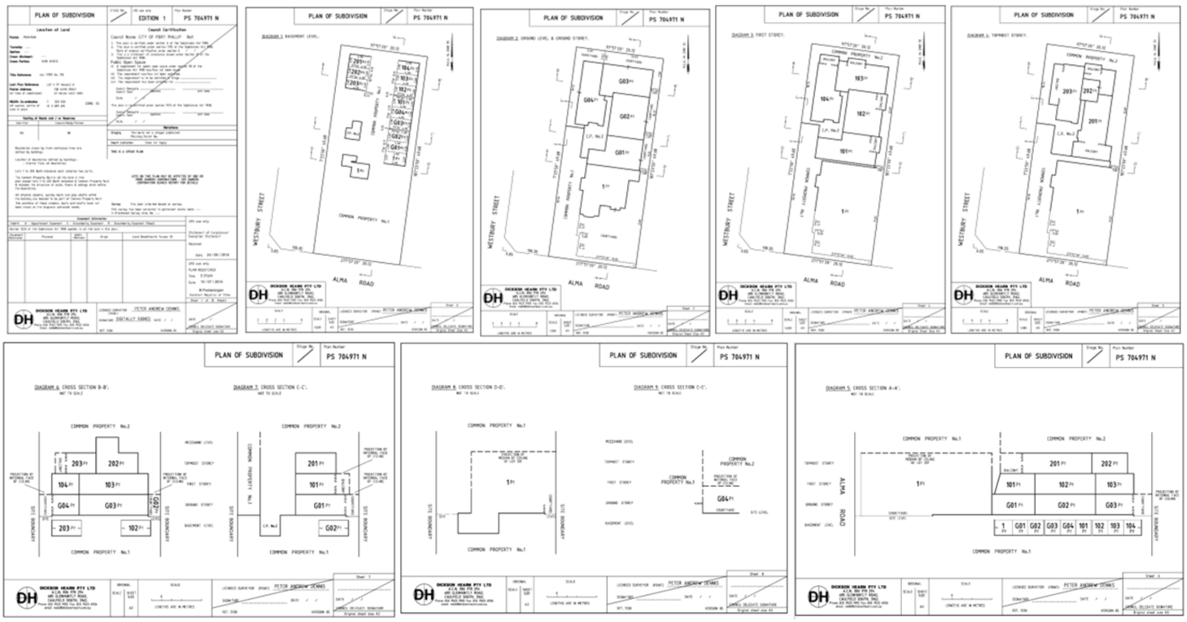


Figure 13. Case study 2, a complex building subdivision plan

3.2.2 Provision of required data

As building subdivision plans do not usually include dimensions (distance, bearing and height) for creating ownership rights, in this step the architectural plans were received from the architect company of this property. Architectural plans include height and distance information required for creating a 3D model.

3.2.3 Creation of a 3D model of the building

Autodesk Revit[4] was used in this step to create a 3D model of the building from the architectural plans. Autodesk Revit is a software application for designing buildings in 3D. There are other similar software applications such as ArchiCAD[5] and AECOsim Building Designer[6]. However, due to the availability of Autodesk Revit for researchers, it was chosen for this study. Figure 14 shows a 3D model created from the architectural plans.

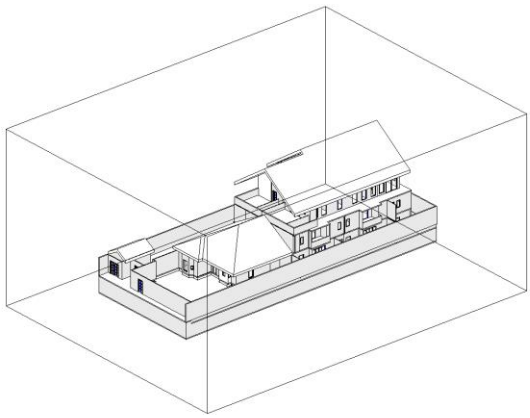


Figure 14. A 3D model created in Autodesk Revit from the architectural plans

3.2.4 Definition of spatial units in the 3D model

Autodesk Revit was used again in this step to define 3D spatial units based on the building subdivision plan. In the Victorian building subdivision plans, four different ownership boundaries can be defined (exterior, interior, median and other) based on Building Subdivision Guidelines (LandVictoria 2012).

In this step, the 'Room' component in Autodesk Revit was used to define spatial units (Shojaei et al. 2014). As this software was not developed for cadastral purposes, there are some limitations when defining spatial units. For instance, unbounded rights above and

[4] www.autodesk.com.au/products/revit-family/overview
[5] www.graphisoft.com.au/archicad/
[6] www.bentley.com/en-AU/Products/AECOsim+Building+Designer/

below the ground surface are difficult to create in Autodesk Revit. In this plan, the Common Properties 1 and 2 are unbounded objects extending below and above the building structure. However, due to the limitation of visualising these unbounded spaces, common properties in this plan are limited to the structure of the building.

The populated 3D model with 3D spatial units is presented in Figure 15. In this figure, the physical structure of the building and associated 3D spatial units are shown.

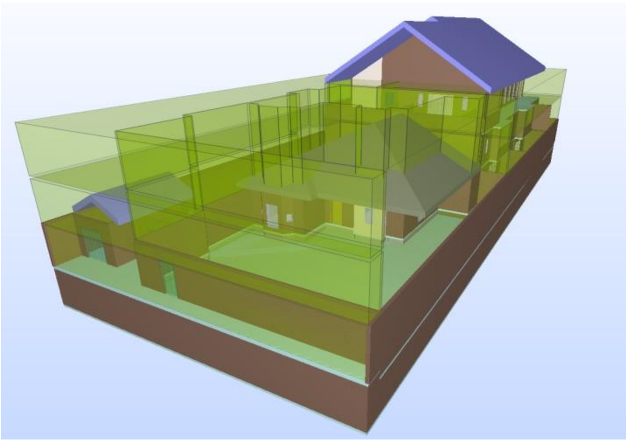


Figure 15. 3D physical structure of the building and associated 3D spatial units

3.2.5 Conversion to ePlan

In order to produce an ePlan from the 3D model, a number of conversions were conducted. These conversions were required to simplify the process of creating an ePlan file from a 3D model. Firstly, the 3D model was converted to IFC,[7] which is a popular format used for Building Information Modelling (BIM). Then, the IFC file was converted to KML[8] using FZK Viewer[9]. KML is an XML based format similar to LandXML in term of geometry modelling. Geometry definition in KML and LandXML formats are based on boundary representation (Kazar et al. 2008, Hegemann et al. 2013).

Then, in this step a converter was written in Java to convert the KML file to LandXML based on the ePlan Protocol. This process resulted in a valid LandXML file based on the referencing approach discussed in Section 3.1.3. The KML file was also visualised in Google Earth (see Figure 16).

[7] Industry Foundation Classes
[8] Keyhole Markup Language
[9] www.iai.fzk.de/www-extern/index.php?id=2315

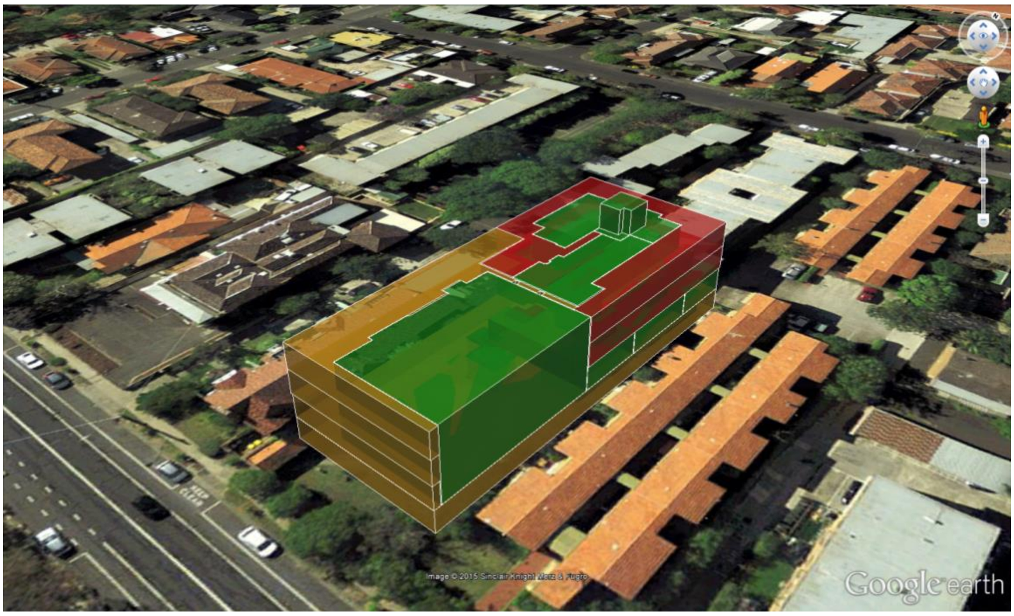


Figure 16. The 3D model in KML format visualising 3D spatial units

Similar to the first phase, the results from this phase confirmed that the ePlan Protocol can support complex building subdivision plans with flat faces. However, when visualising and processing of unbounded objects in 3D, it is not easy to show the boundary of unbounded objects in most current 3D visualisation applications. In subdivision plans, these unbounded 3D spatial units are described by annotation in the plan. For instance the following annotations can be seen in the building subdivision plans: '*Common Property No.1 is all the land in the plan except the lots (and Roads and /or Reserves) and includes the structure of all wall, floor, ceiling, window, door, balustrade (other) which define boundaries except where indicated otherwise*' (LandVictoria 2012).

3.3 Phase 3: modelling curved surfaces in building subdivision plans

In phase 3, modelling of buildings with curved shapes in the ePlan Protocol was investigated. The main steps of this phase are shown in Figure 17.

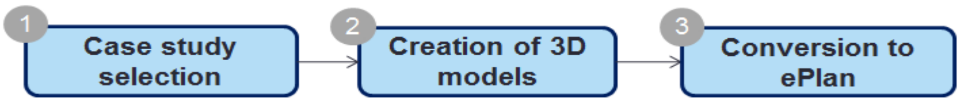


Figure 17. The main steps in the third phase

3.3.1 Case study selection

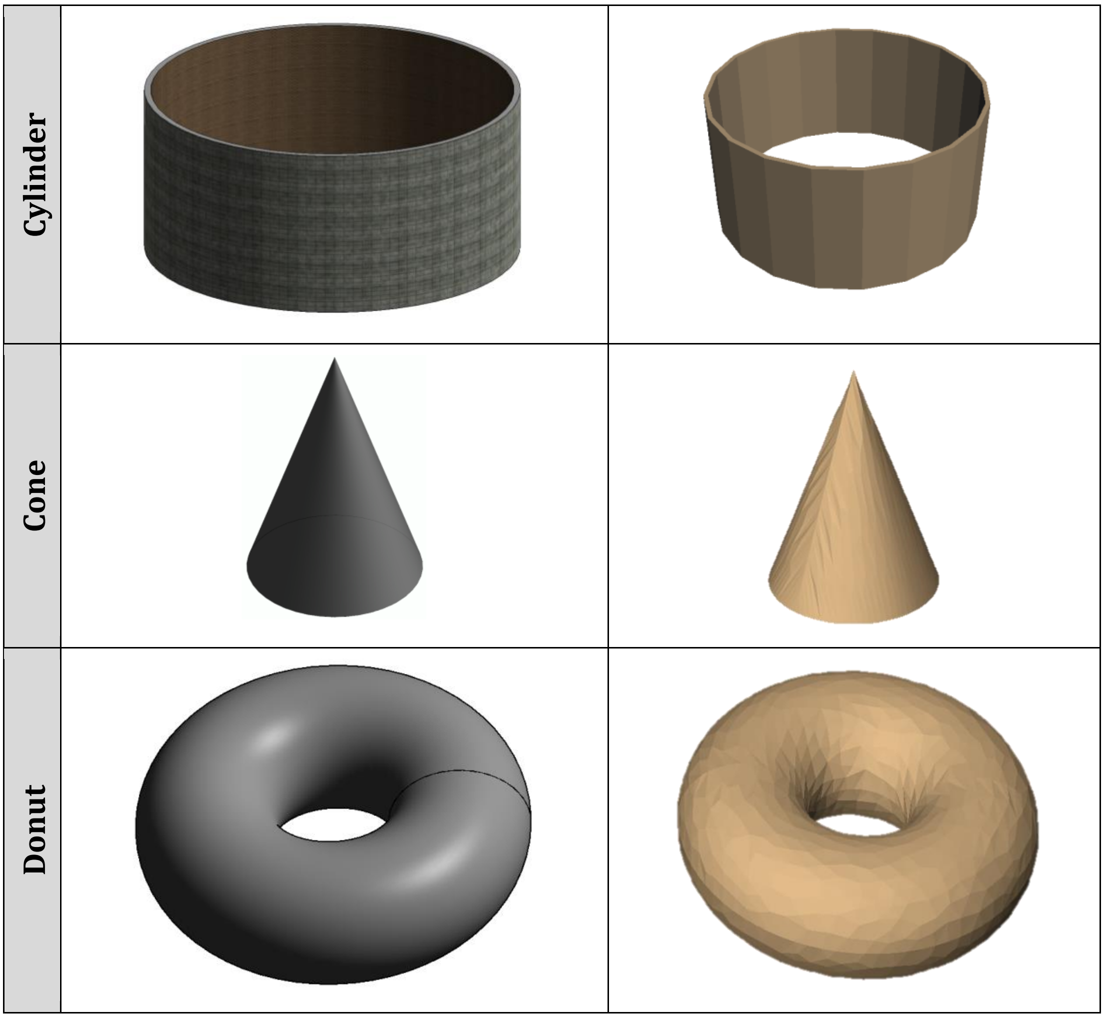
In this step, various curved shapes such as cylinders, cones, donuts, and spheres as well as a building subdivision with curved surfaces were chosen to test the ePlan 3D modelling approach.

3.3.2 Creation of 3D models

The selected objects were modelled in Autodesk Revit and saved in IFC format. As Figure 18 (a) shows, the curved surfaces are very smooth as IFC supports various types of geometry modelling.

3.3.3 Conversion to ePlan

In this step, the 3D models were converted to KML files and visualised in Google Earth. An ePlan converter was also developed to create LandXML files from the KML files. Figure 18 (b) presents the results.



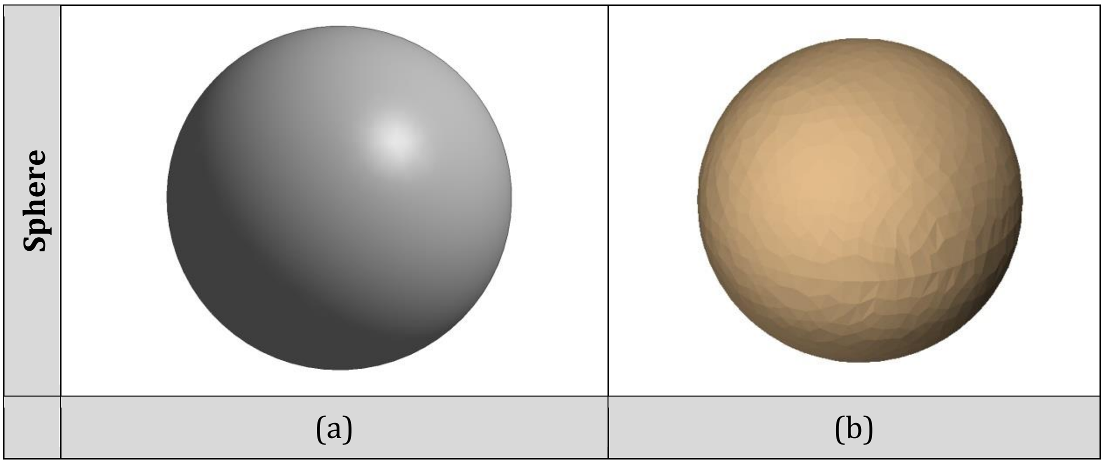


Figure 18. Various curved shapes: Models in Autodesk Revit (a); The corresponding 3D models in KML format (b)

As Figure 18 (a) shows, IFC represents a smooth surface of these objects as IFC has a rich geometrical modelling. However, due to limitations of LandXML and KML in terms of supporting various geometries, the surfaces are modelled by flat faces which are not as smooth as the objects in IFC format. In this case, the objects are generated by small triangles/rectangles which approximate the curved surface of the objects.

In addition to these hypothetical objects, a real building subdivision plan with curved surfaces was chosen as a case study to test the ePlan Protocol 3D modelling capability. Figure 19 shows the selected building subdivision plan.

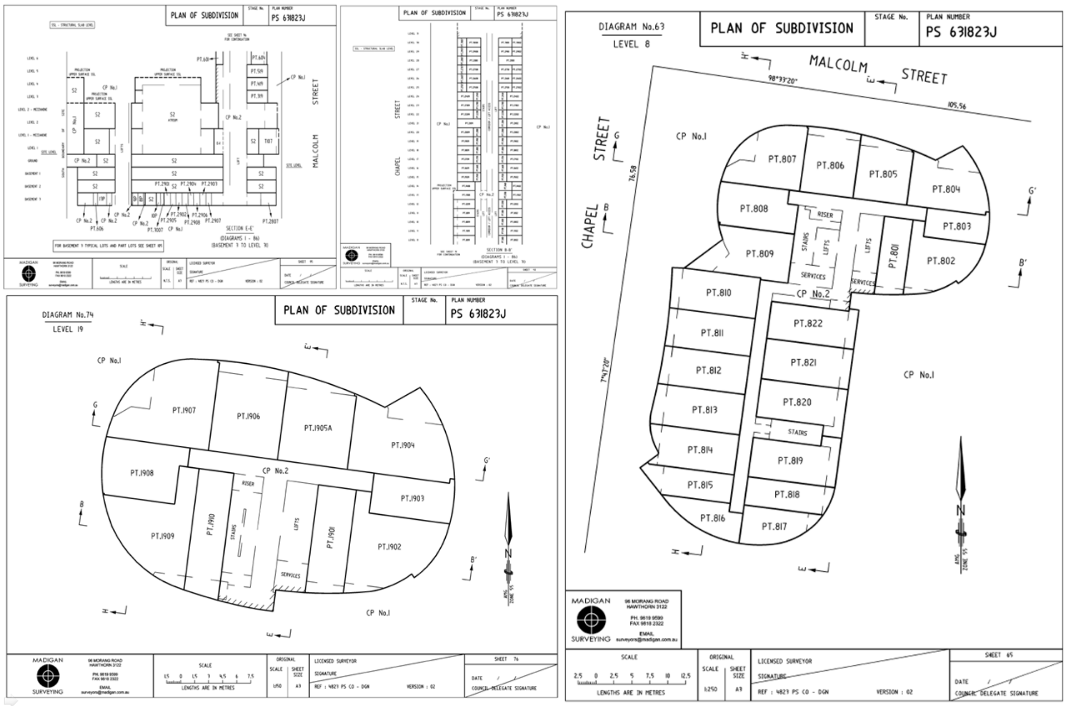
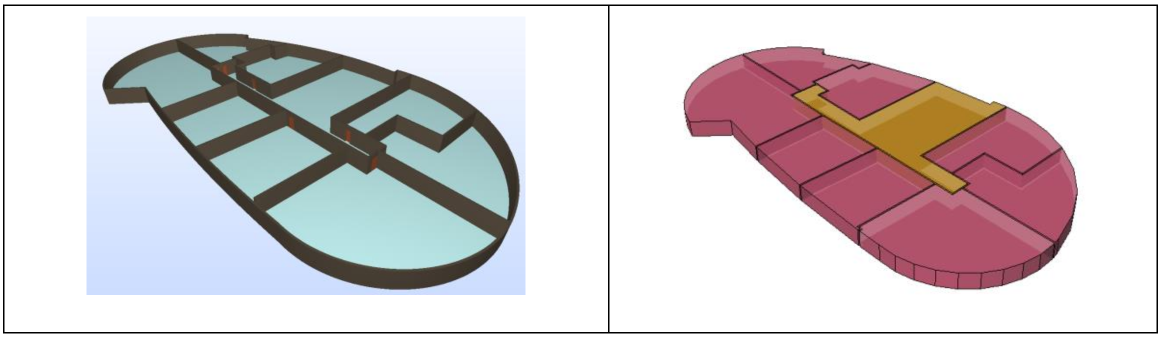


Figure 19. A building subdivision plan with curved surface

This building subdivision plan has more than 500 units on 30 floors. One of the top levels of this building was modelled in Autodesk Revit (Figure 20 (a)) and converted to IFC after defining spatial units. Then, the IFC file was converted to KML and ePlan LandXML. Figure 20 (b) shows the created model in KML. Similar to the other curved faces, the 3D model is approximated by flat faces. The accuracy of modelling would be improved by increasing the number of faces (reducing the size of flat faces). However, the size of files will be increased dramatically.



(a) (b)

Figure 20. One of the top floors of a building modelled in Autodesk Revit (a); This model in KML format (b)

This phase of the investigation confirmed that there is no limitation for modelling curved shapes in ePlan, however 3D objects might be an approximation of the real objects which would have different area and volume.

4 Results and Discussion

As discussed in the previous section, three phases were defined including a number of case studies to investigate the potential of the ePlan Protocol in modelling different scenarios of 3D building subdivisions in Victoria. This investigation confirmed that the ePlan Protocol supports 3D modelling of both simple and complex buildings. However, due to the boundary representation modelling technique being supported by this Protocol, the curved surfaces have to be modelled using flat surfaces. This brings forth an issue with the consistency of area and volume of actual parcels and their corresponding 3D models in ePlan format. The other main technical and non-technical results of this study are discussed below:

- Among the three approaches for modelling 3D objects in ePlan, the ‘Referencing’ approach avoids data redundancy and considers topology for defining 3D objects which enables some 3D analyses such as finding neighbouring parcels. As discussed earlier, the other two approaches record two individual faces for shared boundaries between 3D objects.

- LandXML 1.2, the basis for the ePlan Protocol, only supports boundary representation for modelling 3D objects and therefore approximation is required for modelling of curved surfaces. It is expected that more geometrical modelling approaches would be provided in the future release of LandXML schema (version 2.0). The eWG has been communicating with the LandXML standard maintainer regarding the proposed enhancements.

- Approximating 3D objects with flat faces causes discrepancies in the area and volume calculation. By reducing the size of flat faces, more accurate 3D models can be created. The size of flat faces can be defined based on the required accuracy for 3D model approximation. Also, modelling curved surfaces with flat faces increases the size of the file.

- Autodesk Revit has several limitations in defining 3D spatial units:

    - Narrow spaces cannot be defined. For example, easements with small width cannot be modelled.

    - Defining spaces with different base heights is not feasible in Autodesk Revit. Therefore, spaces are split into rooms with different base heights.

    - Defining unbounded objects such as air space is not easy in Autodesk Revit. Therefore, unbounded rights are annotated in the plan.

    - In buildings, walls and ceilings might belong to common property areas. There are some issues in modelling these spaces in Autodesk Revit. Firstly, Autodesk Revit is not able to define space in the wall thickness. Secondly, defining these spaces increases the complexity of the 3D model and as a result it would be difficult to understand 3D spatial units simply.

  - Defining relationships between 3D spatial units is very important for cadastral analyses. For example to identify which lots have access to Common Property 1, knowing the relationship between lots and common properties is required.

  - Autodesk Revit does not allow defining intersected spaces. However, in cadastre, spatial units can intersect. For instance, easements (such as pipelines) are defined within lots or common properties.

- LISTECH, which already supports 2D ePlan in Australia, has recently released the LISTECH Neo 2015 software package. This package is able to import and export various 3D formats such as KML, IFC, LandXML, DWG and DGN, and was tested as a middleware to import IFC files and export LandXML files.

- Other than the geometry of parcels, ePlan has various elements and attributes such as bearing and distances, administrative areas, instrument and control point information, which are not supported in Autodesk Revit. Therefore, at present those components need to be manually populated in the ePlan file in the final stage of converting IFC files to ePlan.

- Due to the lack of required dimensions in building subdivision plans in Victoria, modelling the existing buildings requires data acquisition or sourcing approaches (Jazayeri, Rajabifard and Kalantari 2014).

The results of this research project showed that the ePlan Protocol can be used by Australian jurisdictions for supporting the lodgement of 3D building subdivisions as long as the 3D data (e.g. IFC file) is available for the cadastral plans submitted to the land authorities and software vendors support the 3D LandXML preparation based on the ePlan Protocol. Supporting building subdivision plans in ePlan provides information about overlapped spatial units which can be used for a variety of other applications such as urban planning, disaster management, and energy consumption modelling. This helps to provide better services to society, particularly in complex urban areas, by developing platforms that can utilise these 3D ePlans.

5 Conclusion and Future Directions

Following the focus of the ICSM Cadastre 2034 Strategy on a 3D digital cadastre for Australia, a research project was conducted in three phases to assess the Australian digital cadastre protocol (ePlan) in terms of supporting 3D building subdivision plans. To achieve the research aim, the geometry modelling approaches supported by the ePlan LandXML Protocol were investigated and 'Referencing' was selected as an efficient approach. Various building subdivision plans and curved shapes were then modelled in ePlan using this approach. As part of this study, the Autodesk Revit was also fully evaluated for cadastral purposes and its main limitations were identified.

The results showed that all the required elements for modelling building subdivisions through the 'Referencing' approach are currently supported by the ePlan Protocol. These elements include 'CgPoint', 'Parcels', 'Parcel' and 'CoordGeom'. However, a few challenges were identified when modelling curved surfaces in ePlan. These surfaces need to be approximated using flat faces. This brings forth an issue with the consistency of area and volume of actual parcels and their corresponding 3D models in ePlan format. This limitation can be considered for future development of LandXML schema to support more advanced 3D geometry modelling methods such as sweeping, extrusion, and constructive solid geometry.

The 3D building models developed in this research project were presented to one of the meetings of the Victorian 3D Working Party, consisting of specialists from academia, councils, surveying industry and land registration tasked with facilitating the development of a 3D digital cadastre for Victoria, and various questions by the surveying industry representatives were raised which need more investigation, including:

- Are 3D models intended to replace or supplement 2D plans?
- Is it intended to integrate with BIM?
- Will it include detailed ownership and/or management details (Owners Corporation rules, leases, licences, boundary definitions, etc.)?
- How will it be used within contracts of sale, marketing, legal documents, etc.?
- How will it deal with ducts, columns, services and other features 'deemed' to be common property?

- How will it deal with information which is currently shown by text or description on a plan rather than by diagram?
- Will we visualise a 2D representation from the 3D model or create a 3D model from a 2D plan, or maybe both?

These questions highlight some important topics that will be considered in future investigations.

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