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3D Modelling of Modern Urban Building Complexes and Sub-units Concept in 3D Cadastre

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Abstract. As space is a fast-reducing commodity in cities, buildings are developed as multipurpose building complexes used for residential, commercial and others. 3D cadastre represents these building complexes as 3D objects with individual building units that have shared surfaces or adjacencies. However, building complexes are often modelled as a single volume. This paper presents the methods to model a 3D building complex with sub-units of mixed uses. A building complex composed of commercial and residential sub-units was modelled based on a building plan and visualized in GIS ready format. The 3D model consists of a set of volumetric units within an exterior shell of the building complex. The sub-units are displayed according to its uses. This can facilitate further spatial analysis that requires adjacency information of sub-units within a mixed-use building complex.

1. Introduction

Visualizing a city in the form of a model is one of the numerous ways to depict a city in forms that can be understood by users with varying levels of understanding. A city model is a representation of urban structures and geographical features that represents the real city [1]. As a result, city modelling can be described as a representation of the actual urban structures that make up a city [2]. Thus, a city model is a 2D or 3D representation of an actual city based on the user's requirements. The availability of 3D data and 3D graphical representation within a 3D city model has allowed users to conduct simulations that allow them to interact with the virtual model in the same way they would in the real world [2]. 3D models can enhance and simplify user interactions when examining the urban system at various resolutions or levels of detail [3]. Furthermore, as compared to 2D representations, 3D models are ideal for user interactions and provide complete representation of spatial information [4]. Furthermore, 3D city models enable the integration of qualitative data and information from other disciplines in order to best reproduce the actual conditions of a city [3]. Then it can be enhanced by including spatial data structure and topology information, allowing it to be utilised for additional function [5,6,7].

It is critical to construct and manage a city model. Without rigorous and organised modelling planning, future applications of the city model will be directly affected. Among the possible applications for this city model are urban environment studies such as determining the impact of urban heat islands [8,9], sensor placement in a city's 3D environment [10], city model integration and Building Information Modeling (BIM) [11], and also conservation of urban heritage buildings [7,12].

Without a well-designed city model, the city model's functionality is limited and cannot be used for further analysis (i.e., [13,14]).

Even still, modelling a city is not a simple and straightforward process. In working towards sustainable development of cities, the management and planning of land parcels need to be given the due attention as space is a fast-reducing commodity. Evidently, housing in cities have long since been developed as vertical units of condominiums, apartments and others. This introduces the third dimension of cadastre where parcels also exist in a vertical dimension. Currently, another trending development is a building complex which comprises of a business or office units in the lower levels and housing units in the higher levels. Therefore, ownership and land use are information which is significant in the management and planning of development. Hence, each unit within a single building complex may have different Rights, Restrictions and Regulations. Different building parts can belong to different owners and be used for different purposes [15]. 3D mapping of multiple properties with different owners in a single building complex are intertwined with the rights, responsibilities and restrictions (RRR) of each property [15]. An example of a building complex which consists of properties with different owners and uses is shown in Figure 1. Therefore, instead of being represented as a 3D solid object, a building complex can be represented as 3D objects segmented by ownership and the respective rights or restrictions (e.g.: residential and commercial). This complete information is crucial to ease understanding of building complexes for decision-makers in planning and zoning for a sustainable development of a city [16].

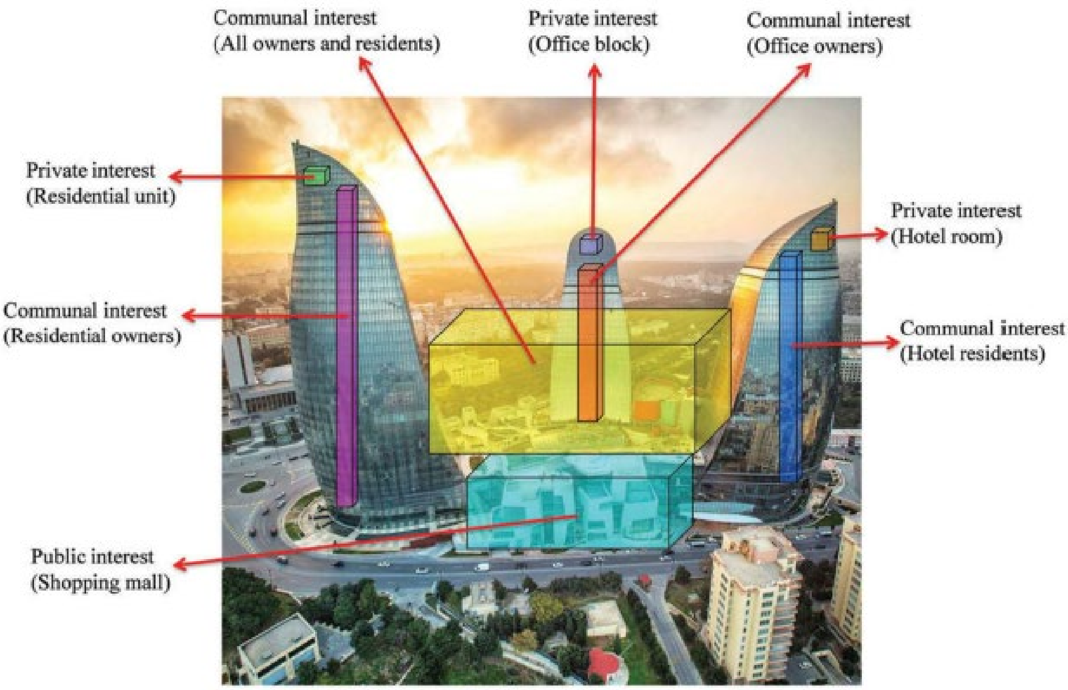

Figure 1. Example of building complex of properties with different owners and uses [15].

This paper presents the methods used to construct a 3D model of a building complex with sub-units of mixed uses such as commercial, residential, accessory and common property. Section 2 of this paper puts forth related works which includes applications of 3D modelling. Next, the methods executed to construct the 3D model are explained in Section 3. The results are presented in Section 4 of this paper. Finally, the paper is concluded in Section 5.

2. Related Works

Current technology that can now collect 3D data has given visualisation a data source that can provide optimum support for the construction of 3D models. 3D modelling has provided a third dimension in representing 3D objects in a space. Parallel to that, 3D cadastre provides a framework for managing cadastral information with an additional vertical component. An accurate 3D model provides the foundation for various applications to carry out more advanced analysis and spatial functions. One of the challenges of high-rise buildings is the ability to accurately represent the complexities of the parcel structures as well as their RRRs. The 3D representation of 3D parcels in a building complex can facilitate efficient management and understanding of ownerships, location and spatial relations between 3D parcels [17]. Applications that require 3D proximity information can also be performed on 3D cadastre such as determining neighbouring parcels and accessibility of parcels [18].

Numerous approaches have been implemented to reconstruct buildings. One of the ways 3D models can be constructed is by extrusion of building footprints. However, in the case of complex or high-rise buildings, the footprints of each floor overlap [19]. An example of overlapping footprints of a complex building is shown in Figure 2. Extrusion of building footprints provides a fast and simple method of constructing 3D models of buildings but at the expense of redundancies, extensive data cleaning and generalization of building facades.

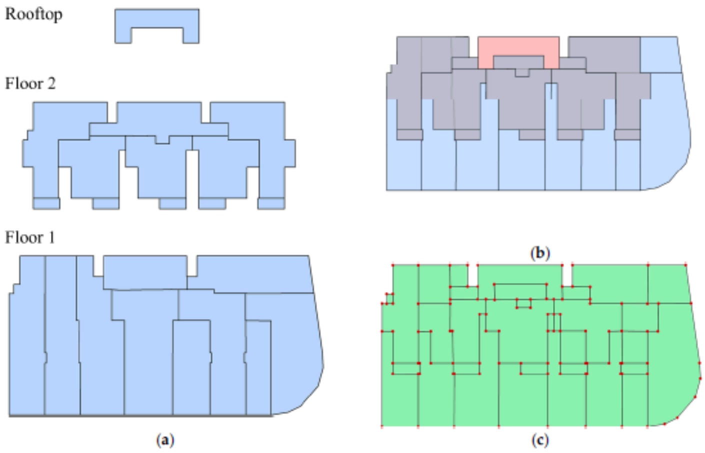

Figure 2. Example of overlapping floor footprints in a complex building [19].

On the other hand, a different approach is needed in situations where data is limited such as underground spaces. Due to its physical conditions, only the interior of the parcel can be surveyed. Therefore, additional methods which require construction data such as ceiling height, floor thickness, height relative to the surface and height relative to the geoid [20]. A 3D model of an underground parcel is illustrated in Figure 3.

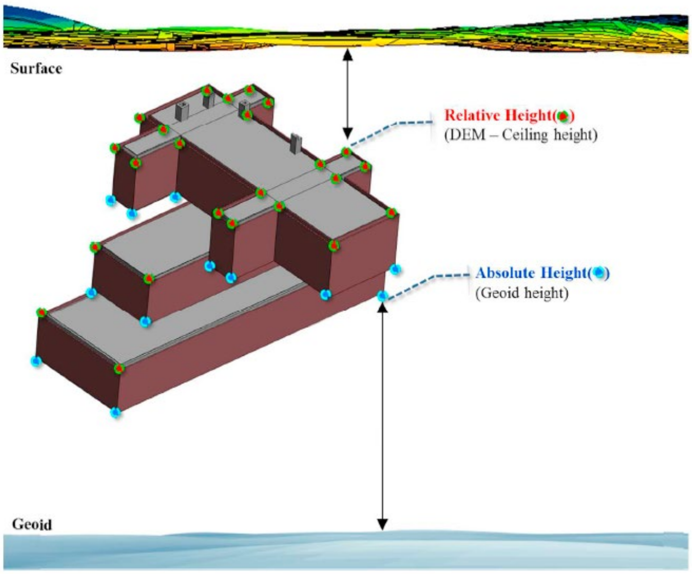

Figure 3. Example of a 3D model for an underground parcel [20].

3. Methodology

The 3D model of the building is constructed to represent the whole building as a unit which consists of sub-units that represents commercial and residential parcels. Currently, the building is still under construction. Therefore, only building plans were available as data. The 3D model is constructed using SketchUp software and visualised in ArcScene. The illustration of the building is shown in Figure 4.

Figure 4. Illustration of building (http://thelouvre.com.my/)

3.1. Data

The data used in this study are AutoCAD drawings of building plans for a high-rise building located in Kajang, Selangor which consists of 37 floors. The sub-units within the building are used for commercial and residential purposes. The building is made up of 2 basement floors designated for public parking, 2 levels for commercial mall units, 4 floors for residential parking, 1 floor for resident amenities, 26 floors for residential units, and 2 floors for utilities. An example of the building plan used is depicted in Figure 5.

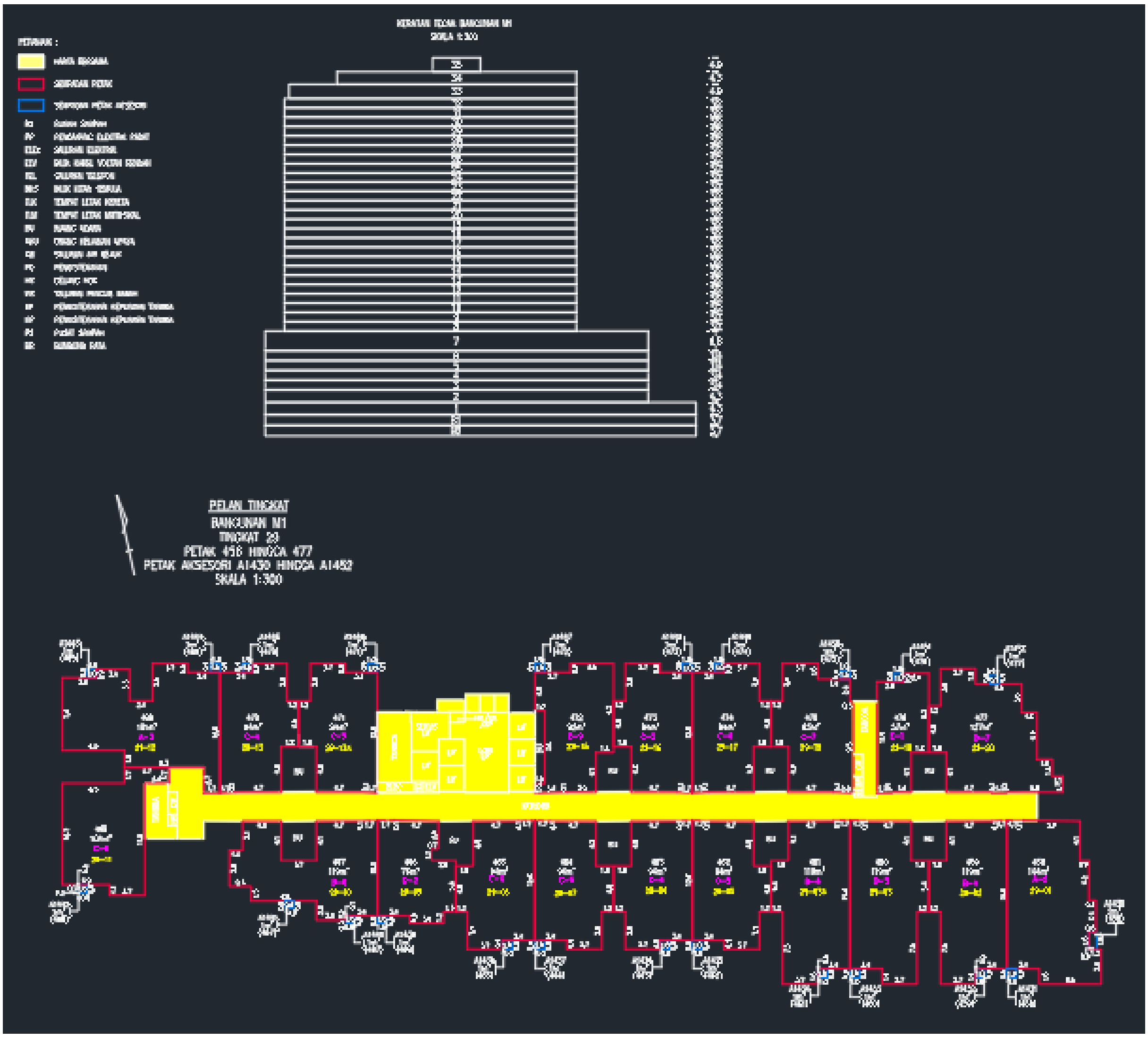

Figure 5. Building plan example for a building.

The building plans describe the dimensions of the units, floor heights, and surrounding spaces such as corridors, elevator shafts, stairs and utility spaces. However, the building plans do not include wall thickness, floor thickness or exterior facades of the building.

3.2. 3D Modelling

The building plans in AutoCAD (.dwg) format were imported into SketchUp as shown in Figure 6. Two layers were created in SketchUp which are “Exterior Wall” and “Interior Wall”.

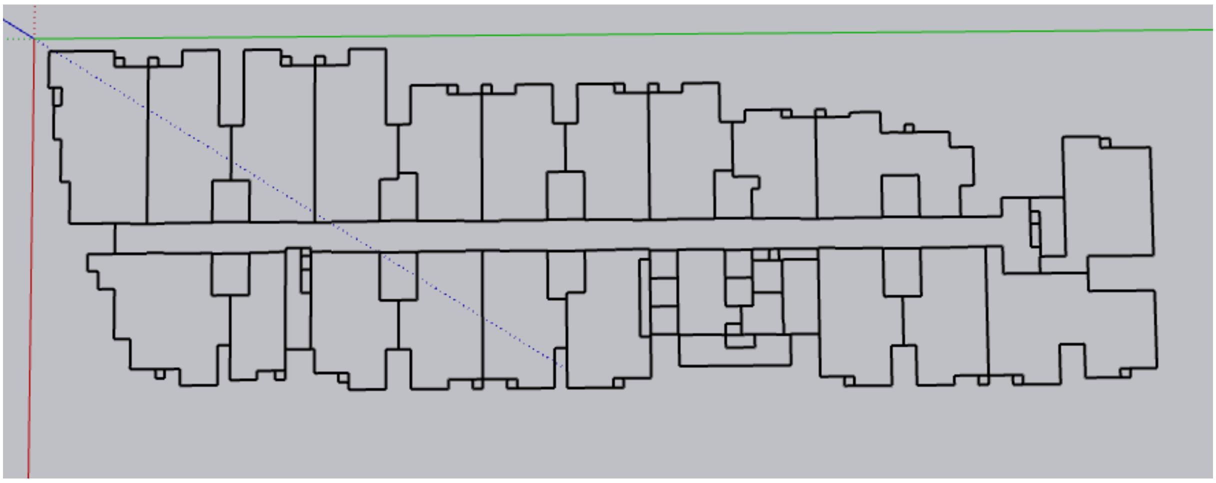

Figure 6. Imported floorplan (.dwg) in SketchUp.

3.2.1. Building Interior

The building sub-units of each floor were drawn in the layer "Interior Wall" as polygons and walls according to floor height defined in the building plan. An example of the interior walls for the building sub-units is shown in Figure 7.

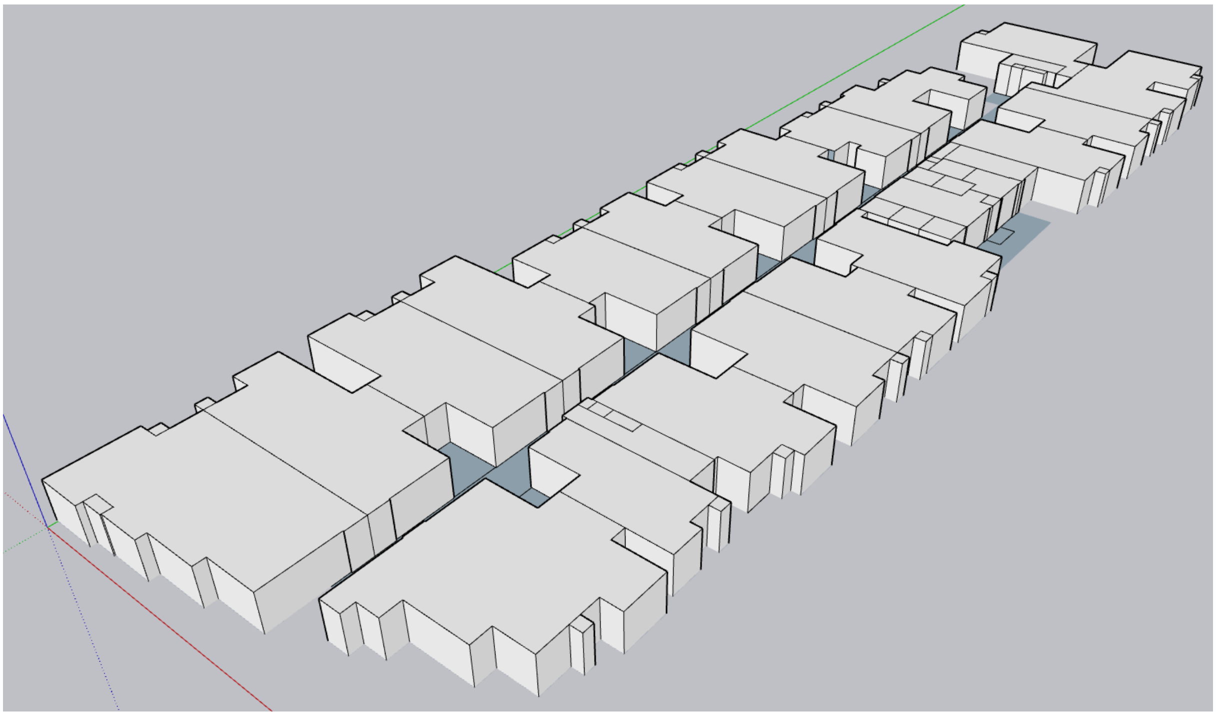

Figure 7. Example of interior walls for building sub-units.

The floor thickness is assumed to be 0.5 meters and the exterior wall line is offset at 0.5 meters from the interior wall line. This assumption was done as no exterior façade information is available from the building plan data. Figure 8 depicts an example of the exterior for a floor from the building.

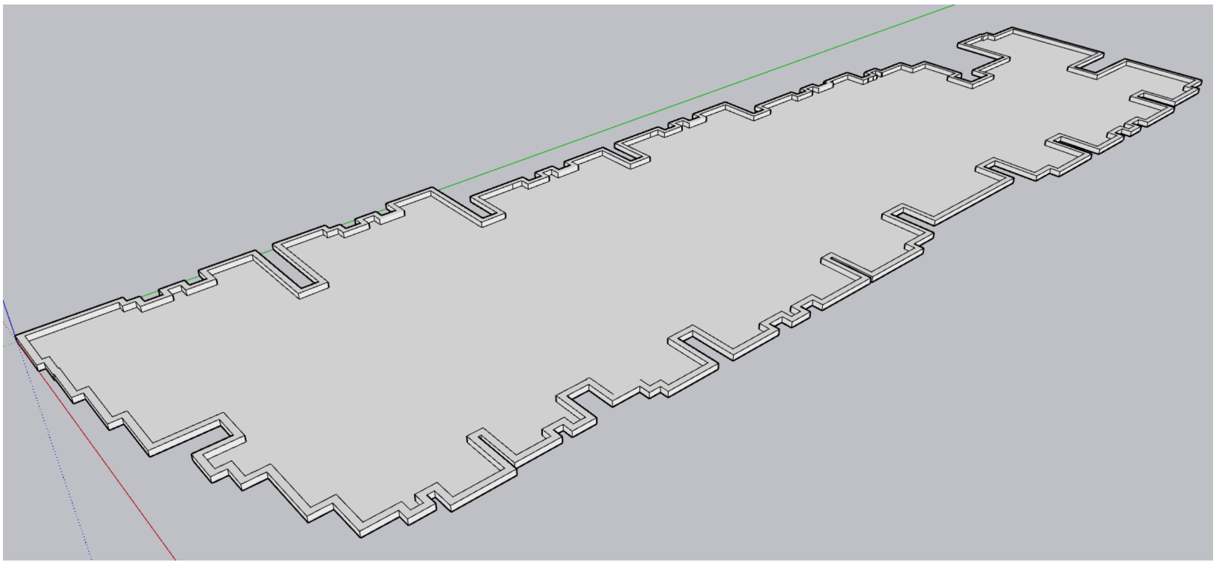

Figure 8. Example of exterior for a floor with thickness of 0.5m and offset at 0.5m distance from interior wall line.

After each floor is drawn, the floors are put together based on shared stair wells and elevator shafts. The floors are then geolocated using the geolocation tool in SketchUp as shown in Figure 9.

Figure 9. Geolocated 3D model of building sub-units.

3.2.2. Building Exterior

The exterior shell of the building is constructed based on the interior floors and a cross-section of the building provided in the building plan as depicted in Figure 10.

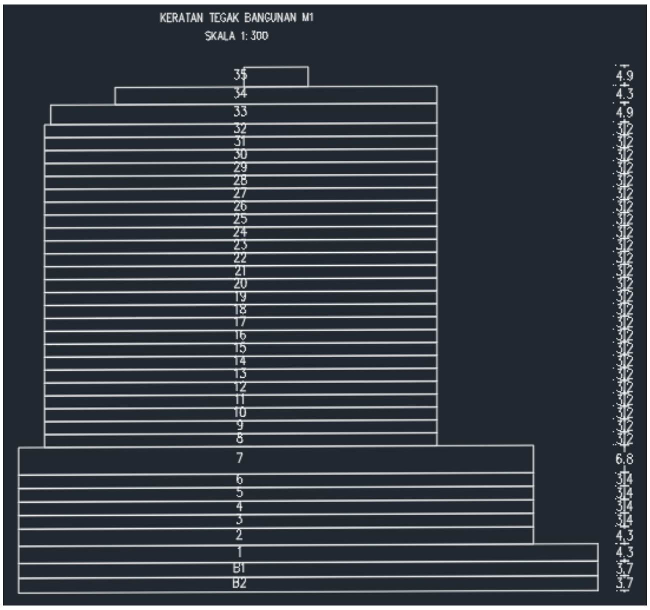

Figure 10. Building cross-section in floorplan.

The exterior shell was drawn floor by floor and merged using the "Intersect Faces with Model" tool in SketchUp as shown in Figure 11.

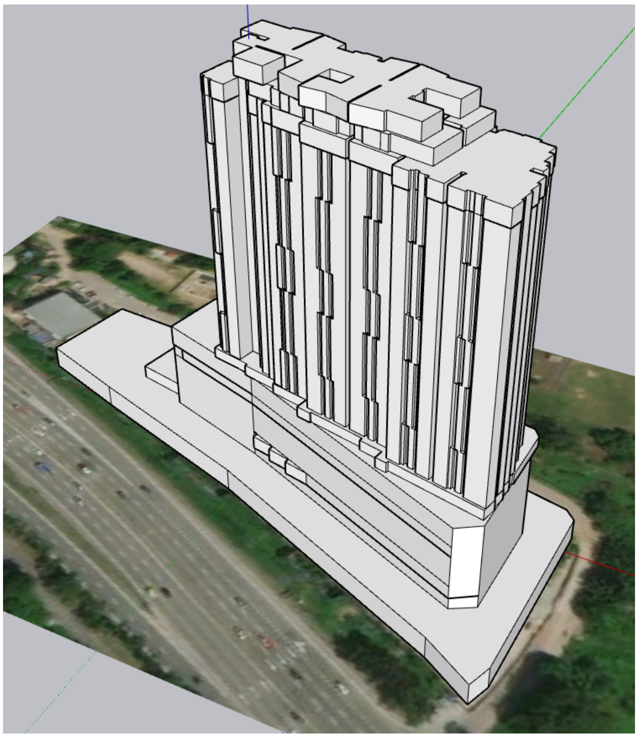

Figure 11. Exterior shell of 3D building.

3.3. *Visualisation*

The 3D models of the building and its sub-units were visualised using ArcScene. The 3D models of the building exterior shell, interior floors and sub-units were exported from SketchUp as 3D collada (.dae) format. The 3D files are imported into ArcScene as "multipatch" geometry. Three layers are constructed in ArcScene which are "Exterior", "Floors", and "Units". The building exterior is imported into the "Exterior" layer while the interior floors are imported into the "Floors" layer. The 3D sub-units of the building are imported into the "Units" layer. Additional attributes such as "Unit Number" and "Use" are input into the attribute table for the features.

4. Results

The resulting 3D model represents the building as a single unit or exterior shell which contains interior floors and sub-units. The 3D model visualised in ArcScene is displayed in Figure 12.

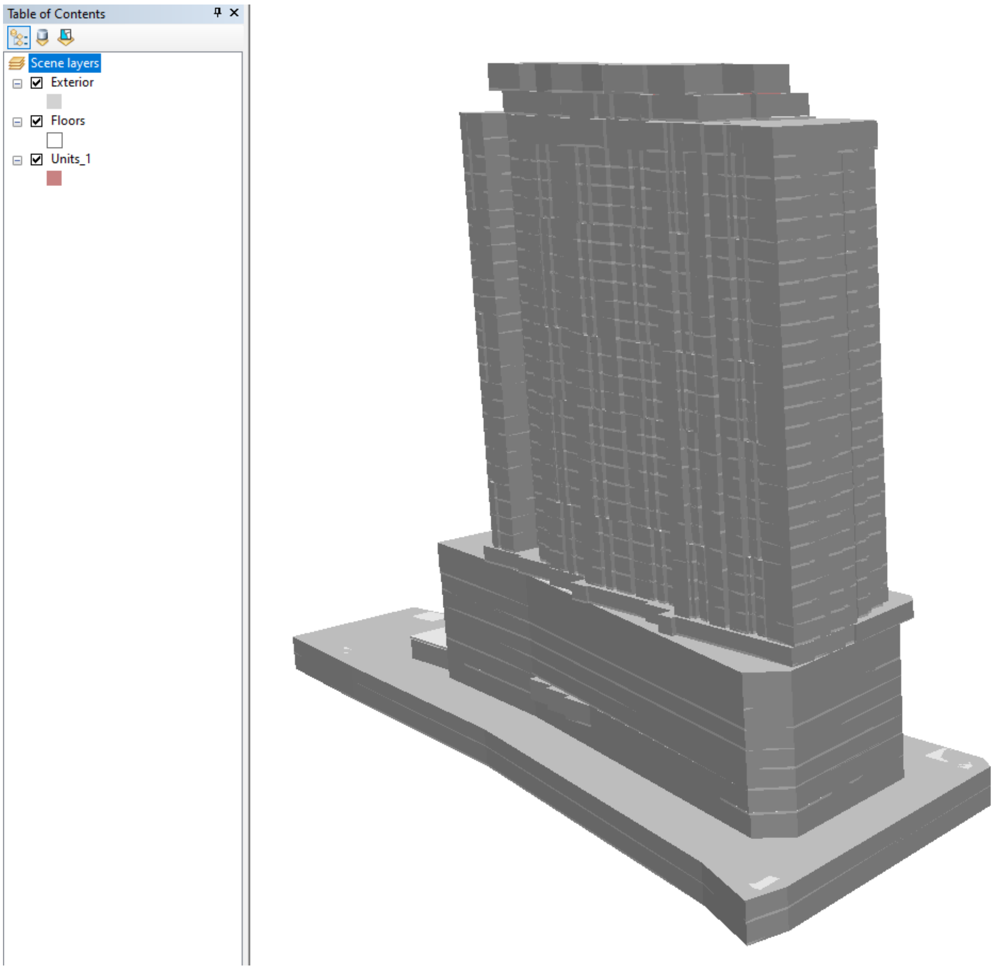

Figure 12. 3D model of building visualised in ArcScene.

The use of each sub-unit was categorised as "Residential", "Commercial", "Common Property" and "Accessory". The attribute table for layer "Units" is shown in Figure 13.

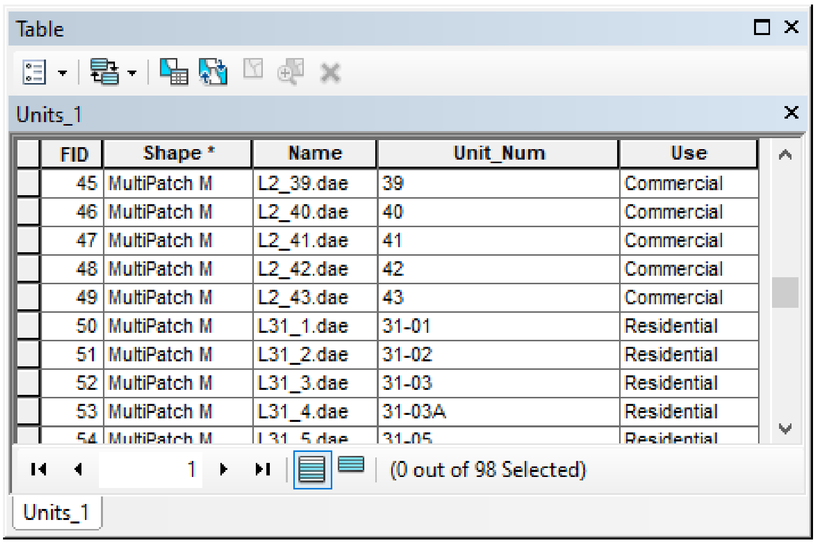
Table
Units_1

FID	Shape *	Name	Unit_Num	Use
45	MultiPatch M	L2_39.dae	39	Commercial
46	MultiPatch M	L2_40.dae	40	Commercial
47	MultiPatch M	L2_41.dae	41	Commercial
48	MultiPatch M	L2_42.dae	42	Commercial
49	MultiPatch M	L2_43.dae	43	Commercial
50	MultiPatch M	L31_1.dae	31-01	Residential
51	MultiPatch M	L31_2.dae	31-02	Residential
52	MultiPatch M	L31_3.dae	31-03	Residential
53	MultiPatch M	L31_4.dae	31-03A	Residential
54	MultiPatch M	L31_5.dae	31-05	Residential

1 (0 out of 98 Selected)
Units_1

Figure 13. Attribute table for layer "Units".

Queries were also performed on the sub-units of the 3D model based on its "Use" or "Unit_Num" using the "Select by Attributes" tool. The results for a query on all sub-units which are commercial sub-units shown in Figure 14.

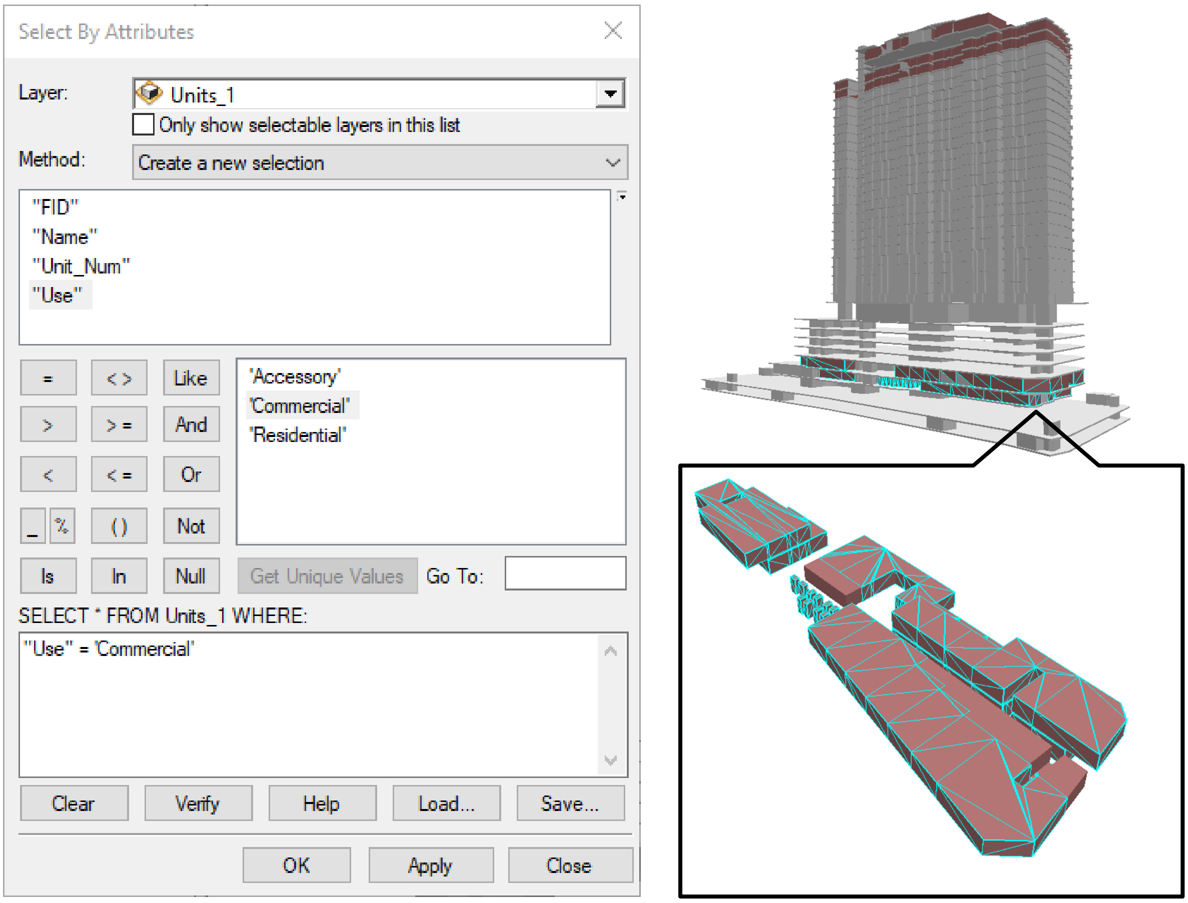

Figure 14. Results of query for commercial sub-units.

Another query was also performed to find a specific sub-unit based on the "Unit Number" using the "Select by Attributes" tool. The results are shown in Figure 15.

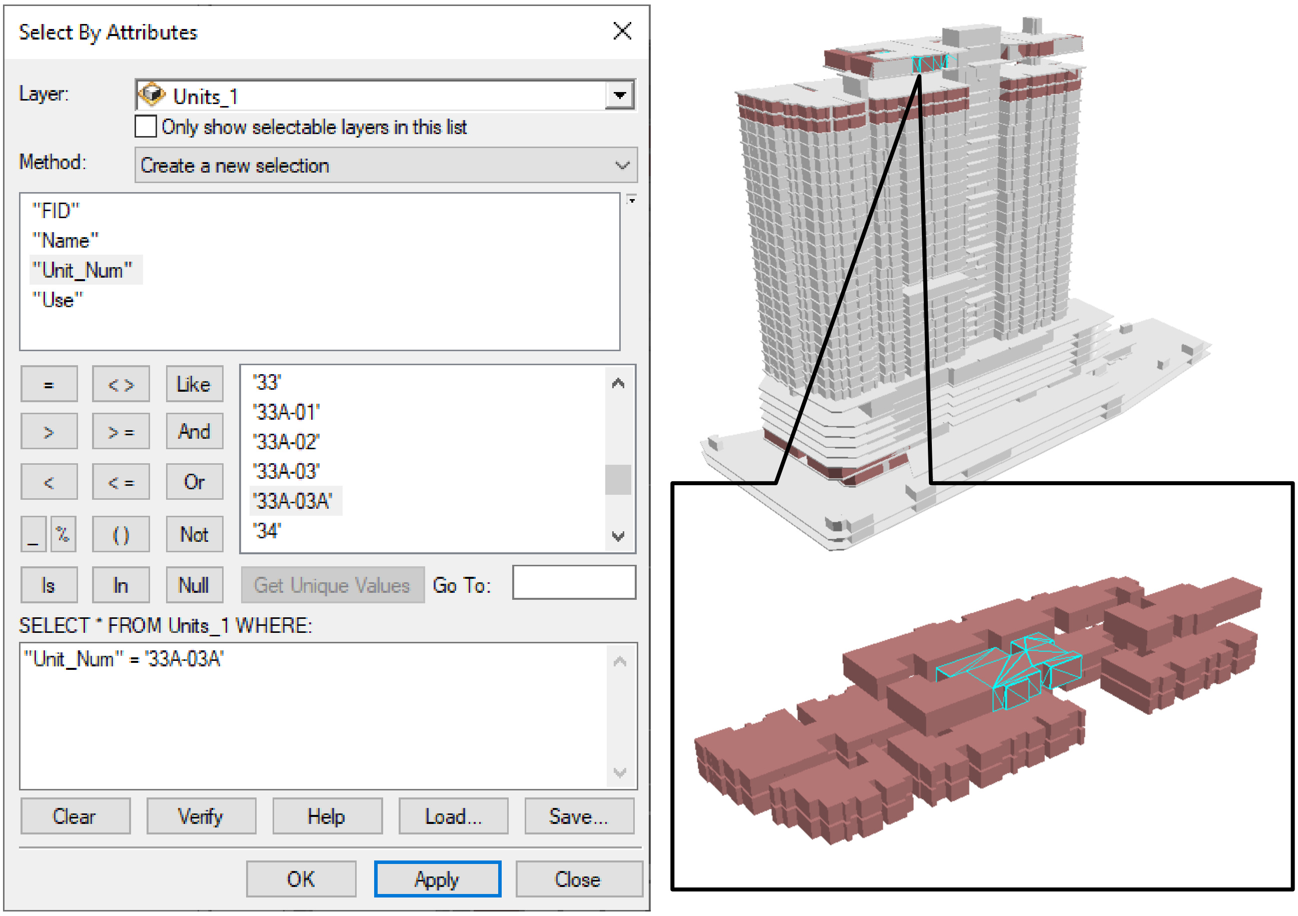

Figure 15. Results of query by unit number.

5. Conclusions

This study presented a methodology for constructing a 3D model of a high-rise building complex for 3D cadastre based on 2D building plan drawings. The high-rise building consisted of 37 floors which included units with mixed uses such as commercial, residential, accessory and common property. The resulting 3D model consisted of a single 3D volume that represented the exterior shell of the building, interior floors and 3D volumes of the sub-units within the building. Additional attributes such as unit number and use were also included. Spatial queries were performed based on the attributes such as commercial use and specific unit number. The visualisation of the 3D model in ArcScene allowed attribute information to be stored together with the 3D geometries. However, the visualisation of individual sub-unit or selected parcel is hindered as it cannot be viewed separate from the rest of the model.

Acknowledgements

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