

Article

Virtual 3D Campus for Universiti Teknologi Malaysia (UTM)

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Abstract: University campuses consists of many buildings within a large area managed by a single organization. Like 3D city modeling, a 3D model of campuses can be utilized to provide a better foundation for planning, navigation and management of buildings. This study approaches 3D modeling of the UTM campus by utilizing data from aerial photos and site observations. The 3D models of buildings were drawn from building footprints in SketchUp and converted to CityGML using FME software. The CityGML models were imported into a geodatabase using 3DCityDB and visualized in Cesium. The resulting 3D model of buildings was in CityGML format level of detail 2, consisting of ground, wall and roof surfaces. The 3D models were positioned with real-world coordinates using the geolocation function in SketchUp. The non-spatial attributes of the 3D models were also stored in a database managed by PostgreSQL. While the methodology demonstrated in this study was found to be able to create LoD2 building models. However, issues of accuracy arose in terms of building details and positioning. Therefore, higher accuracy data, such as point cloud data, should produce higher LoD models and accurate positioning.

Keywords: 3D modeling; city model; CityGML



Citation: Salleh, S.; Ujang, U.; Azri, S. Virtual 3D Campus for Universiti Teknologi Malaysia (UTM). *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 356. <https://doi.org/10.3390/ijgi10060356>

Academic Editors: Wolfgang Kainz and Rudi Stouffs

Received: 29 March 2021
Accepted: 15 May 2021
Published: 22 May 2021

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1. Introduction

In recent years, entire cities are being modeled in three dimensions (3D) to facilitate urban modeling. This has been found to provide a more accurate representation of buildings than 2D visualizations [1]. A 3D city model can be defined as a 3D duplication of urban structures, which can be used to better understand the city [2]. The developments in visualization and data collection technology have brought to light the needs for a city or urban system to be represented in 3D.

Current technologies that can now collect 3D data provide a data source that can provide optimum support for 3D models. The availability of 3D data and 3D graphical visualizations within a 3D city model has allowed users to do simulations that allow them to interact with the virtual model as they interact in the real world [3]. Thompson et al. [4] also found that 3D models can improve and ease user interactions in exploring the urban system in different resolutions or level-of-detail. Therefore, 3D models are better for user interactions and warrant complete representation of spatial information than 2D representations [5]. In addition, 3D city models also allow integrating qualitative data and information from different disciplines to best replicate the actual conditions of a city [4]. This also provides an opportunity for experts from different disciplines to acquire information from the same 3D city model and improve the city. Accurate 3D visualization is crucial as the basis of virtual reality or environment, which underlies any application utilizing 3D models [6].

The simplest presentation of 3D models in visualization is apparent in developments of the virtual environment and augmented reality. Virtual environments that replicate the real world assist users in navigating a new environment by providing a point of view relatable to the user compared to the top view of 2D maps. This being said, virtual

environments can also present 3D data from a top view, which gives users an overview of the area, but users will not be as immersed when experiencing the virtual environment compared to a 3D view of how they would experience it in reality [7]. This is especially useful in urban tourism applications that provide virtual tours of an area to provide familiarity to first-time visitors. A study by Andri, Alkawaz and Sallow [8] developed a mobile augmented reality application of a campus, which includes information of places of interests and events alongside the virtual environment. Replication of landmarks of different levels of realism was also found to affect users' ability to recall routes experienced in the virtual environment [9]. The estimation of distances in a virtual environment by users also affects how the virtual environment is perceived specifically in moving from one area to another [10]. On the other hand, virtual environments can also be utilized in visualizing objects, which are not easily accessible, such as underground infrastructure [11]. This gives users an alternative to understanding inaccessible underground infrastructure as close to reality as possible.

The development of 3D models as a virtual environment can also be extended further to providing a sound foundation for performing analysis, simulations and other applications. For instance, a digital twin of a city with high-level-of-detail will include road networks in addition to buildings, which can be used for visibility analysis, urban heat island detection and air quality simulations [12]. 3D models can also be constructed to document historical structures, such as windmills, as part of cultural heritage conservation [13]. This can also be extended to immersive and interactive virtual reality visualization of pre-historic artifacts [14]. At a building scale, highly detailed 3D models offer support for applications for noise analysis, energy usage and others [15]. Underground infrastructure, such as drainage pipes in addition to 3D models of buildings, can facilitate urban flooding simulations by also including other data, such as elevation, water flow, volume, and others [16]. However, to implement such applications for analysis and simulations, 3D visualization or models cannot remain as merely graphical output. In addition to being a digital twin, 3D models should ensure maintaining spatial and non-spatial attributes as well as geometric, semantic and topological characteristics. Although virtual environments are essentially replicas of the real world, it remains a visualization open to the perception of developers or users and without standards.

As an effort to standardize 3D city modeling, CityGML was established by the Open Geospatial Consortium (OGC) as an international standard and open data model for 3D city modeling [17]. The development of CityGML was targeted to be a shared definition of entities, attributes and relationships within a 3D city model [18]. Similar to the compliance of the CityGML data model to ISO standards, the schema for CityGML also complies with OGC's geography markup language GML3 (GML 3.1.1) [19]. The entities in a 3D city model can also be represented in five different scales or levels of detail (LoD) [17]. LoD0 is generally a 2.5D model of the terrain, which includes building footprints or roof edges. LoD1 represents buildings as blocks with smooth and planar roofs. In LoD2, the roof of a building will be segregated from other thematically different surfaces of the building. LoD3 allows the definition of architectural details of wall and roof structures. LoD4 provides and addition of interior structure for the building, which can include rooms, stairs, doors and other structures. In constructing virtual 3D campus models, using CityGML enables interoperability with future city models, which can be used for different applications.

University campuses can be considered miniature cities, which consist of buildings within a large area. Nonetheless, campuses should also be modeled in 3D to serve as the foundation in moving towards the enablement of smart cities of smart campuses. This study focuses on constructing a 3D campus, which can be extended to meet future applications for campus management using aerial photos and site verifications to produce 3D models adhering to CityGML standards. The CityGML models will be built using feature manipulation engine (FME) software that allows manipulation, conversion and transformation of data. A similar approach was demonstrated for transforming historical buildings into CityGML models from vector Esri Shapefiles obtained from point cloud

data [20]. A study by Beil et al. [12] also utilized FME software to convert multiple sources of data to build CityGML models of detailed street systems and 3Dtile files for 3D web visualization. Another study by Shen et al. [16] also integrated various data sources using FME to produce a comprehensive CityGML file for managing urban flooding. To model campus in 3D, various approaches to modeling buildings can be applied. One of the main differences in modeling approaches depends on the data available at hand. However, due to unavoidable restrictions, only aerial photos and site visits could be carried out in this study.

This paper presents the methods used to construct a virtual 3D Campus for Universiti Teknologi Malaysia (UTM) in the level of detail 2 (LoD2) of CityGML based on aerial photos and site visits and verifications. Section 2 of this paper explains the methodology, which includes the construction of models and data conversion and storage. Section 3 presents the results of the virtual 3D campus and discusses future smart campus applications. Finally, the paper is concluded in Section 4.

2. Methodology

The virtual 3D campus for Universiti Teknologi Malaysia (UTM) was constructed in LoD2 of CityGML. First, the 3D models were created using SketchUp software based on the building footprint and aerial photos. Site visits were also done to acquire a more detailed look at the buildings. Next, the 3D buildings were converted into CityGML files using feature manipulation engine (FME). Finally, the 3D buildings were stored in 3DCityDB as the geodatabase. The overall methodology is described in Figure 1.

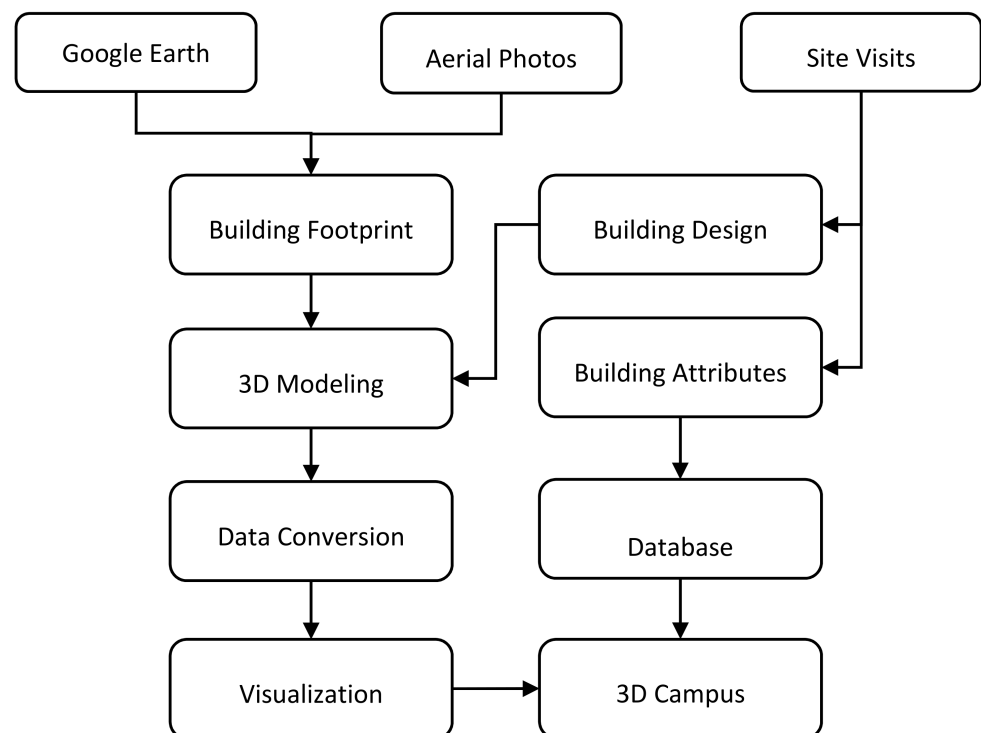


Figure 1. General methodology of virtual 3D campus construction.

2.1. Study Area

The study area situated at coordinates $1^{\circ}33'33''$ N $103^{\circ}38'29''$ E consists of the Universiti Teknologi Malaysia (UTM) Campus, which has an area of 1148 hectares and 381 buildings. Figure 2 illustrates an overview of the study area.



Figure 2. Overview of the study area.

2.2. Construction of 3D Models

Three layers were created in SketchUp, which consists of GroundSurface, WallSurface and RoofSurface. These layers provide the basis of the data conversion from SketchUp to CityGML with the level of detail (LoD) 2. To draw the layers, the building footprint was drawn based on aerial photos and Google Earth. Figure 3 depicts an aerial photo of a building, and Figure 4 illustrates the resulting building footprint.



Figure 3. Example of aerial photo for building footprint.

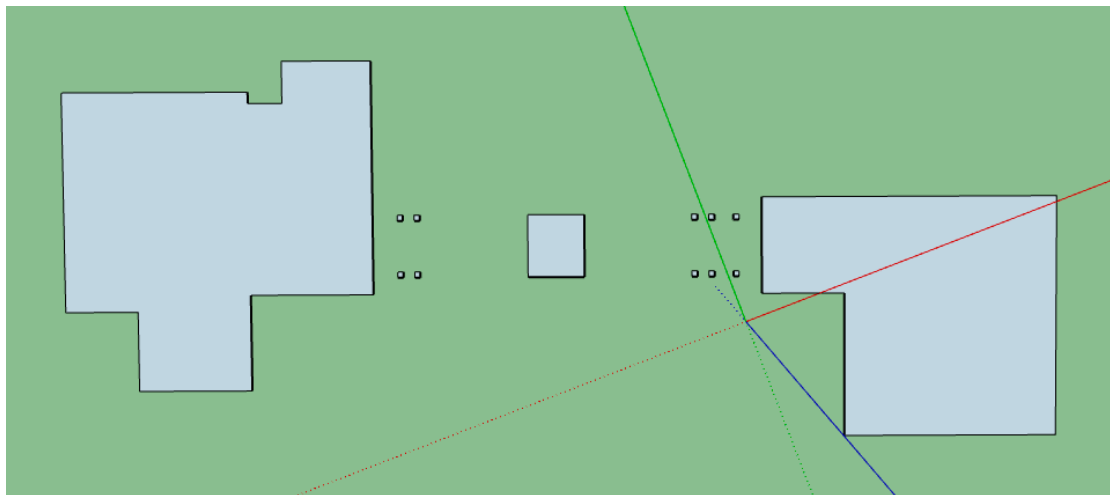


Figure 4. Building footprint based on aerial photos and Google Earth.

Further details, such as roof design, height and observation of buildings, were acquired from site visits. Layers, such as “GroundSurface”, “WallSurface,” and “RoofSurface” were created, and models were drawn in SketchUp. Figure 5 depicts (a) Ground Surface layer, (b) Wall Surface layer and (c) Roof Surface layer. These layers will be used for filtering in the data conversion process.

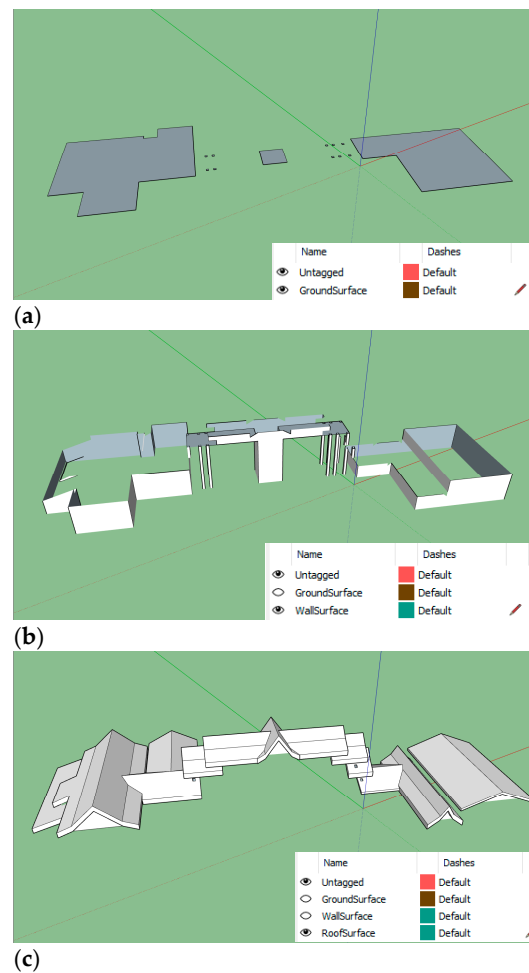


Figure 5. 3D model drawn in SketchUp according to (a) “GroundSurface” layer, (b) “WallSurface” layer and (c) “RoofSurface” layer.

Once constructed, the 3D building was geolocated using the Geolocation function in SketchUp, which provides the coordinates and position of the building. Figure 6 shows a 3D model of a building constructed in SketchUp.

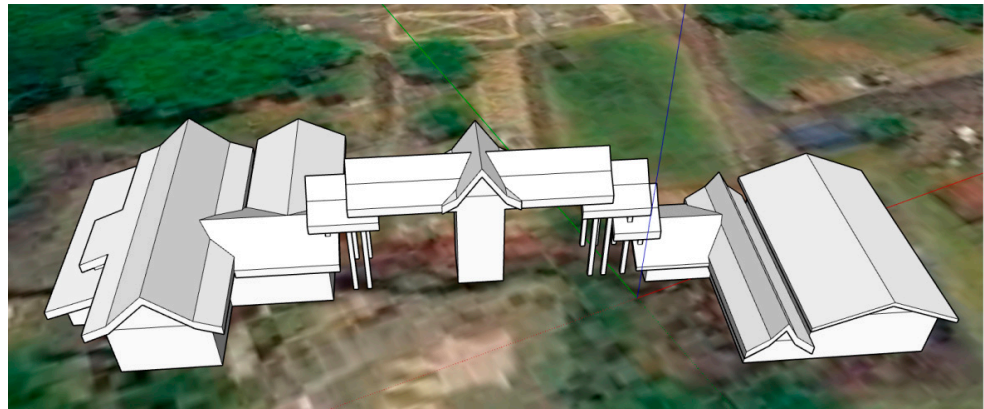


Figure 6. 3D model of building constructed in SketchUp.

2.3. Data Conversion and Storage

To create a 3D model, which adheres to the international standard of city modeling (CityGML), a conversion process was required to convert the 3D models drawn in SketchUp (.skp) to CityGML (.gml) files. This was done using FME software that provides an engine for spatial data conversions using various transformers. The general flow of processes executed in FME is depicted in Figure 7.

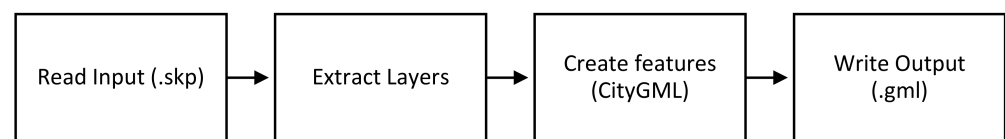


Figure 7. Data conversion processes executed in FME.

The first process done in FME was the layer extraction from SketchUp, which differentiates the surfaces of the 3D building as ground surface, wall surface and roof surface. The transformers used for the extraction process include the deaggregator, geometry property extractor and test filter. The deaggregator transformer was used to break up the source input file (.skp) into the surface layers. The geometry property extractor transformer extracted the surface layers according to the layers defined in the SketchUp file. The ground, wall and roof surfaces were then filtered using the test filter transformer to separate the surface features. The layer extraction process done in FME is depicted in Figure 8.

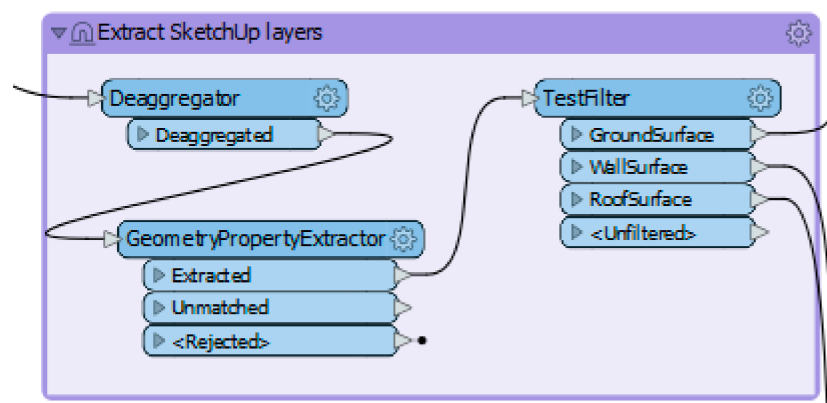


Figure 8. Layer extraction from SketchUp file conducted in FME.

After the layers are extracted, the CityGML features or surfaces are created using transformers, such as attribute renamer, attribute creator, CityGML geometry setter and feature merger. The attribute renamer transformer was used to rename the layer according to CityGML, such as “GroundSurface”. Additional attributes required in CityGML, such as GML ID was created using the attribute creator transformer. Next, the CityGML geometry setter transformer was used to assign the features LOD and feature role. The feature merger transformer was used to combine the geometries and attributes of the features. The CityGML surface creation process for each surface layer is shown in Figure 9. The resulting CityGML file after being converted is displayed in Figure 10.

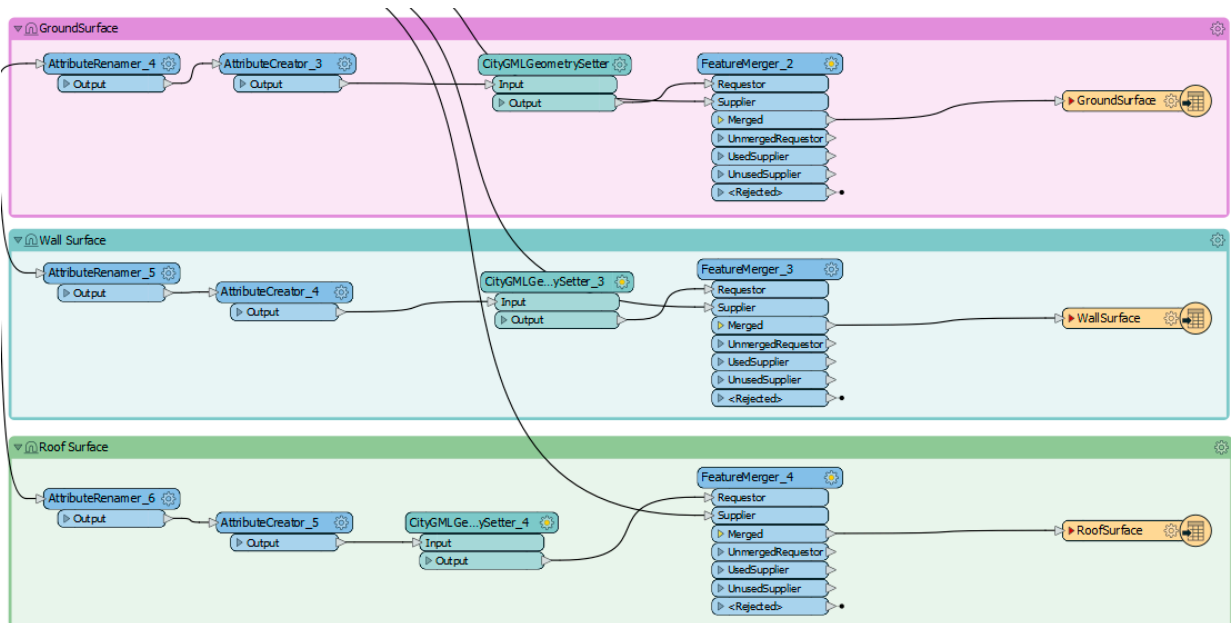


Figure 9. Surface creation for CityGML conducted in FME.

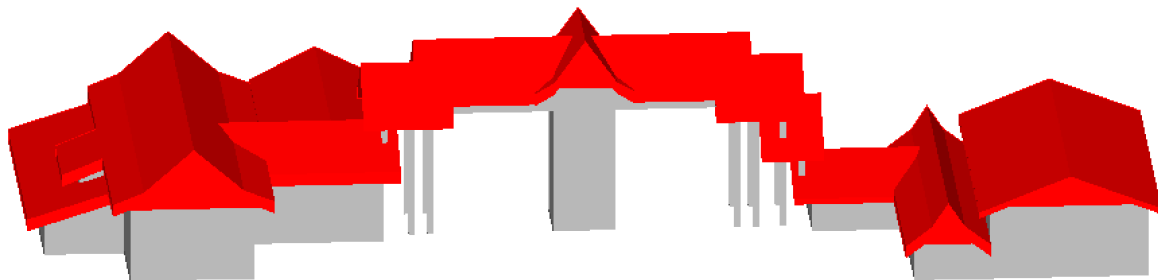


Figure 10. Resulting 3D model of building in CityGML format.

The converted 3D models of buildings were stored in a geodatabase using 3DCityDB, where the attribute data are managed by PostgreSQL. Spatial data were handled by the PostGIS extension. Additional non-spatial attributes of buildings were obtained from site visits and stored in the PostgreSQL database. The attributes are described in Figure 11.

Building
ID_Building CHARACTER(6)
ID_Property CHARACTER(50)
Building Name CHARACTER(100)
Building_Use_Type CHARACTER(100)
No_of_Level INTEGER
Latitude DOUBLE PRECISION
Longitude DOUBLE PRECISION

Figure 11. List of non-spatial attributes stored in a database.

3. Results and Discussions

The imported 3D models stored in 3DCityDB geodatabase are displayed in CityGML format using FZK Viewer, as shown in Figure 12 and visualized as 3D tiles in Cesium as depicted in Figure 13.



Figure 12. Virtual 3D of Universiti Teknologi Malaysia campus with 381 buildings as displayed using FZK Viewer.



Figure 13. Virtual 3D campus of Universiti Teknologi Malaysia as displayed in Cesium.

The first phase of this study consisted of 3D modeling based on aerial photos and site visits. The building footprint was generated from aerial photos, while the wall and roof surfaces were drawn based on on-site visit observations. Therefore, the resulting 3D building models for 381 UTM buildings were in LoD2, including ground, wall and roof surfaces. Figure 14 illustrates an example of building details that were generalized in producing the LoD2 buildings. A higher LoD could not be achieved with the data at hand. More accurate data are required to achieve a higher scale of 3D models, such as point cloud data.

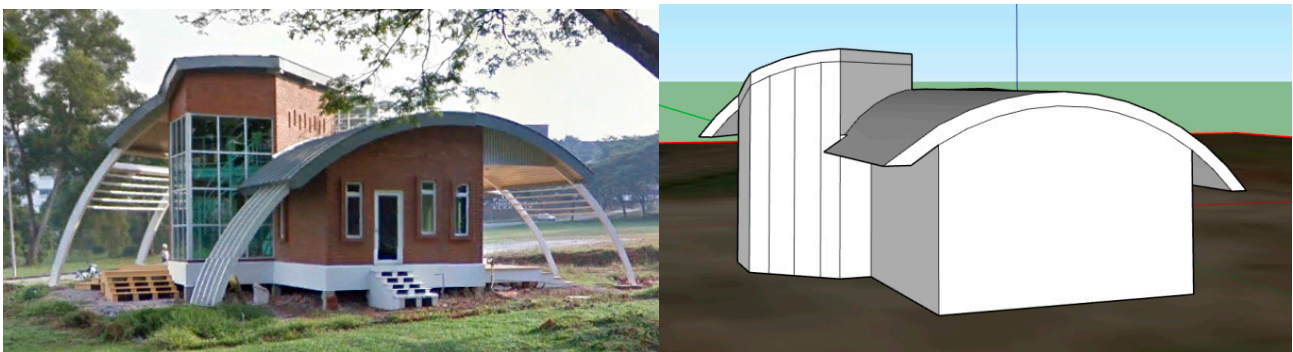


Figure 14. Example of real-world building and generalized LoD2 building.

The modeling phase also included the positioning of the 3D models with real-world coordinates. The geolocation function in SketchUp was used to position the 3D models. However, some 3D models were inaccurately positioned. This is due to the nature of the geolocation function, which relies on manually placing the building on the imported satellite image. An example of the inaccurate placing of the 3D models is depicted in

Figure 15. However, this error could be avoided by utilizing geopositioned data, such as point cloud data, where each point is registered with X, Y and Z coordinates.

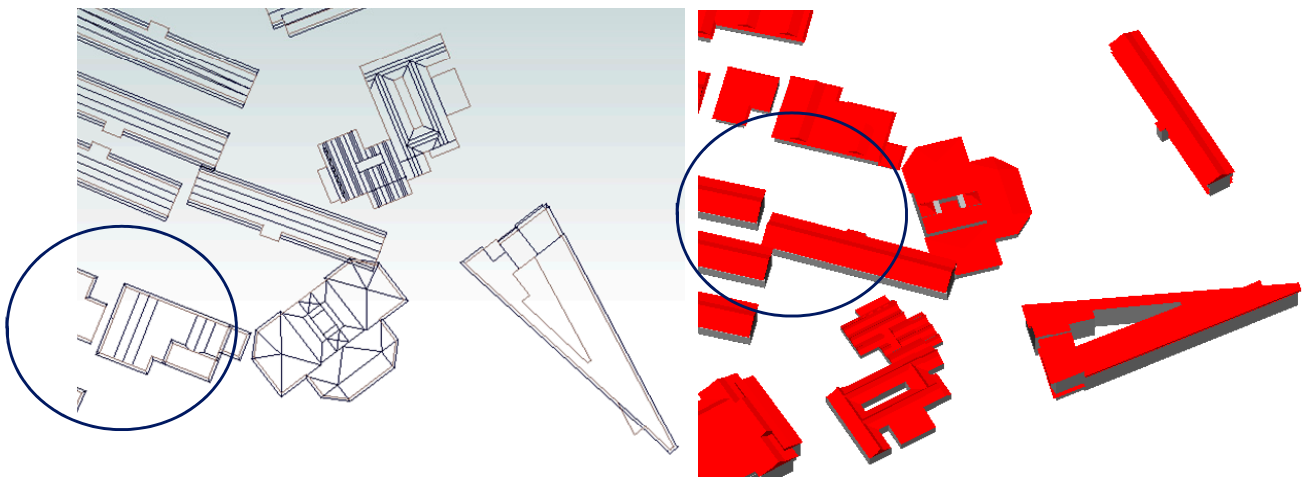


Figure 15. Example of inaccurate positioning of buildings in 2D and 3D.

Digital twins or smart cities will happen in the future. Therefore, constructing a 3D city model like this virtual 3D campus is necessary as it will be the base map to the digital twin or smart city Development. This virtual 3D campus base needs to be developed prudently so that applications built based on 3D city models later in the future can operate properly.

The foundation for smart cities relies on developing 3D models to ensure accurate output of specific applications. An automated approach for constructing 3D models can be developed as a system module, which supports an energy usage application where 3D models are constructed based on 2D building footprints and building height [21]. In high-rise buildings, 3D models were also constructed based on building footprints and floor-to-floor height to determine spaces for vertical urban farming [22]. Another open approach includes using building footprint data from OpenStreetMap and a single photo to accurately determine building height to construct 3D models [23]. A separate open-source software can also be used to automatically construct 3D models based on point cloud data and building height, such as 3dfier [24]. A machine learning approach can also be implemented by integrating point cloud data and other data sources, such as building footprints to generate accurate 3D models [25]. Generation of 3D models with both geometric and texture properties from point cloud data complemented by photogrammetry techniques was found to provide a precise representation of historical cities for tourism, historical documentation or cultural heritage preservation [26].

To develop the 3D models as accurate representations of the real world, utmost importance lies in the data collected as input for the 3D models. Point cloud data are known to be one of the highest accuracy data for generating 3D models. However, point cloud data can be costly and requires extensive processing. Another data source for 3D modeling is UAV data, which can be processed using photogrammetry methods and sewn together to produce 3D models. This method should adhere to the photogrammetry overlap principle of photos to obtain an accurate 3D model. Therefore, the data collection of UAV data are often time-consuming and reliant on weather conditions. This study attempted to appropriate the data at hand, which consisted of aerial photos and site visits to construct 3D models of the campus. The methods of manually constructing and converting the 3D models resulted in a good representation of the buildings, but with estimated height and low accuracy in the placement of the 3D models.

As suggested in this research, this virtual 3D campus is developed based on a 3D city modeling development approach that follows international standards (CityGML and ISO TC211). Therefore, applications developed based on the virtual 3D campus can subsequently be done easily. Examples of applications that can be used are; knowing the

appropriate sensor placement around the campus (both 2D and 3D) [27–29], finding out the proper hall for academic activities that require good ventilation space and high ceilings to enter machinery equipment [30], systematic energy management by looking at the location of spaces of offices that use relatively high electricity, but the low number of users [31], and selecting appropriate new facilities to accommodate students or staff on campus, who need to undergo the process of quarantine due to pandemic [32].

All this can facilitate the university in managing the administration of the university in the future. It will be more efficient, and the data will be faster to acquire before any decisions are made. The research conducted in this paper is the initial steps to build the foundation of a smart campus to be utilized by users (students and staff) in the future.

4. Conclusions

The study presented a methodology for generating 3D models of buildings in LoD2 for a virtual 3D campus based on aerial photos and Google Earth images. The 3D building models were created in CityGML and visualized in Cesium as 3D tiles. However, an issue of accuracy in the location of some of the 3D models was found to occur. This is due to the 3D model creation based on the building footprint and Geolocation function in SketchUp. This issue could be resolved by manually correcting the location in Cesium. Nonetheless, this issue could be avoided by using more accurate data, such as point cloud data. In addition, higher LoD of the 3D buildings could also be achieved with higher quality data.

Author Contributions: Conceptualization, Uznir Ujang and Suhaibah Azri; Methodology, Uznir Ujang, Suhaibah Azri and Syahiirah Salleh; Validation, Uznir Ujang, Syahiirah Salleh and Suhaibah Azri; Formal Analysis, Syahiirah Salleh; Investigation, Uznir Ujang and Syahiirah Salleh; Writing-Original Draft Preparation, Syahiirah Salleh and Uznir Ujang; Writing-Review & Editing, Suhaibah Azri and Uznir Ujang; 3D Visualization, Syahiirah Salleh and Uznir Ujang; Supervision, Uznir Ujang and Suhaibah Azri; Model Optimization, Syahiirah Salleh. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universiti Teknologi Malaysia (UTM) Research University Grant, Vot Q.J130000.2652.15J95 entitled “Universiti Teknologi Malaysia (UTM) 3D City Campus”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: We would like to acknowledge the 3D GIS Research Lab internship students, Haziqah Abdul Hadi, Noridayu Kosni and Muhammad Tahfiz, who assisted in this study.

Conflicts of Interest: The authors declare no conflict of interest.

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