Three Dimensional Visualisation Of Port Dickson Polytechnic Campus In Cityengine Web Viewer

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Abstract

Development of modern technology and its ability to store, process and supply of digital data has led to a demand for three dimensional (3D) modeling of virtual campus has increased dramatically. Of late, many educational institutes have developed their own campus geodatabase in 3D environment. In this study, the emphasis is given on the development of the 3D building model campus using close range photogrammetry (CRP) approach due to high cost of data acquisition techniques using airbone laser scanning, terrestrial laser scanning techniques and availability of data. Thus, the CPR technique has been selected due to low cost method for data acquisition through capturing the selected buildings photographs using digital camera. Six buildings with different architectural designs and geometries in Port Dickson Polytechnic campus have been chosen as prototype which are modelled using CRP approach. The photographs of buildings are then processed using PhotoModeler software to produce the 3D buildings models in the level of detail (LoD)2. The buildings models are textured with the real photographs taken from the field while the roof of the buildings are edited using the SketchUp software. The building models are also georeferenced to the real world coordinate system based on the geocentric Rectified Skew Orthomorphic (RSO) coordinate system. Due to the lack of buildings information access on the web in 3D, CityEngine Web Viewer is used for 3D visualisation of the buildings models and supported features are also be added to create a realistic model of 3D virtual campus. Through the viewer, the users are able to navigate the 3D buildings models, zooming and performing the spatial query to extract the information of the buildings. The accuracy of 3D buildings models are compared, evaluated and determined based on the visual analyses and quantitative analyses with the actual buildings on the ground. The root means square error (RMSE) is assessed to determine the accuracy achieved by the 3D buildings models for quantitative analyses. The lower the value of RMSE is the higher the accuracy of the models. The study shows that the accuracies of the 3D building model can be achieved below 1.5 using CRP technique. At the end of the study, the 3D buildings models can be visualised in the LoD2 on web through CityEngine Web Viewer.

1. Background of Study

Development in 3D virtual campus has been mushrooming rapidly in modern digital era. Across regions and continents, many educational institutes, universities have developed their own 3D virtual campus for difference purposes, techniques and methods. The success in the implementation the 3D virtual campus around the world has encouraged the study to expand on the development 3D virtual campus in Malaysia.

There are many methods and technologies that can be used to obtain the 3D points. The 3D points consists of local coordinate information system (x,y) and height information (z) can be attained using total stations, global positioning system (GPS), close range photogrammetry, aerial photogrammetry, remote sensing and laser scanning technology (Ahmad & Rabiu, 2011). There are some advantages and limitations of each methods (Singh, Jain, & Mandla, 2013). In development of 3D modelling, the selection on the technique to be used need to be considered which are depending on the availability of the data sources, the level of detail (LoD), accuracy, quality, cost and time. Data acquisition using aerial images and airborne laser scanning can be used to reconstruct the roof and the building geometry, however, it is not possible to obtain the building facades due to step observation angle (Brenner, 1999) and also depends on the skill of the pilot. Besides, airborne laser scanning and terrestrial laser scanning are very costly and not many organizations can afford to buy it due to limited budget (Singh, Jain, & Mandla, 2014). Another method to reconstruct the 3D buildings model is using manual method. In this method the geometries of the buildings are measured manually on the ground and created the model one by one using CAD or 3D modelling software such as 3D Studio Max and Maya. Details structures such as windows and doors are manually created using 3D modelling software. However manually reconstruct the 3D building model is time consuming and not suitable for larger area. Besides, the CAD digital data can be used to create the model and it depends on the availability of the resources.

There are also a demand for on-line mapping services such as Microsoft Virtual Earth and Google Earth. Obviously, the most important elements in modelling are the buildings (Armenakis & Sohn, 2009). However these online mapping have some limitations. Presentation and 3D visualisation on the web based platform require linked between spatial and non-spatial attributes data. However, current implementation has limitation on retrieving the spatial and attributes information especially when visualising the 3D model on web mapping platforms. Due to this, CityEngine Web Viewer is selected for 3D visualisation of the model and to evaluate the potential and effectiveness the CityEngine Web Viewer in

performing the query process for retrieval information of the 3D buildings models.

After taken into considerations in several factors such as the restricted budget, availability of the data and the cost involve in the development the 3D model, the close range photogrammetry (CRP) technique is chosen as the best option plus it is economical method in data acquisition towards achieving the study aim. Besides, CRP technique is able to provide high LoD of 3D building model. Although the airborne laser scanning and terrestrial laser scanning are able to provide the high LoD, yet the method is not suitable due to some limitations. As had been noted, CRP has its advantages and limitations.

Initially, this study is initiated at the Port Dickson Polytechnic campus located at Negeri Sembilan, Malaysia as a prototype for development the 3D virtual campus. The aim of this study is to visualise the 3D building model of Port Dickson Polytechnic campus generated from close range photogrammetry technique in City Engine Web Viewer. The objectives of this study are: -

    i)   To generate the 3D model of buildings using close range photogrammetry technique.

    ii)   To integrate the 3D model of buildings into CityEngine Web Viewer for 3D visualisation.

    iii)   To evaluate the accuracy of the generated 3D model of buildings in term of building geometries and textures of the buildings.

This study involves the data collection from existing data such as digital surface model (DSM), building footprints and the orthophoto which are obtained from Malaysian Centre for Geospatial Data Infrastructure (MaCGDI), while the selective 3D buildings models are developed using close range photogrammetry technique. Data collections from the field are carried out to obtain the photos images of selected buildings using non-metric digital camera. Six buildings in Port Dickson Polytechnic campus are randomly selected to be modelled in 3D and focused on the exterior of the buildings due to the complexity of the building's designs, facades patterns, and the strategic used while taken the photo of the buildings in the campus. The buildings which have been selected in this study includes academic and non-academic buildings such as laboratory building, student learning centre, TNB power stations and store. The photos are processed using PhotoModeler software to develop the 3D building model at LoD2. Other buildings in the study area are modelled as a block models which are extruded vertically to create the flat roofs of the building model at LoD1. At the end of the study, the 3D buildings models can be visualised in LoD2 using CityEngine Web Viewer. The generated 3D buildings models are evaluated and the accuracy assessments are compared with the actual building. Root means square error (RMSE) is assessed to evaluate the accuracy of the generated 3D

buildings models in terms of heights and distances with the actual buildings for quantitative analyses. The study shows that the accuracies of the 3D building model can be achieved below 1.5 using CRP technique.

2. Data sources and study area

The scope of study area is located at Port Dickson Polytechnic campus which has been chosen as a prototype for development the 3D virtual campus. This area is selected as a pilot project due the availability of the data which is provided by the government agency. Various data sources primary and secondary data are collected for development of 3D virtual campus. The primary data is the data which contains the photos of the buildings to be modelled in 3D buildings model. Six buildings with different architectural designs and geometries in Port Dickson Polytechnic campus have been chosen as prototype to be modelled in 3D using CRP approach. The selections of the buildings to be modelled are based on the geometries of the buildings, different level of difficulty and the suitability of the technique to be used. The photos of the six buildings are taken at the field using non-metric digital camera. Data collected at the field is primary data sources which are the main interest of the study.

Modelling the buildings in 3D city model can be divided into four levels of detail (LoD) categorizes from LoD1 to LoD4, ranging from the coarsest block model to interior architectural details such as stairs and furniture. Objects more details with increasing of LoD (Kolbe, Gröger, & Plümer, 2005). Figure 2.1 shows the LoD of the building model define by City Geography Mark up Language (CityGML).
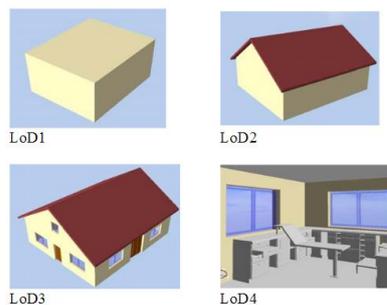

Figure 2.1 : The four levels of detail (LoD) defined by CityGML for building model (Fan & Meng, 2007)

However, the study focused at LoD2 in the development of the 3D buildings models. The differences between buildings at LoD2 and LoD1 are the buildings at LoD2 have roof shape and texture which can be created by stereo plotting or from LIDAR data while the buildings at LoD1 are blocks model without any roof structures or textures which is created by extruding the height of the building from the buildings footprints based on the average height. This creates flat roofs of the building (Redweik, 2013).
Besides, secondary data is also collected and used in this study as a supported data for 3D environment in the 3D visualisation. The

secondary data sources are obtained from MaCGDI which contains orthophoto images of the study area, buildings foot prints and the digital surface model (DSM) data. The data supplied by MaCGDI are in GDM 2000 coordinate system. The resolution for orthophoto and DSM data is 0.09 meters. In addition, non-spatial data have been obtained from Port Dickson Polytechnic which contains the list of building names that are shown on the hardcopy layout plan.

a. Development of 3D building model

Close range photogrammetry (CRP) technique is used to model the buildings in 3D at LoD2. Paul R. Wolf, Bon A. Dewitt, and Benjamin E. Wilkinson (2014) states that a close-range photogrammetry is a part of terrestrial photogrammetry and generally used for terrestrial photographs having object to camera distances not more than 300 meters. In close-range photogrammetry, the photographs are taken with cameras located on the surface of the earth. The photographs of the buildings to be model in 3D are captured using Sony Cybershot DSC-L digital camera using the CRP approach. This type of digital camera model has the characteristics such as able to provide the picture quality in 4 megapixel camera with 3X Carl Zeiss zoom lens. This camera model is chosen due to low cost and the size of the camera. Figure 2.2 shows six buildings in the study area are selected as samples for 3D buildings modelling. Buildings number 1 and 3 are the power station for TNB which are the smallest buildings to be modelled in 3D. Building number 2, 4 and 6 are the academic buildings while buildings number 1, 3 and 5 are non-academic buildings.
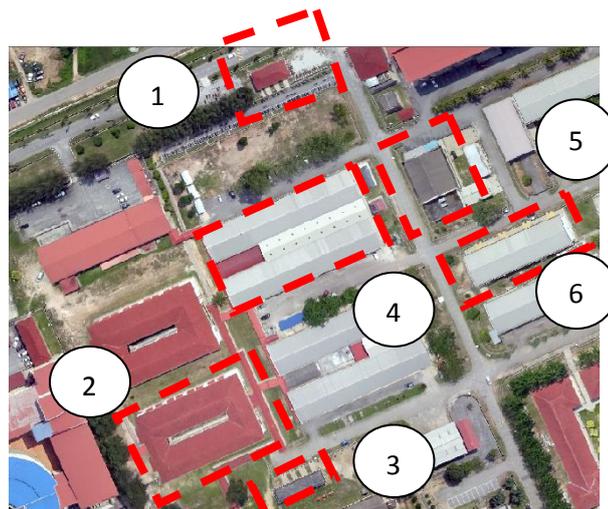

Figure 2.2 : Six buildings to be modelled in 3D

2.1.1 Camera calibration

Before acquiring the photographs of the respective buildings using non-metric digital camera, the digital camera has to undergo the camera

calibration process. The calibration process is needed to determine the interior orientation parameters of the camera so that the camera can be used as a measurement device. The camera interior parameters include focus length, principal point (Xp,Yp) and lens distortion including radial and decentring distortion parameters (K1,K2,K3,P1,P2).

PhotoModeler software is used in CRP technique to extract measurements and 3D models from photographs. PhotoModeler has the capabilities to produce high accurate model, able to measure small or large objects and scenes and easy to integrate of other measurement data source (laser scanners and total station). The advantages of the PhotoModeler software has been proven by Amat, Setan, and Majid (2010) in the study on the generation a 3D building model for the small building which are difficult to recognize from orthophoto. PhotoModeler software supports the automatic calibration or self-calibration. In order to perform self-calibration method, eight photographs of the actual buildings are captured using the digital camera in four camera positions with one landscape and one portrait for every shot at each camera position where the distances between camera and the objects are within 10 meters away.

The points are marked manually on the photographs and referenced to all photographs. Each point is marked and referenced at the same position on each photographs. After the sufficient points marked on the photographs, the calibration is performed. The successful calibration is determined based on the root mean square error (RMSE) of overall point residual and the total error for self-calibration processing. As stated in PhotoModeler, a good camera calibration will have a final total error less than 0.1 and the lower RMSE marking residual. The total error obtains in this study is 0.034 and the RMSE marking residual is 0.847. The result from calibration process is a camera interior parameters and these parameters are stored in calibration file contains *.CAM in its file name.

2.1.2 Generation of 3D building model based on close range photogrammetry technique

The 3D building model at LoD2 can be reconstructed using close range photogrammetry technique using PhotoModeler software. PhotoModeler software needs the information on the camera parameters which are stored in the calibration files to produce the accurate model. Marking is the process of identify the objects and mark it on the photograph. In this process, the points are marked on photographs. Each time the points are marked on the photographs, it creates its own unique identification number for an object. These unique identification numbers are used for marking and referencing the photographs represent the same physical object in space. All marking is done by putting PhotoModeler into a mark point mode and then using the mouse, position the cursor over the location to be marked.

After marking the objects on the photographs, the objects must be referenced on two or more different photographs represent the same physical object in space. After completing marking and referencing the

objects on the photographs, digitizing process are done to create the 3D buildings model. The line mode is used to join objects points. The 3D models are assigned to the real world coordinate system based on the known coordinates or control points of the buildings in which the coordinates are obtained from the building footprints. In order to transform the 3D model into the real world coordinate system three point rotations in PhotoModeler is used. It requires three known coordinates to be assigned on the buildings into the model. Figure 2.3 shows the three objects points with unique identification number 5, 23, and 25 on the model are used for known coordinates to transform the building model into real world coordinate system.


Figure 2.3 : Three known coordinates of buildings

Sometimes the roof of the buildings models creates problem especially on roof textures due to insufficient photographs taken to cover the roof of the buildings. The roof building models are required to touch up using SketchUp which is a software used to edit and texture the roof of the buildings.

2.1.3 Generation of block model of building

Ledoux and Meijers (2009) state the simplest way to create the 3D building model by extruding vertically the height of the buildings footprints from the ground plan. This method creates horizontally flat roofs of building and known as a block model. For visualisation purposes of the buildings model at LoD1, the buildings model are extruded vertically based on the buildings height. This method generates the buildings block model with flat roof. However heights of each building are not available from the secondary data sources. The only data contains the height information is DSM data. Therefore to obtain the height value of each building, normalized Digital Surface Model (NDSM) is required and generated. Figure 2.4 shows the buildings footprints are extruded vertically from the base height.

2D building footprints

3D block model of buildings
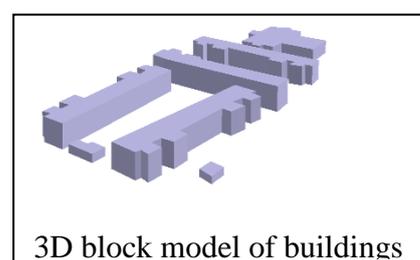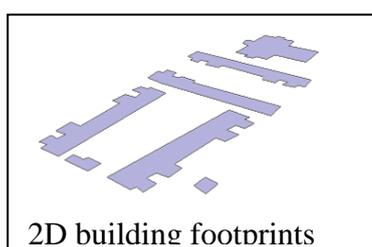
Before Extrusion   After Extrusion

Figure 2.4 : Building extrusion from 2D into 3D block model

2.2   Feature extraction

In order to generate the 3D virtual campus which contains the buildings, roads, green areas, sport areas, trees and terrain of the study areas, additional features class are required and extracted from orthophoto. Geodatabase which is created in Arc Catalog is used to store the feature classes. The feature classes are digitised using on screen digitizing method in ArcMap software.

2.3   3D building model integration

Integration process is the process to import the 3D buildings model produced from CRP into 3D base model in ArcScene software. Figure 3.5 shows the differential between 3D block building model with LoD1 and LoD2 in ArcScene software and Figure 2.4 shows the combination of 3D buildings model (LoD1 and LoD2).

3D block Building(LoD 1)
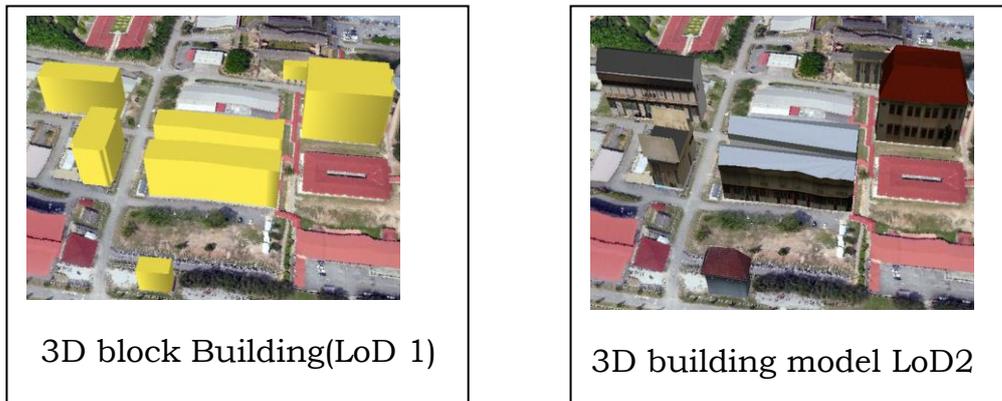

3D building model LoD2

Figure 2.4 : The differential between 3D block building model with LoD1 and LoD2 in ArcScene software.

Figure 2.5 : Combination of 3D buildings model (LoD1 and LoD2)

2.4   Visualisation

For visualisation purposes on the web using CityEngine web viewer, ArcScene software is used for exported the 3D scene into Web Scene format. All the feature classes created and stored in geodatabase are added in ArcScene. Edit placement tools in 3D Editor toolbar is used to select the 3D buildings model at LoD1 to replace the model with the new 3D buildings model reconstructed from CRP. The models are replaced by locating the new 3D models in 3DS format which are previously exported from PhotoModeler software. The new models are located accurately on the real world coordinate system in ArcScene. Replacing the 3D model using this method is able to preserve the attributes of the buildings. Figure 2.6 shows the 3D buildings at LoD1 extruded from the buildings footprints are replaced with the 3D buildings model at LoD2 generated from CRP.
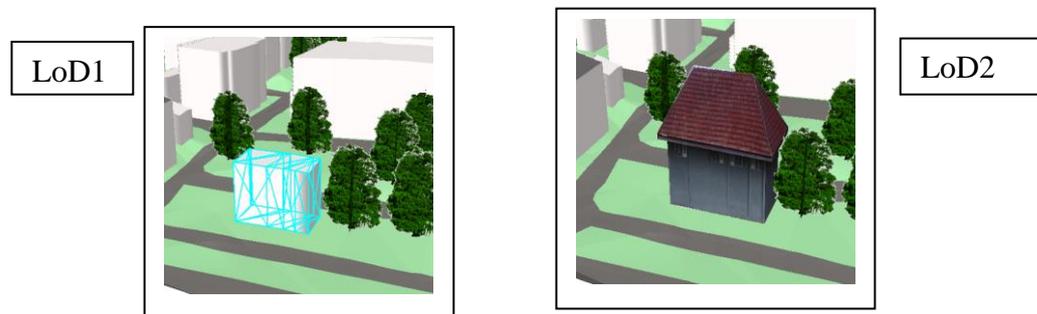

Figure 2.6 : 3D building models replacement from LoD1 to LoD2

3. Results And Analysis

The 3D building models are created by extruding vertically to create the block models of the building based on the individual average height of the buildings. At this stage, the building models are categorised as LoD1 with flat roof without textures of building facades. The generated 3D buildings models are then combined with the terrain models. The LoD of the building models can be upgraded to higher LoD using a CRP technique. The CRP technique is able to generate the LoD2 of the buildings models. Figure 3.1 shows the result of height extrusion of the building to create the 3D buildings model.

Figure 3.1 : Visualisation of 3D block building model (LoD1)

3.1　　Three dimensional of buildings model based on Close range
　　　　Photogrammetry technique

The LoD1 of the block building models can be upgraded to LoD2 using CRP technique. In order to attain the objective of the study to produce the 3D building model using CRP, six buildings with differences architectural designs and geometries are selected on the study area as sample for generation the building model in 3D.

The types of 3D models produced by PhotoModeler are divided into the wireframe model, solid model and photorealistic model. The wireframe model is produced from the digitising process using mark line mode in PhotoModeler and suitable for engineering field. Besides the wireframe model can be converted into 3D drawing. Figure 3.2 shows a 3D wireframe model of the student learning centre building. The 3D building model is resulted from CRP technique using PhotoModeler software as close range photogrametry software. Due to the complexity of the buildings geometries and difficulties to assess some locations of the buildings while taken the photos, the building to be modelled in 3D requires more photographs to be taken during the data collection at the field. The photographs are imported into PhotoModeler software to process the image to generate the 3D building models.
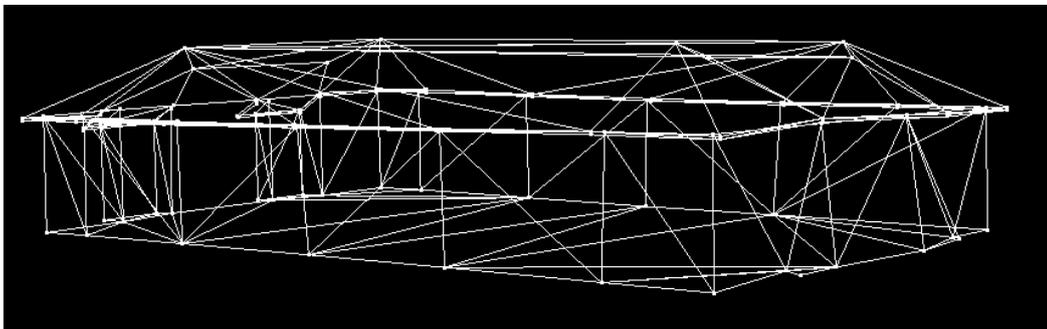

Figure 3.2 : Wireframe model

On the other hand, the PhotoModeler software generates the 3D solid model as shown in Figure 3.3. This type of model is suitable to reduce the rendering time for visualisation especially on the complex 3D city model.
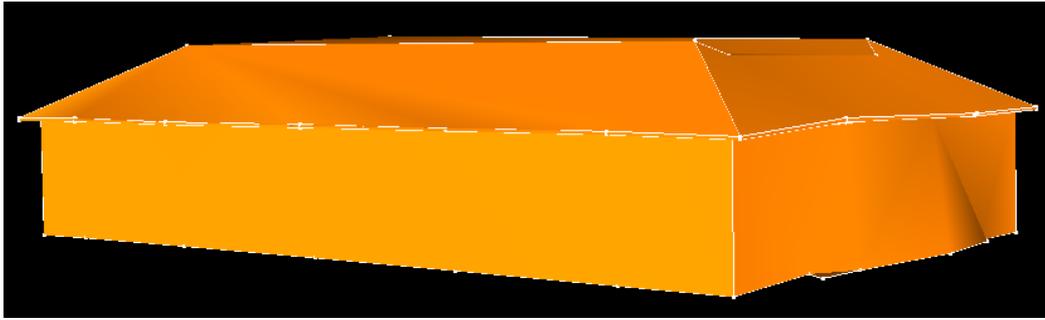
Figure 3.3 : Solid model

For 3D visualisation purposes, the solid model of building is textured with photo to produce the photorealistic model. The buildings are oriented and position in the real world coordinate system on the earth. Figure 3.4 shows the photorealistic model of building.

Figure 3.4 : Photorealistic of 3D building model

3.2   Visualisation in CityEngine Web Viewer

Visualisation the 3D virtual Port Dickson Polytechnic campus can be accessed through CityEngine Web Viewer. For visualisation the 3D virtual campus in CityEngine Web Viewer, the 3D scene in ArcScene is converted to the format supported by the CityEngine Web Viewer. Through the Web Viewer, the user is able to visualize the 3D scene from web browser as long as the web browser is compatible with the CityEngine Web Viewer requirement. On the top of that, the user is also able to navigate the 3D scene, turning on and off the layer to be visible on the web and searching the information.

Besides, the 3D building models can also draped on top of the orthophoto image in the viewer as shown in Figure 3.5. It shows that the buildings are referenced in the real world on the earth. Only the required layers to be visible on the web are turn on.

Figure 3.5 : 3D building model draped on top of the Orthophoto image

CityEngine Web Viewer enables the users to extract the information of the buildings. In order to get the information of the buildings, the users are required to give the input of the names of the buildings in the searching functions which are provided at the web. The web will automatically respond to the users' request and zoom to the selected buildings. The results for the success query are also highlighted.

4. Analyses

In this study, the analyses are carried out based on the visual analyses and quantitative analyses. For visual analyses, the analyses involve are the comparisons in level of detail (LoD) of the buildings and comparisons between the real view models and the 3D building models. The quantitative analyses involve the accuracy assessments. Visual analyses can be divided into LoD analyses and real and model comparisons.

4.1.1 Level of detail (LoD) analyses

Level of detail (LoD) analysis for the 3D building models comprises the comparison between 3D building models generated from CRP and the 3D building block models. Figure 4.1 shows differences in the LoD of the 3D building models in terms of textures and roof geometry.
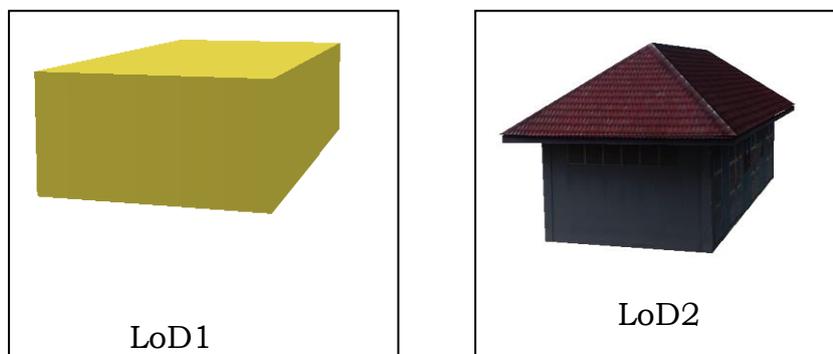

Figure 4.1 : Differences between LoD1 and LoD2 of the building model

Both building models have differences in the LoD. The 3D building models are generated from CRP and are categorised in LoD2 while the 3D building block models are categorised in LoD 1. The 3D building block models do not have building textured and have a flat roof buildings while the 3D building models generated from CRP have roof shape and building are textured with the realistic photograph. The 3D buildings block models appeared as a box while the 3D building model from CRP shown as a real view model.

4.1.2 Real view and model view

Another method for visual analyses is by comparing between the real view models and the 3D building models generated based on the CRP. Figure 4.2 shows the building from real view model and 3D building model view. In reality, the buildings have detail windows and doors, however in 3D modelling, the windows and doors of the building are textured using the real photograph as the buildings' facades for doors and windows so that the building model has similarities as real model.

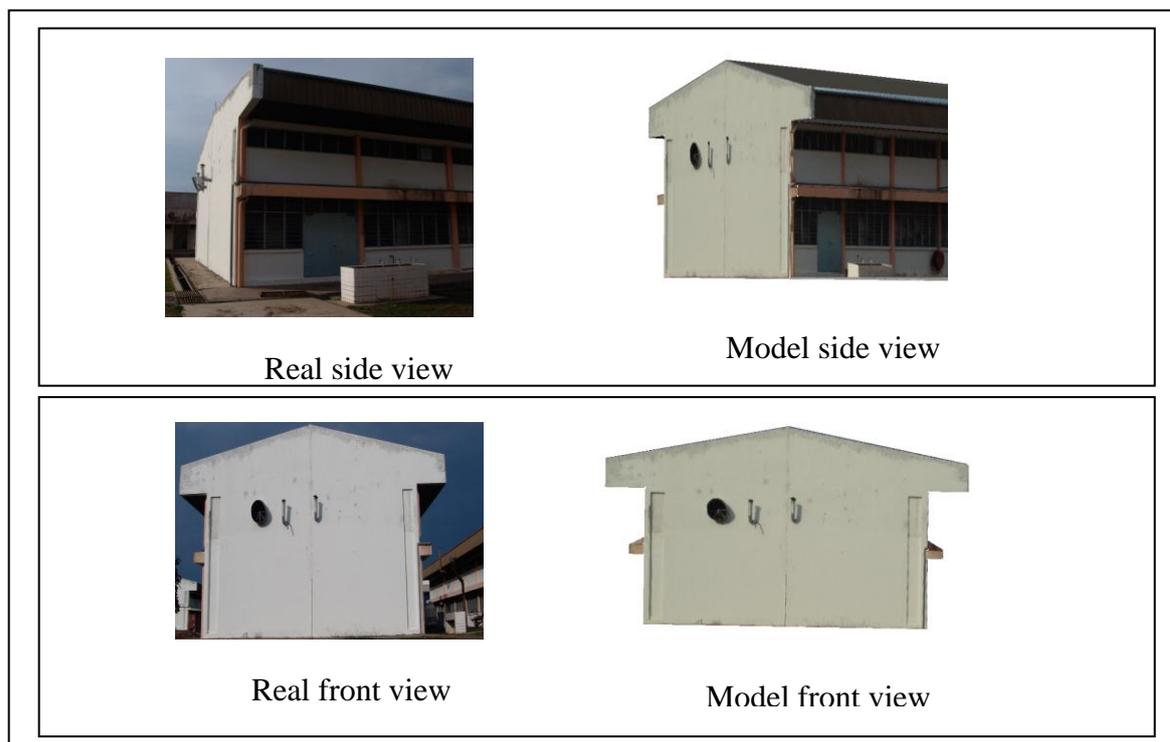| Real side view | Model side view |
| Real front view | Model front view |

Figure 4.2 : Different between real view and model

Besides, looking from the side and front view of the building, the analyses have also been carried out on the roof geometries of the building. Figure 4.3 shows the differences between roof seen from real view and the roof seen from model view. Modelling this type of roofs will have few difficulties due to inaccessible to take the photographs from the top of the building as well as the large size of the buildings have resulted to the problem in roof geometries and roof textures of the building. Thus, the

editing of the model using SketchUp software and textured the roof by using the available textures in the software is required.

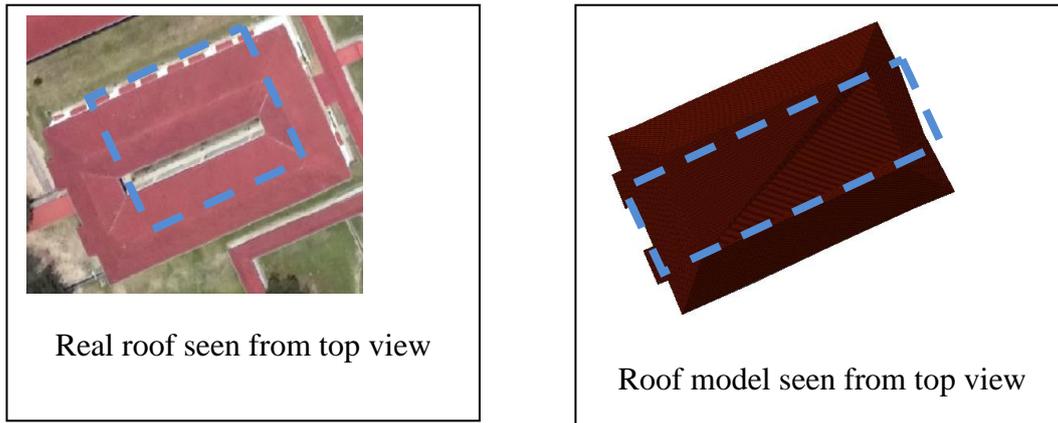| Real roof seen from top view | Roof model seen from top view |

Figure 4.3 : Differences in roof geometry between real view and model

The roof type of this building as shown in Figure 4.4 is successful modelled in term of shape however it creates a problem in roof textures. Thus, the roof textures are edited using SketchUp software.
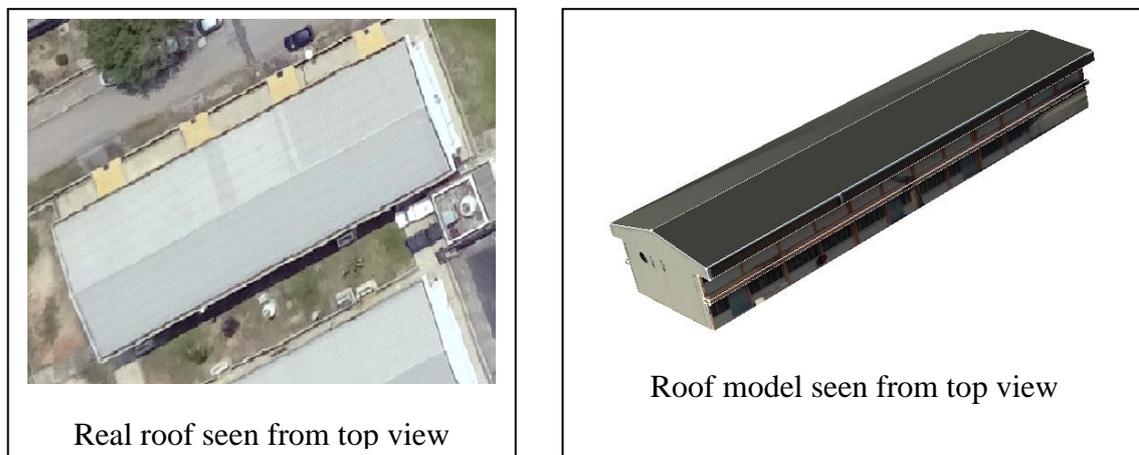

| Real roof seen from top view | Roof model seen from top view |

Figure 4.4 : Differences in roof geometry between real view and model

4.1.3 Distance measurement analyses

In the study, quantitative analyses are carried out to assess the quality of the 3D buildings models. The qualities of 3D buildings models are checked based on the distance comparison between the 3D buildings models and the actual buildings. The root means square error (RMSE) is used to determine the accuracy achieved by the model. The lower the value of RMSE is the higher the accuracy of the models. The distance measurements of the actual buildings are determined by using the measurement tape for measuring the lengths and widths while the heights of the buildings are measured using distometer.

The accuracy of the 3D buildings models is also compared with the external data sources to evaluate the quality of the models. In determining the accuracy of the models, distance comparison is used to measure the distance between two points of the actual buildings that can be easily identified with the external device. Measuring tape and distometer are employed in the measurement where the measuring tape is used for measuring the widths and lengths of the buildings while the distometer is used to measure the heights of the buildings. The distance measurements from the actual buildings are compared with two points at the same distance of the models in the PhotoModeler. The differences between these two distances are called errors and the RMSE is used to determine and evaluated the overall accuracies in the comparisons. Table 4.1 shows the distance comparison between actual building and the building model of TNB power station.

Table 4.1 : Distance comparison between actual building and the building model of TNB power station

TNB power station			
Actual Distance measured by tape		Distance of the model from PhotoModeler	
Line ID	Distance (m)	Distance (m)	Difference
5-17	22.180	21.914	0.266
17-10	5.850	4.802	1.048
10-8	22.180	21.896	0.284
8-5	5.850	4.883	0.967
Distometer (Height)		PhotoModeler (Height)	
5-6	3.135	3.157	-0.022
8-9	3.125	3.157	-0.032
RMSE			0.603

The summaries of the buildings model are shown in the Table 4.2. Based on the Table 4.2, it shows that the accuracies of the building model can be achieved below 1.5 using CRP technique for these types of buildings.

Table 4.2 : The accuracies of the 3D building models

Building Number	Building Name	Total Number
1	TNB power station	RMSE : 1.347

2	Student learning centre 	RMSE : 0.571
3	TNB power station 	RMSE : 0.603
4	Laboratory 	RMSE : 0.797
5	Store 	RMSE : 1.09
6	Laboratory of Mechanical building 	RMSE : 1.00

5. Discussion

A few problems have occurred and these affected the appearance of the 3D buildings model in the results. These problems have been summarized as below:

i. During data collection on the field, there are few obstacles around the buildings area such as trees, uneven terrains and other buildings which make it difficult to attain the photographs of the buildings. From six buildings to be modelled in this study, the student learning centre building is more complicated due to the large size of the building. It requires more photographs to be taken on the field.

ii. Some photographs of the buildings cannot be processed to generate the 3D building models due to the insufficient reference point marks on the adjacent photographs. The gaps are exists on photographs due to the insufficient overlapped the photograph on the adjacent photographs of the buildings. This requires retaking the photographs of the buildings to fill in the gaps.

iii. Digital camera which has been used for the study has low resolution. This creates the effect on the precision of the marking the points on the photographs.

iv.   Weather condition also creates the constraint that delays in taking the photographs. The weather condition is another factor that influences the quality of the pictures and another valuable experience in this study. The photographs of the building are retaken in the field due to insufficient photographs. It is suggested to possibly avoiding taken the photograph on the rainy and cloudy weather because it may affect the lighting and the appearance of the photographs. The low lighting of the photographs creates problems on the appearance of the 3D building model.

v.   The roof of the buildings have no photograph due to some of the constrains in the accessibility and resources.

Based on the analyses result, there are many factors which affect the accuracy of the 3D building models and needs some improvement to achieve the higher accuracy. The factors affect the accuracies are as follows:-

i.   Photo Resolution
The higher the resolution of the images, the higher accuracy can be achieved because the points can be marked precisely on the image on the photographs. The camera which is used for this study has four megapixels thus contributes to the low accuracy of the study due to the low resolution of the image and affecting the marking precision.

ii.   Camera Calibration
There are many methods of calibration in determining the camera focal lengths, format sizes, principal points and lens distortions while taking the photographs. In this study, field calibration is used to calibrate the camera to achieve the accuracy where the points are marked manually on the photographs can also contribute to errors of the residual of the point marked on the photographs.

iii.   Angle between Photos
The low angle of two photos which are taken closely to each other of the buildings also contribute to the lower accuracy of the 3D building models.

iv.   Photo redundancy
The more identical points in every overlapping photograph, the calculation of the points will be more accurate. For instance, if point 1 is overlapping in 5 different photographs thus the calculation of point 1 is more accurate rather than overlapping in just minimally two photographs.

6. Conclusion

The overall objectives of the study are successfully achieved. The first objective is to generate the 3D building models by using CRP technique which undoubtedly, is cost saving method. The 3D buildings models with LoD2 were successfully developed using CRP technique. Different types of buildings with several architectural designs can be produced by using CRP. By using CRP, the building models appearance as block model categorised in LoD1 were successfully upgraded to LoD2. The buildings models in LoD2 appeared as photorealistic building model in 3D.

The 3D building models using CRP technique are successfully integrated in CityEngine Web Viewer for 3D visualisation. Through the viewer, users are able to navigate the models and extract the information of buildings. The textures of the buildings model generated from CRP were successfully rendered in CityEngine Web Viewer. This shows the integration of the 3D building model into CityEngine web viewer for visualisation and query the information is attained for the second objective.

The buildings models generated from CRP are then analysed in term of visual analysis, accuracy assessments analysis and processing analysis. In visual analysis, the comparisons are made between the 3D building model with the 2D image which include the roof geometries, the texture of the buildings, and the building façades. The accuracy assessment is done by comparing the model with the actual buildings and evaluated through the PhotoModeler software accuracy. Based on the analysis, it can be concluded that the 3D building models generated from CRP are acceptable for visualisation purposes. Thus, the third objective to evaluate the generated buildings models in term of the building geometries, facades and textures of the buildings is accomplished.

The findings of the study provide several beneficial contributions to the users. By using CRP, the 3D virtual campus can be developed using low cost method compared to laser scanning data due to the availability of instrument for data acquisition. The study also provides the prototype for development the virtual 3D campus using photogrammetry approach. Besides, models can be shared on the web pages for easy access. It also improves the current visualisation in the study area and provides potential to move forward from 2D mapping into 3D mapping.

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