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 research, the emphasis is given on the development of the 3D building model campus using close range photogrammetry approach due to high cost of data acquisition techniques using airbone laser scanning, terrestrial laser scanning techniques and availability of data. Thus, the close range photogrammetry technique has been selected due to low cost method for data acquisition through capturing the selected building photographs using digital camera. In order to develop the 3D building models, six buildings with different architectural designs and geometries in Port Dickson Polytechnic campus have been chosen as prototype which are modelled using close range photogrammtry approach. The photographs of buildings are then processed using PhotoModeler software to produce the 3D building models in the level of detail (LoD) 2. The building 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 information access on the web in 3D, CityEngine Web Viewer is used for 3D visualisation of the building 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 building models, zooming and performing the spatial query to extract the information of the buildings. The accuracy of 3D buildings models are evaluated and determined based on the visual analyses and quantitative analyses. At the end of the research, the 3D buildings models can be visualised in the LoD 2.

ABSTRAK

Perkembangan teknologi moden serta berkemampuan untuk menyimpan, memproses serta membekalkan data digital telah menyebabkan permintaan kepada permodelan tiga dimensi (3D) kampus maya telah meningkat secara mendadak. Sejak kebelakangan ini, banyak institusi pendidikan telah membangunkan geodatabase kampus mereka sendiri dalam persekitaran 3D. Kajian ini memberi penekanan kepada pembangunan model bangunan dalam 3D menggunakan pendekatan fotogrametri jarak dekat kerana kos yang tinggi dalam perolehan data menggunakan teknik pengimbasan laser dari udara, teknik pengimbasan laser jarak dekat dan kesediaan data. Oleh itu, teknik fotogrametri jarak dekat telah dipilih kerana kaedah kos yang rendah untuk perolehan data dengan cara mengambil gambar bangunan yang hendak dimodelkan menggunakan kamera digital. Dalam usaha untuk membangunkan model bangunan 3D, enam bangunan dengan reka bentuk seni bina yang berbeza dan geometri di kampus Politeknik Port Dickson telah dipilih sebagai prototaip untuk dimodelkan dengan menggunakan pendekatan fotogrametri jarak dekat. Gambar-gambar bangunan kemudiannya diproses menggunakan perisian PhotoModeler untuk menghasilkan model bangunan 3D di tahap perincian (LoD) 2. Bangunan model bertekstur menggunakan gambar-gambar sebenar yang diambil dari padang manakala bumbung bangunan diperbaiki menggunakan perisian SketchUp. Model akan berada di kedudukan sebenar di atas muka bumi berdasarkan sistem koordinat RSO geocentric.Oleh kerana kekurangan akses maklumat di web dalam 3D, CityEngine Web Viewer digunakan untuk visualisasi 3D model bangunan dan pelbagai data ditambah untuk mewujudkan satu model realistik 3D kampus maya. Melalui CityEngine Web Viewer, pengguna dapat mengemudi model bangunan 3D, zoom dan melaksanakan pertanyaan spatial untuk memperolehi maklumat bangunan. Ketepatan bangunan 3D model dinilai dan ditentukan berdasarkan analisis visual dan analisis kuantitatif. Pada akhir kajian, 3D bangunan boleh divisualisasi pada LoD 2.

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LIST OF ABBREVIATIONS

3D	Three dimensional
CityGML	City Geography Mark up Language
CAD	Computer Aided Design
CRP	Close range photogrammetry
DSM	Digital surface model
DOF	Depth of field
DEM	Digital elevation model
DTM	Digital terrain model
GPS	Global Positioning System
GE	Google Earth
GDM 2000	Geocentric Datum of Malaysia 2000
HTML	Hypertext Markup Language
KML	Keyhole Markup Language
LoD	Level of detail
LIDAR	Light Detection and Ranging
MRSO	Malaysia Rectified Skew Orthomorphic
MaCGDI	Malaysian Centre for Geospatial Data Infrastructure
NDSM	Normalized Digital Surface model
RSO	Rectified Skew Orthomorphic
RMS	Root Mean Square
TNB	Tenaga Nasional Berhad
TIN	Triangulated irregular network
TLS	Terrestrial laser scanning
VRML	Virtual Reality Markup Language
VR	Virtual Reality
WebGL	Web Graphic Library

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Today, application in three dimensional (3D) model can been seen in diverse fields such as civil engineering, architecture, archaeology, town planning, automotive industry and others especially for visualization applications (Ahmad & Rabiu, 2011). The application in 3D modelling can also be seen in the development of 3D virtual campus. Campus is the terra firma where the institute, school, college, or university buildings are situated. Buildings in the campus include academic and non-academic building for instance utilities, mosques, libraries, lecture halls, residence halls, student centres, administration blocks and hall for students' activities. Virtual models provide an interactive visualization in 3D environment (Armenakis & Sohn, 2009) and gives a good photo-realistic appearance for the user (Singh *et al.*, 2013a). It is more useful if the models include the attributes of the buildings information and images texture to enable the user in making a query and visualisation purposes (Song & Shan, 2004).

. 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. Armenakis and Sohn (2009) create the 3D virtual model of York University campus using airborne lidar data, aerial photogrammetry, terrestrial laser scanning to create man made features and natural terrain object. Ahmad and Rabiu (2011) have developed 3D campus for Universiti Teknologi Malaysia using photogrammetry technique through digitizing the buildings from stereo-photo images. Singh *et al.* (2013a) creates 3D virtual Campus of Department of Civil Engineering, Indian Institute of Technology, Roorkee using SketchUp software. The 3D buildings facades are textured using the images taken from digital camera. Kahraman *et al.* (2011) developed a web based 3D campus information for University of Karabuk, Turkey from Computer Aided Design (CAD) data. The buildings are integrated with CityServer3D for data storage. Yuniarti *et al.* (2015) developed the 3D campus for Institut Teknologi Sepuluh Nopember (ITS) on the web based on the WebGL, a web standard for 3D graphic and publish though web.

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. Initially, this research is initiated at the Port Dickson Polytechnic campus located at Negeri Sembilan as a prototype for development the 3D virtual campus. The research focuses on the development the 3D buildings model in the campus using close range photogrammetry (CRP) technique due to the limited budget and cost. Although close range photogrammetric has capabilities to capture highly accurate 3D data on large objects (Rasam *et al.*, 2013), it also has weakness such as the skill and experience of photographer taking the image, roof texture and problem to find suitable position for photographs (Singh *et al.*, 2014). Amat *et al.* (2010) recommended the CRP technique to create 3D model of building due to its cost effective and provide the good accuracy for the model.

The supporting data for 3D virtual campus such as such as orthophoto, buildings footprints and digital surface model (DSM) have been obtained from government agency due to constrain in the availability of data sources and cost. Reconstruction of the 3D buildings model requires data collection in the field to capture the photos images of selected buildings. The images are processed and then reconstructed the model by using PhotoModeler. Other buildings in the campus are extruded as the block model although these buildings are not in the main focus for this study.

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. Due to this, CityEngine Web Viewer is used for visualisation the 3D virtual campus and to perform spatial query for extraction the building information. However the scopes of visualisation have limitations because visualisation of the model can be done on the client computer only. At the end of the study, the 3D buildings model can be visualised in LoD 2 using CityEngine Web Viewer. The models are evaluated and the accuracy assessments are determined based on the actual building.

1.2 Problem Statement

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 *et al.*, 2013b). 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 *et al.*, 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. If the resources are unavailable, another effective method can be used.

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 researchers choose the close range photogrammetry (CRP) technique as the best option plus it is economical method in data acquisition towards achieving the research 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.

Presentation and 3D visualisation on the web based platform require linked between spatial and non spatial attribute data. However, current implementation has limitation on retrieving the spatial and attributes information especially when visualising the 3D model on web mapping platforms. For instance, the users require to install the plug-in or install the specially software before user are able to visual the model. Besides, developers have to customize the user interface which requires a skill in programming to display the attribute data based on the user inputs. Due to this, the research selected the CityEngine Web Viewer 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.

1.3 Aim of Study

The aim of this research is to visualise the 3D building model of Port Dickson Polytechnic campus generated from close range photogrammetry technique in City Engine Web Viewer.

1.4 Objective of Study

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 building with Digital surface model (DSM) and Digital terrain model (DTM) into CityEngine Web Viewer.

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

1.5 Scope of Study

i) The study area is located at Port Dickson Polytechnic campus, Negeri Sembilan. This area is selected as a pilot project due the availability of the data which is provided by the government agency. Figure 1.1 shows location of academic and non-academic buildings in campus. The buildings are shown in 2D image obtained from the Google map.

Figure 1.1 : Location of Port Dickson Polytechnic campus

The façade of the roof textures and the buildings geometries of the study area can only be seen from air. However, the textures of buildings such as windows, doors are not visible. Interest of level of details (LoD) is the main topic in 3D modelling as the high LoD represent the details facade and the geometry of the building. The 2D image does not provide high LoD for visualisation purposes.

ii) The buildings to be model in 3D are randomly selected 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 project are academic buildings which contains laboratory buildings and student learning centre. Non academic buildings include TNB power stations and store. The buildings to be model in 3D are stated in Table 3.1 in Section 3.3.1.1

iii) PhotoModeler software is used to process the photo images taken by non metric camera. The levels of details (LoD) for the buildings model are limits to LoD 2 due to time constrain, limited budget and availability of data and equipments.

iv) ArcScene software is used for conversion the 3D scenes into the format acceptable by the CityEngine Web Viewer. Visualisation of 3D model on web is performed in client computer locally.

v) Data sources obtained from Malaysian Centre for Geospatial Data Infrastructure (MaCGDI) are buildings footprints, Orthophoto and Digital Surface Model (DSM). Data is provided in geocentric RSO coordinate system. Orthophoto data is used to extract the location in real world while the DSM data is used to extract 3D information of for the study area. Buildings footprints is used to extrude vertically based on the building height to generate the block model of the buildings campus.

1.6 Significant of Study

i) Low-cost method in the development of 3D virtual campus

The development of 3D city model by using CRP approach is low cost method as compared to the laser scanning in term of data acquisition and data processing.

ii) Share to the public

The 3D virtual campus can be shared in the web for public visualization and query purposes. The users can visualize the buildings using the function available in CityEngine Web Viewer and obtain the information of the buildings.

iii) Milestones for the development of 3D virtual campus for polytechnic.

The development of 3D model in polytechnic campus is the initial stage for development of 3D campus using low cost method.

iv) Enhance the current visualisation of campus

The new environment for displaying the polytechnic campus on the web is able to enhance the delivery system and effectiveness for public information.

1.7 Structure of Thesis

The thesis is divided into five chapters: -

i. Chapter 1 : Introduction

This chapter discusses on the topic of the research such as background of study, problem statement, aim, objectives, scope and significance of study.

ii. Chapter 2 : Literature Review

This chapter discusses on the references based on the 3D model related to the research interest which covered the methods and techniques, 3D building reconstruction, LoD, classification, visualisation of the 3D model and the reviews from previous methods to serve as research guidelines.

iii. Chapter 3 : Methodology

This chapter discusses the whole method in developing the 3D model campus including data collection, data processing and 3D visualisation by integrating the developed model into the CityEngine Web Viewer. Development 3D model campus involves three stages. The first stage involves the data collection from existing data. The second stage involves close range photogrammetry for data collection of the buildings. The third stage involves data processing start from the beginning of the project until the end of the project. The softwares used for modeling the 3D building model and to integrate the 3D model into CityEngine Web Viewer are also discussed in this chapter.

iv. Chapter 4 : Results and Analysis

The results and analysis are discussed in this chapter. Result shows the 3D buildings models generated from CRP produces the LoD 2. The accuracy assessment of the model generated from CRP and comparisons based on the visual analyses and quantitative analyses are also discussed in this chapter. The 3D buildings models generated from CRP are visualises in the CityEngine Web Viewer which includes the additional data such as roads, buildings and green areas.
The problem occurred during research implementation are also discussed.

v. Chapter 5 : Conclusion and Recommendation

This chapter consists of conclusion of the research and the recommendations on future research.

REFERENCES

Ahmad, A., & Rabiu, L. (2011). *Generation of three dimensional model of building using photogrammetric technique*. Paper presented at the 2011 IEEE 7th International Colloquium on Signal Processing and its Applications, Pulau Pinang.

Al-Hanbali, N., Fadda, E., & Rawashdeh, S. (2006). Building 3D GIS Modeling Applications in Jordan: Methodology and Implementation Aspects. In A. Abdul-Rahman, S. Zlatanova, & V. Coors (Eds.), *Innovations in 3D Geo Information Systems* (pp. 469-490). Berlin, Heidelberg: Springer Berlin Heidelberg.

Amat, N. A., Setan, H., & Majid, Z. (2010). Integration of aerial and close range Photogrammetric methods for 3D City modeling generation. *Geoinformation Science Journal, 10*(1), 49-60.

Armenakis, C., & Sohn, G. (2009). *iCampus: 3D modeling of York University campus.* Paper presented at the ASPRS 2009 Annual Conference, Baltimore, Maryland.

Atkinson, K. B. (2001). *Close range photogrammetry and machine vision*. UK: Whittles publishing.

Balsa-Barreiro, J., & Fritsch, D. (2015). Generation of 3D/4D Photorealistic Building Models. The Testbed Area for 4D Cultural Heritage World Project: The Historical Center of Calw (Germany). In G. Bebis, R. Boyle, B. Parvin, D. Koracin, I. Pavlidis, R. Feris, T. McGraw, M. Elendt, R. Kopper, E. Ragan, Z. Ye, & G. Weber (Eds.), *Advances in Visual Computing: 11th International Symposium, ISVC 2015, Las Vegas, NV, USA, December 14-16, 2015, Proceedings, Part I* (pp. 361-372). Cham: Springer International Publishing.

Booth, B. (2000). *Using ArcGIS 3D Analyst*. USA: ESRI.

Brenner, C. (1999). Interactive modelling tools for 3D building reconstruction.

Brenner, C., Haala, N., & Fritsch, D. (2001). Towards fully automated 3D city model generation. *Automatic Extraction of Man-Made Objects from Aerial and Space Images (III)*, 47-57.

Döllner, J., Kolbe, T. H., Liecke, F., Sgouros, T., & Teichmann, K. (2006). *The virtual 3d city model of berlin-managing, integrating, and communicating complex urban information.* Paper presented at the Proceedings of the 25th Urban Data Management Symposium UDMS, Aalborg, Denmark.

El Garouani, A., Alobeid, A., & El Garouani, S. (2014). Digital surface model based on aerial image stereo pairs for 3D building. *International Journal of Sustainable Built Environment, 3*(1), 119-126.

Eran Sadek Said, M. S., Sayed Jamaludin , S. A., & Mohd. Rosdi, M. K. (2005). The Design and Development of a Virtual 3D City Model. Retrieved from www.hitl.washington.edu/people/bdc/virtualcities.pdf

Ewald, K., & Coors, V. (2005, 6-8 July 2005). *Appraisal of standards for 3D city models.* Paper presented at the Ninth International Conference on Information Visualisation (IV'05).

Faig, W. (1975). *Photogrammetric equipment systems with non-metric cameras.* Paper presented at the American Society of Photogrammetry- Close-Range Photogrammetric Systems, Virginia.

Fan, H., & Meng, L. (2007). *Automatic derivation of different levels of detail for 3D buildings modelled by CityGML.* Paper presented at the 24th International Cartographic Conference, Santiago, Chile

Ftáčnik, M., & Borowský, P. (2004). Low Cost High Quality 3D Virtual City Models. *CORP & GeoMultimedia, Vienna, Austria, Selbstverlag des Instituts für EDV-gestützte Methoden in Architektur und Raumplanung der Technischen Universität Wien*.

Gomarasca, M. A. (2009). Elements of Geographical Information Systems *Basics of Geomatics* (pp. 481-560). Dordrecht: Springer Netherlands.

Isikdag, U., & Zlatanova, S. (2010). Interactive modelling of buildings in Google Earth: A 3D tool for Urban Planning. In T. Neutens & P. Maeyer (Eds.), *Developments in 3D Geo-Information Sciences* (pp. 52-70). Berlin, Heidelberg: Springer Berlin Heidelberg.

Jie, S. (1998, 22-26 Jun 1998). *Visualizing 3-D geographical data with VRML*. Paper presented at the Computer Graphics International, 1998. Proceedings, Hannover, Germany.

Kahraman, I., Karas, I. R., & Rahman, A. A. (2011). Developing web-based 3D campus information system. *Conference Name*|, Conference Location|. Type retrieved rom URL

Karara, H. M., & Faig, W. (1980). An expose on photographic data acquisition system in close-range photogrammetry [J]. *International Archives of Photogrammetry, 23*, 402-418.

Kobayashi, Y. (2006). Photogrammetry and 3D city modelling. *Digital Architecture and Construction, 90*, 209.

Kolbe, T. H., Gröger, G., & Plümer, L. (2005). CityGML: Interoperable Access to 3D City Models. In P. van Oosterom, S. Zlatanova, & E. M. Fendel (Eds.), *Geo-information for Disaster Management* (pp. 883-899). Berlin, Heidelberg: Springer Berlin Heidelberg.

Kraus, K. (2007). *Photogrammetry: geometry from images and laser scans*: Walter de Gruyter.

Ledoux, H., & Meijers, M. (2009). Extruding building footprints to create topologically consistent 3D city models *Urban and Regional Data Management, UDMS Annual* (Vol. 2009, pp. 39-48). London: CRC Press, Taylor & Francis group.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (1991). *Geographical information systems: principles and applications*. Harlow: Longman.

Luhmann, T., Robson, S., Kyle, S., & Harley, I. (2006). *Close range photogrammetry: Principles, methods and applications*. UK: Whittles publishing.

Ma, Q., Wang, R., Xin, Q., Wang, F., & Yang, J. (2013, 20-22 June 2013). *The research on the key technology of building 3D virtual scene in Wendeng City based on Google Earth*. Paper presented at the 2013 21st International Conference on Geoinformatics.

Mao, B. (2011). *Visualisation and generalisation of 3D City Models*. (Doctorial Thesis), KTH Royal Institute of Technology Stockholm.

Mayer, s. (2004). *Automated object recognition for the interpretation of high resolution image data in terrestrial remote sensing*. Humboldt University of Berlin.

Mikhail, E. M., Bethel, J. S., & McGlone, J. C. (2001). *Introduction to modern photogrammetry*. New York: John Wiley & Son.

Peckham, R. J., & Gyozo, J. (2007). *Digital terrain modelling*. New York: Springer.

Pu, S., & Vosselman, G. (2006). Automatic extraction of building features from terrestrial laser scanning. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 36*(5), 25-27.

Rasam, A. R. A., Hamid, N. A., Hamid, M. Z. A., Maarof, I., & Samad, A. M. (2013). *3D photorealistic modeling of university building using Digital Close Range Photogrammetry.* Paper presented at the Control and System Graduate Research Colloquium (ICSGRC), 2013 IEEE 4th, Shah Alam, Malaysia.

Redweik, P. (2013). Photogrammetry. In G. Xu (Ed.), *Sciences of Geodesy - II: Innovations and Future Developments* (pp. 133-183). Berlin, Heidelberg: Springer Berlin Heidelberg.

Remondino, F., & Fraser, C. (2006). Digital camera calibration methods: considerations and comparisons. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 36*(5), 266-272.

Shashi, M., & Jain, K. (2007). Use of photogrammetry in 3D modeling and visualization of buildings. *ARPN Journal of Engineering and Applied Sciences, 2*(2), 37-40.

Singh, S. P., Jain, K., & Mandla, V. R. (2013a). Image Based 3D Modeling of Campus (Department of Civil Engineering, IIT Roorkee, Uttarakhand, India) by Using SketchUp. *International Journal of Advanced Civil Engineering and Architecture Research, 2*(1), pp. 65-71.

Singh, S. P., Jain, K., & Mandla, V. R. (2013b). Virtual 3D city modeling: techniques and applications. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 1*(2), 73-91.

Singh, S. P., Jain, K., & Mandla, V. R. (2014). Image based virtual 3D campus modeling by using CityEngine. *American Journal of Engineering Science and Technology Research, 2*(1), 01-10.

Song, Y., & Shan, J. (2004). *Photorealistic building modeling and visualization in 3-D geospatial information system*. Inter. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. Istanbul, Turkey.

Takase, Y., Sho, N., Sone, A., & Shimiya, K. (2003). Automatic generation of 3d city models and related applications. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 34*, 5.

Truong-Hong, L., Pham Thi, T. T., Yin, J., & Carswell, J. D. (2013). Preparing Detailed 3D Building Models for Google Earth Integration. In B. Murgante, S. Misra, M. Carlini, C. M. Torre, H.-Q. Nguyen, D. Taniar, B. O. Apduhan, & O. Gervasi (Eds.), *Computational Science and Its Applications – ICCSA 2013: 13th International Conference, Ho Chi Minh City, Vietnam, June 24-27, 2013, Proceedings, Part IV* (pp. 61-76). Berlin, Heidelberg: Springer Berlin Heidelberg.

Wei, H., & Bartels, M. (2012). 3D Digital Elevation Model Generation. In N. Pears, Y. Liu, & P. Bunting (Eds.), *3D Imaging, Analysis and Applications* (pp. 367-415). London: Springer London.

Wolf, P. R., Dewitt, B. A., & Wilkinson, B. E. (2014). *Elements of Photogrammetry with Applications in GIS, Fourth Edition*: McGraw-Hill Education.

Yalcin, G., & Selcuk, O. (2015). 3D City Modelling with Oblique Photogrammetry Method. *Procedia Technology, 19*, 424-431.

Yuniarti, A., Atminanto, A., Mardasatria, A., Hariadi, R. R., & Suciati, N. (2015, 16-16 Sept. 2015). *3D ITS campus on the web: A WebGL implementation.* Paper presented at the Information & Communication Technology and Systems (ICTS), 2015 International Conference on.

Zhang, S. (2012). Development of virtual Campus System Based on ArcGIS. *Physics Procedia, 33*, 1133-1139.

Zlatanova, S. (1999). *VRML for 3D GIS.* Paper presented at the Proceedings of the 15th Spring Conference on Computer Graphics.

Zlatanova, S., & Tempfli, K. (2000). *Modelling for 3D GIS: Spatial analysis and visualisation through the web.* Paper presented at the International Archives of Photogrammetry and Remote Sensing Vol. XXXIII, XIXth Congress ISPRS, Amsterdam, 2000.