APPLICATION OF REAL-TIME VIRTUAL REALITY STREAMING MOBILE DEVICES FOR INTEGRATED PROJECT DELIVERY

Ali Ghaffarianhoseini, Tongrui Zhang, Dat Tien Doan, Attiq Ur Rehman, Nicola Naismith, John Tookey, James Rotimi,

Department of Built Environment Engineering, School of Engineering, Computer and Mathematical Sciences, AUT University, Auckland, New Zealand

Kai Wang, Fukun Ruan, Guoyong Wang, Wange Zhang, Bobing Li

Shanxi Bimcraft Technology Co., Ltd, China

Tianming Yu, Zhentao Mu, Yicao Qi

Shenyang Huayu Architectural Design CO., LTD, China

Amirhosein Ghaffarianhoseini,

Department of Geography, Faculty of Arts and Social Sciences, University of Malaya (UM), Malaysia

Keyu Chen

The Hong Kong University of Science and Technology, Hong Kong Special Administrative Region

ABSTRACT: *Researchers have indicated promising futures concerning the application of Virtual Reality (VR) for Architecture, Engineering and Construction / Facilities Management (AEC/FM) as an industry. Technological advancements have allowed for utilization of highly-efficient computer-based cloud servers. To cater for this potential, contemporary AEC/FM practices demand application of a higher quantity and more advanced mobile devices. Conventionally, contractors often rely on printed drawings, slides and videos to facilitate/inform on-site workers. These methods can be out of date and fail to account for variabilities in usage patterns. On the other hand, establishment of comprehensive VR scenes requires expensive hardware not perfectly suitable for on-site conditions, most specifically in conventional circumstances. Moreover, development of all-inclusive VR frameworks including various components namely: video roaming, VR scene creation, AEC/FM simulation, etc are usually not cost-effective and require considerably time/energy consuming efforts. Correspondingly, this research proposes an integrated methodology for utilizing BIM models in Unreal Engine 4 or Unity 3D for mobile streaming services. Initially, BIM models for this research are generated by designers using Autodesk Revit. Subsequently, digital point-cloud terrain models from Satellites are transformed into GPS Elevation Fitting Models in World Machine. Next, BIM and GPS Elevation Fitting Models are integrated in Unreal Engine 4 or Unity 3D. Then, the Virtual Reality scenes are projected by GeForce Experience. Finally, Stream Theater is used in mobile devices such as mobile phones, pads, etc. to receive frames from the cloud server. Eventually, the proposed*

methodology is validated in the Bailintou Monastery project. The results of this research are expected to significantly reduce the work redundancy and hardware requirements while promoting the visualization of VR-based project presentations and user mobility adaptions.

KEYWORDS: Mobile Cloud Streaming; Virtual Reality (VR); Building Information Modeling (BIM); Integrated Project Delivery (IPD).

1. INTRODUCTION

As the nature and complexity of communication within AEC/FM projects has changed significantly in recent years (Goulding et al., 2014), VR technologies offer emerging potential for AEC/FM industry (Marc, 2014). Conventionally, 2D has been used by construction contractors as the principal means of communicating design information in the construction industry (Cory, 2001, Schantz, 1989, Watson and Anumba, 1991). This method of communication is not flexible enough and can fail to account for variabilities in usage patterns (Aouad et al., 2013, Watson and Anumba, 1991). Shiratuddin (2015) indicated that conventional two-dimensional (2D) diagrams used in textbooks are not sufficient for conveying the actual representation of the building system in contrast VR technologies show excellent performance in construction training and education. Marc (2014) examined the benefits of VR for design review, and found that VR can bring a better understanding of the design, more involvement within the design review process, an increase in useful feedback on the design and more efficient design review meeting to the design projects.

Advances in computer hardware and software have allowed for utilization of highly-efficient computer-based cloud servers (Koutsabasis et al., 2012). To meet the requirements of VR, the application of higher quantity and more-advanced mobile devices is essential (Shiratuddin, 2015). However, on-site conditions are not always suitable for VR applications for a number of reasons, onsite hardware and software conditions are always not sufficient enough for the implementation of VR. On-site engineers are usually not IT experts or specialists in software technologies , additionally the development of all-inclusive VR frameworks are usually not cost-effective and require considerably time/energy including various components: video roaming (Tian et al., 2011), VR scene creation (Shiratuddin, 2015), and AEC/FM simulation (Goulding et al., 2014), etc Woksepp and Olofsson (2008) indicated that there is a need to reveal the attitudes of the average person working at a construction site rather than of an IT expert, the condition of an average construction site instead of a lab and the actual benefits for normal projects and find solutions based on it. Thus, a solution that can largely decrease the demand of hardware requirements, software skill needed, and development costs is needed in BIM level 3.0. In addition, it will offer an innovative way to excel in construction management (Goulding et al., 2014). Meanwhile, the adoption of this solution in the paradigm of Integrated Project Delivery (IPD) holds potential. This study provides a current literature review concerning related technologies such as Building Information Modeling (BIM), mobile cloud streaming, VR and IPD. It goes on to provide a solution to solve the hardware problems by integrating BIM, VR and mobile cloud streaming in IPD. A case study of the Bailintou Monastery will be used to validate the effectiveness of the solution. Finally, the study discusses the results in context and draws conclusions based on it with several limitations and futuristic works.

2. METHODOLOGICAL APPROACH

This study will explore the use of a real-time mobile cloud streaming method in IPD project in through analysis and induction and validation process. Firstly, analysis is a classic research method by dividing a complex topic or substance into several key parts to gain a better understanding of the topic. This technique has been applied in many fields, especially in the study of workflow logic, and it has been widely adopted in literary review. This study mainly divides the background of the proposed method into four main technologies, including Building Information Modeling (BIM), Virtual Reality (VR), mobile cloud streaming and Integrated Project Delivery (IPD) and makes analysis on the trend of AEC industry related to the topic of this paper. Secondly, induction is a way of reasoning using known facts to produce general laws. This study has drawn the technological roadmap of the proposed method. Thirdly, validation is a way of give evidences for a method to prove or confirm its effectiveness and efficiency. In this study, Bailintou Monastery is selected as a case study to validate the proposed method. This project meets three requirements of validation case for the proposed method as following: Firstly, this project is designed by our team and all the data can be approached on its own. Secondly, this project faces the main issues that the proposed method deals with, such as complex construction process, terrible onsite hardware conditions onsite and unskilled onsite workers for 3D visualization. Thirdly, the volume of this project is not too much, which has a short lifecycle for the research process while remains the effectiveness of the results.

3. BACKGROUND

3.1 BIM

Building Information Modeling (BIM), originated from Building Description System (BDS), which was proposed by Eastman (1974), was first documented by G. A. van Nederveen (1992). A white paper entitled "Building Information Modeling" was released by Autodesk Inc. (AutodeskInc., 2002) which introduces the concept of BIM with its definitions, characters, benefits, road maps for better building projects. Wang (2016) researched the relationship between BIM and VR to keep the sharing and transformation of building information in the whole process of construction. Thus, taking advantage of BIM platform, the proposed method obtains a high-accuracy model full of information in a visual environment.

3.2 VR

VR can assist construction project stakeholders to complete their projects successfully, VR has the potential to enhance the effectiveness and efficiency during the project lifecycle, from initial conceptual design through planning, preparation and detailed design, to construction completion (Thabet et al., 2002). Shi et al. (2016) indicated that VR enables real-time interactions of remote stakeholders in the same environment, with a shared immersive walkthrough experience, which can largely increase the design intent's understanding, improve the project's constructability, and minimize changes and abortive work that can be detected prior to construction's start. Based on a BIM model, the creation of a VR environment could be easier as the 3D model will be available as soon as the BIM-based design is done.

3.3 Mobile cloud streaming

With the fast development of the mobile communication technology, video streaming over phones has become a hot topic among researchers (Banerjee and Bhatnagar, 2014). It opens up new interactive mobile opportunities, including high-performance games and video-related applications (Lawton, 2012). However, the need of resources on mobile devices for multimedia application's increases and Patil et al. (2015) proposed to use cloud resources for mobile multimedia application. Banerjee and Bhatnagar (2014) designed and implemented an adaptive video streaming and effective sharing of video framework for mobile users by using cloud assistance. Thus, mobile cloud streaming is becoming an important computing paradigm to support mobile media services for providing data and control between the cloud and mobile devices through wireless networks, including 3G and Wi-Fi (D.Londhe et al., 2015).

3.4 IPD

Since the 1960s, construction projects have experienced issues with adversarial relationships, low rates of productivity, high rates of inefficiency and rework, frequent disputes, and lack of innovation. These issues result in the increase of construction cost and duration of the project as well as the decrease of construction quality and safety. IPD is structured to address these basic problems (Thomsen and Darrington, 2010). IPD is a delivery system that utilizes a team-based method to combine integrated practices. Therefore, with the fast development of BIM technologies, the adoption of BIM and VR in IPD is urgency needed (Serginson et al., 2013).

4. THE CASE STUDY: BAILINTOU MONASTERY PROJECT

4.1 General description

Bailintou Monastery is located in Yuci District, Shanxi Provence of China. With a total area of 5000 m^2 in a mountain valley terrain, the client has a high expectation on the quality of both design and construction. Due to previous construction project experience the client is very cautious concerning the amount of time and money invested into this Monastery project; therefore, BIM and VR were used to show the client how effectively the money could be managed and display the aesthetics of the building.

4.2 Issues to be faced

This project faced three main issues as below:

a) This project adopts numbers of types of Luban Lock joints for the joint design of the external walls. Luban Lock is a traditional Chinese fabrication method with a complex structure. This increased the difficulty of fabrication and installation process. Meanwhile, as this was an IPD project, the interior decoration was also included in the project scope. The combination of building design and interior decoration was needed. Due to the complex processes above, this project needed more visual methods to coordinate onsite for IPD. Conventional 2D method would not successfully show the construction workers how to work onsite. In addition, onsite workers might not have enough 3D software skills. Thus, the first issue was the 3D visualization for the construction processes.

b) Facing the complex construction process indicated in the first issue, this project needed to involve BIM method to coordinate onsite. BIM can provide a nD model that can involve rich information including installation and

fabrication processes data, however the traditional BIM platform do not have mobile devices that can achieve VR-level applications for it. Conventional popular mobile BIM platforms such as BIM 360 GLUE, BIMx only present the roaming of a building in shade mode, which cannot make the users feel like onstage. Thus, the creation of VR environment onsite was the second issue.

c) As mentioned above, this project needed to involve video streaming to make the users feel onstage. However, the hardware requirement for it is much too high. The technology for stereoscopic videos is in common use in recent while a simple stereoscopic video would take large amounts of hardware input from the devices. It is not feasible to install the output file in the mobile phone due to the very nature of the complexity of the BIM model and texture. Moreover, video streaming normally has two screens for both eyes, which means it requires twice the amount of pipelines than the traditional graphic card. On this condition, the mobile devices might not have the power to run the calculations that such compute-intensive programs (Lawton, 2012). Thus, the work redundancy and hardware requirements while promoting the visualization of VR-based project presentations and user mobility adaptions became the third issue.

4.3 Implementation

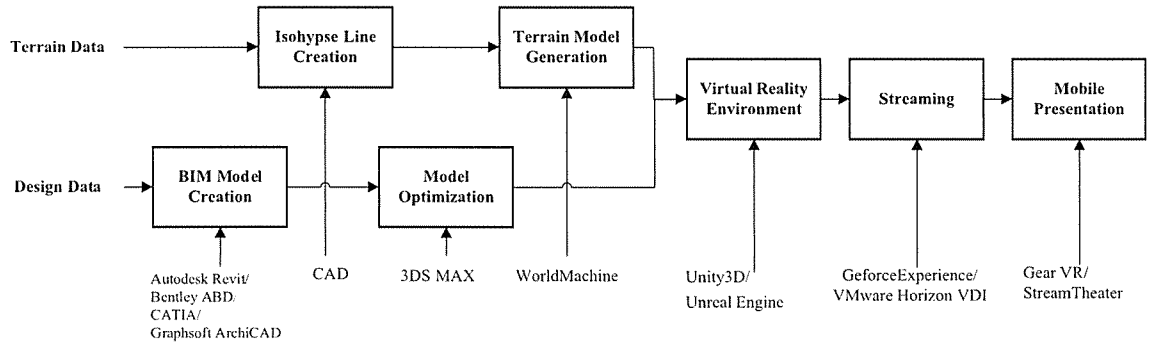

Fig 1. The process of real-time virtual reality streaming mobile devices

This proposed method is to deal with two kinds of models, including terrain models and building models. The workflow of this project is illustrated in Fig. 1. Firstly, terrain models should be generated. In World Machine, digital point-cloud terrain models from Satellites are transformed into GPS Elevation Fitting Models. Subsequently, GPS Elevation Fitting Models are integrated in Unreal Engine 4 or Unity 3D. In this project, Bailintou Monastry is located on a mountainous region. Digital point-cloud terrain models from Satellites were provided (See in **Fig. 2**) and the project team used World Machine to transform the point-cloud terrain models into GPS Elevation Fitting Models (See in **Fig. 3**). During the fitting process, a grey scale height map was used. The grey scale height map can store geographic information.

Fig. 2 Isohypse line for Bailintou Monastry project

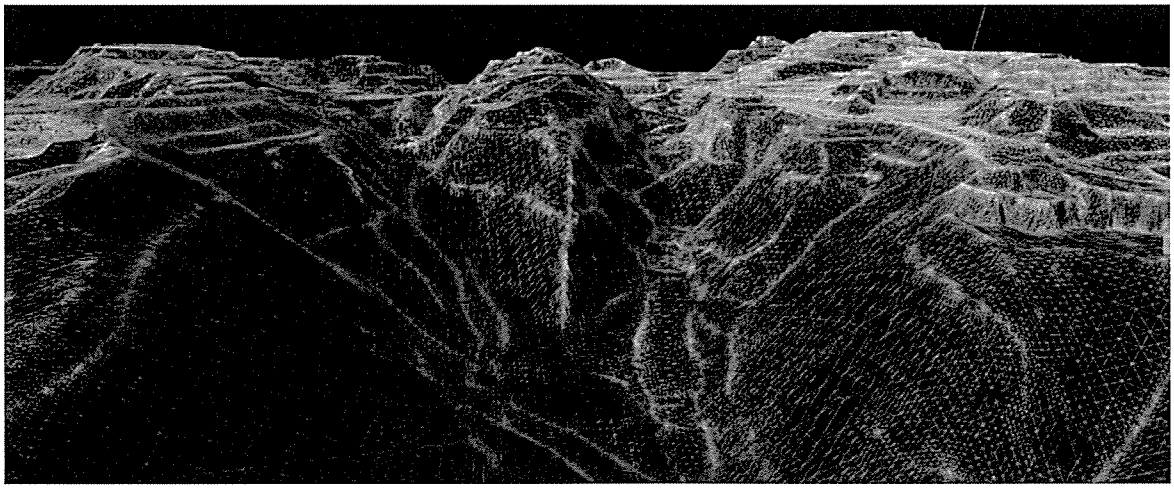

Fig. 3 Fitting terrain for Bailintou Monastry project

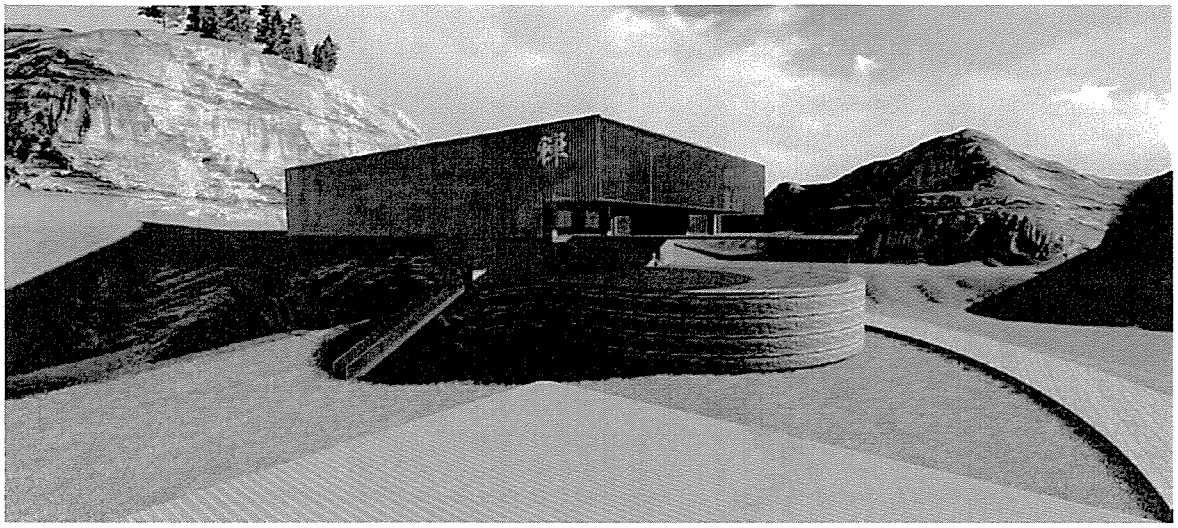

Fig 4. BIM model for Bailintou Monastry project

Secondly, BIM models should be created. Initially, BIM models for this research are generated by designers using Autodesk Revit (See in **Fig. 4**). Next, 3DS MAX is used to optimize the models, including decreasing the amount of triangle faces, distinguish different systems and setting light, reflection, texture and camera. Then, BIM models were integrated in Unreal Engine or Unity 3D, aligning with the terrain models (See in **Fig. 5**).

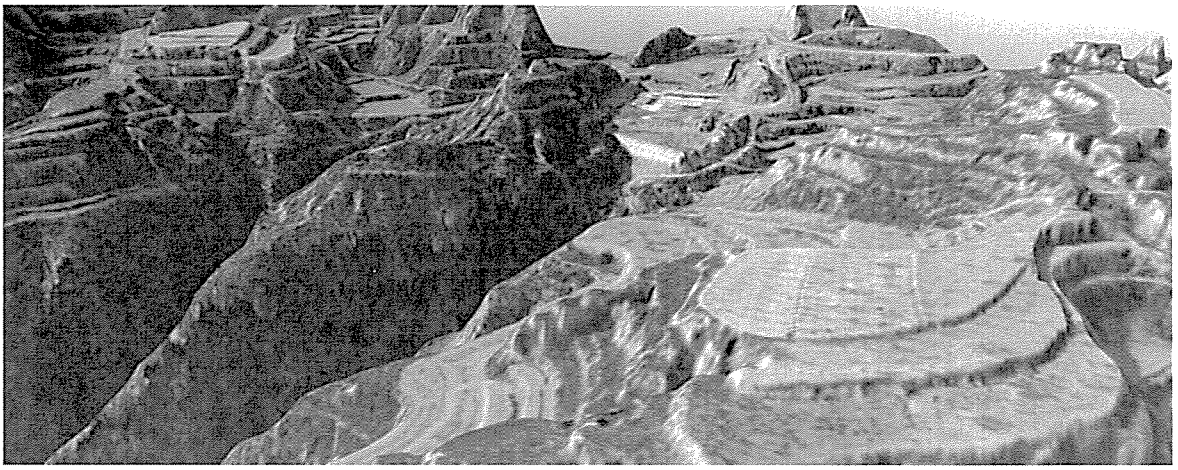

Fig. 5 Integrating BIM model and Fitting terrain for Bailintou Monastry project

Fig 6. 360-degree Stereoscopic video for Bailintou Monastry interior

Thirdly, a series of functional settings should be made in Unreal Engine or Unity 3D. At the outset, the User Interface (UI) of the VR environments should be designed. Following this, the icon, splash image and publishing settings should be set. Then, published the executable file (See in **Fig. 6**).

Fourthly, the Virtual Reality scenes can be projected by mobile cloud streaming. They were then loaded in VMware Horizon VDI with Tridef as a screen divider media. Thus, any mobile phone that connecting the VDI cloud platform can bypass the hardware limitation and enjoy the power of a workstation (See in **Fig. 7**). Despite the bandwidth the internet, VMware uses PCoIP protocol which delivers high compressed H264, aka MPEG-4 stream code of image, however, the experience shown that in order to experience a smooth control over the phone, a high upload bandwidth and reliable internet service provider are preferred. However, it faces challenges such as latency (Lawton, 2012). The mobile users often suffer from disruptions and very long buffering time while receiving video through networks like 3G or 4G due to short bandwidth and link fluctuations (Banerjee and Bhatnagar, 2014). Furthermore, problems such as privacy and reliability are also remained to be solved (Patil et al., 2015).

5. DISCUSSIONS OF THE RESULTS

Our results confirm that real-time VR has a significant impact on IPD. As IPD is expected to combine integrated practice of all stakeholders, the coordination among each stakeholder cannot be emphasized more (Thomsen and Darrington, 2010). During onsite coordination, 2D method cannot fully show the design intents. BIM can provide rich information for the installation and fabrication processes data (Wang, 2016)

The adoption of real-time VR has largely increased the project's constructability, and minimized design changes and abortive work. Due to the expensive mobile devices and small effects of mobile visualization, conventional onsite workers prefer to use interphones to communicate. Although the development of technologies has met with the requirements of mobile applications onsite, the low adoption rate of BIM and VR onsite leave the effects only conceptual. This project adopts the proposed method to integrate cloud computing in the mobile environment and

overcomes these obstacles. Onsite workers without 3D visualization skills provided good feedbacks on the effectiveness of this method that they neither need to hold expensive devices, nor receive 3D complex visualization trainings. Thus, this method can largely facilitate the adoption of BIM and VR onsite. Moreover, the improvement of the networks environment is needed. The proposed method currently can only be used onsite with a good network environment, which still largely limits the adoption of it.

Fig. 7 Cloud-based VR in mobile devices

6. CONCLUSIONS

The promotion of real-time VR in IPD has been proposed and applied in Bailintou project, while the mobile cloud streaming has been used to minimize the hardware requirements. With the development of IT technologies, the utilization of highly-efficient computer-based cloud servers is available, which means the hardware requirement of wearable devices is already set free. By applying the proposed approach, the results of the case study reflect a highly visualized coordination onsite.

The proposed approach merges BIM, VR, and mobile cloud streaming in an IPD process. Initially, BIM models are created on BIM platform such as Autodesk Revit, outputted for optimizations and imported into VR environment along with GPS Elevation Fitting Models. Next, VR environment should be created, including UI design and publish settings. After that, mobile cloud streaming can be made through VMware Horizon Client. Finally, the users login to the cloud platform in VMware and use Tridef 3D to enjoy the real-time coordination with all the stakeholders.

The proposed approach provides a simple and useful technique for IPD. Firstly, by adoption of BIM, the work

redundancy of remodel has been avoided. The building models created in BIM platform can be utilized with minor optimizations and do not need to remodel. Meanwhile, BIM platform can integrate multiple dimensional building information, which largely facilitate the visualization of VR-based project presentations. Secondly, mobile streaming provides a mobile visualization for the construction process while onsite workers are always on the construction site instead of staying in the office along with the computers. It is expected to significantly promoting the user mobility adaptions. Thirdly, the use of mobile cloud streaming can largely decrease the requirements of hardware while the hardware onsite is usually not satisfied with the requirements of VR.

However, due to the current condition, the proposed approach still faces limitations such as latency, privacy and reliability. Although this method can largely decrease the hardware requirements of onsite environment, the bandwidth and the workload of the networks could limit the effectiveness of the operations of mobile cloud streaming. Meanwhile, the network safety should be guaranteed, because this method significantly rely on networks rather than stand-alone solutions.

Thus, the futuristic research would focus on these limitations. Wide-broad Internet access and reliable network environment solution should be normalized. Otherwise, research on local area network for this topic should be adopted to avoid network troubles.

REFERENCES

AOUAD, G., WU, S., LEE, A. & ONYENOBI, T. 2013. *Computer aided design guide for architecture, engineering and construction*, Routledge.

AUTODESKINC. 2002. Building Information Modeling. *In:* INC., A. (ed.) *Autodesk Building Industry Solutions*

BANERJEE, S. & BHATNAGAR, R. Adaptive and Efficient Video Streaming and Sharing for Mobile Users Using Cloud Assistance. SARC-IRF International Conference, 12th April-2014, 2014 New Delhi, India.

CORY, C. A. 2001. Utilization of 2D, 3D, or 4D CAD in construction communication documentation. *Fifth International Conference on Information Visualisation.* IEEE.

D.LONDHE, R., SHEREKAR, S. S. & THAKARE, V. M. 2015. Cloud-based Mobile Video Streaming Techniques. *International Journal of Computer Applications*, 0975-8887.

EASTMAN, C. F., DAVID; LAFUE, GILLES; LIVIDINI, JOSEPH; STOKER, DOUGLAS; YESSIOS, CHRISTOS 1974. An Outline of the Building Description System.

G. A. VAN NEDERVEEN, F. T. 1992. Modelling multiple views on buildings. *Automation in Construction,* 1, p215-224.

GOULDING, J. S., RAHIMIAN, F. P. & WANG, X. 2014. Virtual reality-based cloud BIM platform for integrated AEC projects. *Electronic Journal of Information Technology in Construction,* 19, 308-325.

KOUTSABASIS, P., VOSINAKIS, S., MALISOVA, K. & PAPAROUNAS, N. 2012. On the value of Virtual

Worlds for collaborative design. *Design Studies,* 33, 357-390.

LAWTON, G. 2012. Cloud Streaming Brings Video to Mobile Devices. *Computer,* 45, 14-16.

MARC, B. 2014. Exploring the impact of virtual reality in design review processes.

PATIL, N., PATIL, N., BAGAL, A., DESAI, M. & BHOSALE, A. 2015. Development of Android Mobile Application for Cloud Video Streaming using Mobile Cloud Computing. *International Journal of Computer Science and Information Technologies,* 6, 1990-1993.

SCHANTZ, H. 1989. Banking, information, and imaging standards from a users' perspective.

SERGINSON, M., MOKHTAR, G. & KELLY, G. 2013. A Theoretical Comparison of Traditional and Integrated Project Delivery Design Processes on International BIM Competitions. *International Journal of 3-D Information Modeling,* 2, 52-64.

SHI, Y., DU, J., LAVY, S. & ZHAO, D. 2016. A Multiuser Shared Virtual Environment for Facility Management ☆. *Procedia Engineering,* 145, 120-127.

SHIRATUDDIN, F. 2015. A comparative study of Virtual Reality displays for construction education. *Jundishapur Journal of Microbiology,* (8).

THABET, W., SHIRATUDDIN, M. F. & BOWMAN, D. 2002. Virtual Reality in Construction. *Engineering Computational Technology.* Saxe-Coburg Publications.

THOMSEN, C. & DARRINGTON, J. 2010. Managing integrated project delivery.

TIAN, C., GUO, H. P., ZHANG, J. & XU, X. T. The Design of Hydraulic Virtual Roaming System Based on Virtual Reality Technology. International Conference on Fluid Power and Mechatronics, 2011. 775 - 778.

WANG, S. S. 2016. Research on Data Conversion of BIM Building Model in VR System. *Value Engineering.*

WATSON, A. & ANUMBA, C. 1991. The need for an integrated 2D/3D cad system in structural engineering. *Computers & structures,* 41, 1175-1182.

WOKSEPP, S. & OLOFSSON, T. 2008. Credibility and applicability of virtual reality models in design and construction. *Advanced Engineering Informatics,* 22, 520-528.