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A STEP-BY-STEP PROCEDURE FOR IMPLEMENTING MIXED REALITY VISUALIZATION INTERFACES IN DESIGN AND CONSTRUCTABILITY REVIEW SESSIONS

Suleiman Alsafouri[1] and Steven K. Ayer[2]

Abstract: In modern construction projects, architects, engineers, and designers use different methods of construction visualization to support the conceptualization and final appearance of design ideas. This includes the use of virtual Building Information Modelling (BIM) content, as well as physical mock-ups to support design visualization for decision-making prior to construction. Prior research has demonstrated a variety of benefits that BIM can provide for visualization. Mixed Reality (MR) may be able to offer some of the benefits of both purely physical mock-ups and purely virtual BIM walkthroughs. However, the prior studies used specific computing devices and MR applications for specific construction use-cases. The goals were to solve a specific problem, or to prove the concept that MR is possible for various uses. Therefore, it was necessary to develop the exact same MR environment that could run on different computing devices. This will allow for identification of the differences between different computing devices running the exact same MR environment. This paper presents a consistent methodology for leveraging existing BIM contents to generate marker-based MR environments on various commercially available computing devices. This study tests the methodology for development and validates it through successfully building and running the same MR environment on various devices. Additionally, challenges associated with implementing this visualization mode in design and constructability review sessions were highlighted. The research questions addressed include: 1) What are the steps needed for developing MR visualisation interfaces in design and constructability review sessions? and 2) What are the possible constraints that may influence MR performance on different mobile computers? The conclusion from this study will help researchers better understand the process for MR implementation and the limitations in using this visualization environment. Additionally, it may help to expand the use of MR interfaces for different construction use-cases.

Keywords: Mixed Reality, Mixed Reality Markers, design and constructability review session, construction technology, and construction visualization.

1 INTRODUCTION

Various new developments in computing, modelling, and visualization technologies have allowed Architecture, Engineering, and Construction (AEC) industries to use emerging computer visualization interfaces in their review sessions. These technologies include the use of virtual Building Information Modelling (BIM) contents, Physical Mock-ups, and Mixed Reality (MR) technology. Such technological advancements have become essential

[1] Graduate Research Associate, School of Sustainable Engineering and the Built Environment, Arizona State University, Arizona, USA, suleiman.alsafouri@asu.edu

[2] Assistant Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, Arizona, USA, steven.ayer@asu.edu

in driving the design process because they support collective decision making and ease the visualization approaches used throughout different project phases, especially when project stakeholders come together to review a concept within a project design during design and constructability review sessions.

MR technologies have become increasingly accessible due to their inexpensive hardware components and the overall effect of the mass-market demand for such technologies. As a result, there is a need for the establishment of detailed procedures to guide how this MR technology can and should be used most effectively during design and constructability review sessions. MR has been widely used by researchers in the construction industry who interact with various hardware and software technologies daily. There are now many different mobile computing options available that can enable MR, and this paper presents a consistent methodology for leveraging existing BIM contents to generate marker-based MR environments on various commercially available mobile computing devices to be used in design and constructability review sessions. To begin establishing such a procedure, this research addresses the following research questions: 1) What are the steps needed for developing MR visualisation interfaces for design and constructability review sessions? and 2) What are the possible constraints that may influence MR performance on different mobile computers?

2 Design and Constructability Review Sessions

Prior work reveals that design review sessions are crucial for detecting and identifying conflicts, errors and inconsistencies in designs (East et al. 1995; East 1998; Spillinger 2000; and East et al. 2004). Additionally, the design review process produces immediate benefits for the stakeholders involved (East et al. 2004). While various benefits of current design review practices were highlighted by researchers, there are also various drawbacks that may impede the progress of these sessions. According to East (1998), design reviewers are subject to many pressures in the design review process such as time-consuming processes, backlogs of un-reviewed drawings, and specifications, which can lead to reviewers sacrificing the thoroughness of their reviews. This highlights the need to implement effective and efficient review sessions.

3 Mixed Reality

Virtual Reality and Physical Mock-up techniques have been used by many researchers to support design review sessions (Bassanino, M., 2010; Stern, 2004). These prior studies often present the opportunities and challenges that were observed through the use of these technologies. Physical Mock-ups allow users to interact with physical objects and physically navigate a design to support decision making (Stern, 2004), but they can be challenging to quickly modify to try multiple "what-if" design scenarios. On the other hand, Virtual Reality mock-ups can allow for quick modification to experiment with design alternatives, but some research suggests that what is communicated through VR is prone to misinterpretation among viewers (Saleeb N. 2015). Mixed Reality combines both the tangible elements of Physical Mock-ups with the rapidly modifiable elements of Virtual Reality, which suggests a potential for it to enable effective and collaborative design and constructability review sessions (Dong S. et al. 2013; Wang X and Dunston P. 2008).

MR has been widely used by researchers in the construction industry. For example: MR has been used in site management, inspection processes, and on-site construction procedures (Kim et al. 2013), as well as for supporting collaboration among design team members (Jun Wang et al. 2014). Additionally, MR technology was facilitate on different mobile interfaces such as smartphones (Kim et al., 2013; Hakkarainen et al., 2008), laptops for inspection processes (Shin and Dunston 2010), tablets (Riera et al., 2014), and head mounted displays for supporting collaboration among design team members (Wang and Dunston 2011; Jun Wang et al., 2014). The prior works have effectively proved the concept that MR may be able to offer value in various design and construction use-cases. However, most prior studies aimed to develop an MR environment for just one device (Ayer S. et al. 2014). Therefore, with the increased potential of using mobile computing to facilitate several BIM use-cases in the industry (Alsafouri S. et al. 2015), and with the plethora of mobile choices available today, it was necessary to develop the exact same MR environment that could run on different computing devices. This will allow for identification of the differences between different computing devices running the exact same MR environment. This paper illustrates a step-by-step procedure for leveraging existing BIM contents to generate marker-based MR environments on various commercially available computing devices.

4 Research Aim and Methodology

A marker-based MR application was designed specifically for this research in order to illustrate the procedures necessary for creating an effective and efficient review session using MR technology. The process of developing the MR application was divided into three main phases as shown in Figure 1.

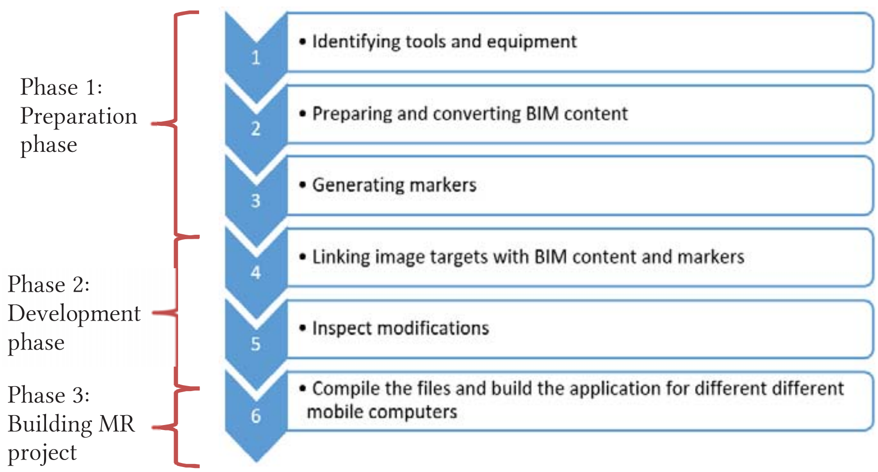


Figure 1 the sequence of the steps used throughout developing an MR interface in design and constructability review sessions

4.1 Preparation Phase

4.1.1 Identifying tools and equipment required for the MR visualization interface

There are several different tools currently available for developing MR applications, but it is essential that, in terms of hardware, the equipment have a computer component with a camera attached, such as desktop computers, handheld computers (e.g. smartphones and tablets), and wearable devices (e.g. transparent smart glasses and head-mounted displays). Additionally, there are several Software Development Kits (SDKs) commercially available for developing MR applications, such as ARPA, ARLab, Vuforia, and Wikitude. These

SDKs offer numerous features for MR interfaces such as 3D object rendering, multi-image detection or tracking, and user interaction (e.g. selection, rotation, scaling). Finally, in order to compile SDK and modified scripts into the application program interface, a gaming engine or rendering engines such as 4A engines, Alamo, and Unity 3D editor are necessary.

In this study, the authors used Unity 3D gaming engine because of its ability to use one development environment and then export the application to different platforms such as Android, IOS, and Windows machines. This flexibility allowed for the same development kit to be implemented on different mobile computers that run different platforms. This research also used Vuforia SDK to develop the marker-based MR environment.

4.1.2 Preparing/converting model content into an understandable language for MR

When choosing a gaming engine, it is essential for the gaming engine and BIM content format to be compatible. Because this study used the Unity 3D editor, different model file formats could be imported, such as .fbx, .obj, .dea, dxf, 3DS, and .skp. If the 3D contents environment uses different file formats than the gaming engine, those files need to be converted and exported into readable file formats. Various programs for converting files, such as 3DS Max or Blender, are commercially available to export and convert files into required file formats.

4.1.3 Generating Markers

Several marker-based MR tracking systems have been commonly used within different disciplines in the AECO industries. Research papers have been published on the performance of MR markers by using different algorithms to enhance tracking and localizing markers in 3D spaces (Olson, Edwin 2011). ARToolkit was among the first MR marker-based tracking systems used. The markers developed in this system contained a square-shaped surrounded by a black border and used symbols such as monochrome, Latin, characters (H. Kato and M. Billinghurs 1999). Another example provided improved detection and coding schemes, where the detection mechanism was based on the image gradient, making it robust to changes in lighting (M. Fiala 2005). In addition to monochrome tags, other coding systems have also been developed for several MR uses (Bagherinia, H. and Roberto M. 2013). Color information has been used to increase the amount of information that can be encoded (D. Parikh and G. Jancke 2008). Also, 3-dimensional, real-time object identification and registration markers were developed by researchers (Collet A. et al. 2009). However, this particular study did not aim to develop a new or unique algorithm to enhance MR tracking and localization approaches. Instead, this paper aimed to illustrate a single process of steps that would enable development of a MR environment and markers that could be used for various different commercially available computing. The goal behind this illustration is to use same MR application on different mobile computing devices, allowing researchers to not only study MR and marker developments to facilitate a specific implementations, but also how human users interact with and behave while using different MR interfaces. Therefore, the steps presented illustrate this process for consistent development. Additionally, potential challenges and factors that might influence the tracking and localization processes through the development were highlighted.

After preparing BIM content (section 4.1.2) and setting up the required software (e.g. Unity 3D and Vuforia SDK) for a specific MR design review scenario, markers were prepared. These markers were designed to work properly with the modified Image Target scripts within the MR application. There were several challenges that had to be overcome, such as ensuring the quality of the application's outputs related to the tracking process, tracking distance, and marker sizes. For example, if a user wanted to see a large-scale object, the camera of the device being used would have to be able to track the object marker over a sizeable enough distance for the large-scale object to be observed accurately in the space. However, with the increase in distance between the device's camera and the object marker, sometimes the camera could not read the marker anymore and the virtual large-scale object would disappear. Therefore, larger markers were created so that the devices' cameras could track them over longer distances, allowing users to see whole, large-scale objects at once. This means that the size of the markers should be determined based on the scale of the chosen objects for each design review scenario.

Another factor that influenced tracking behaviour was the marker quality. The quality of the markers is determined by the quantity of pre-identified features on each marker. The more features on the markers, the better the tracking process becomes. Markers with more features also produce more stable objects. Therefore, optimizing marker quality is an important process that can lead to better outcomes for design review scenarios. The following steps illustrate the process for generating the high-quality markers used in this research:

In general the markers used in this study are two dimensional symbol markers, similar to a QR code that allows a camera to determine position and rotation relative to a surface by reading features embedded in that symbol. The amount of features in any symbol is not only limited special markers generators or QR codes engines. Any picture captured from any camera (ex. Smartphone camera) may also include a good amount of features which facilitate MR tracking processes, thus using those features as marker. Figure 2 is an example to illustrate how any picture taken from a smartphone camera could be a marker with several amount of features.

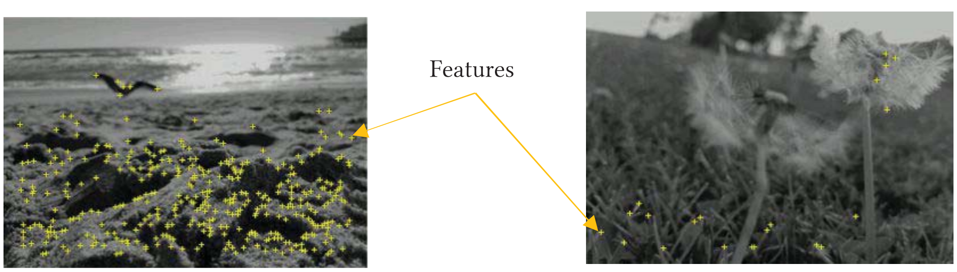
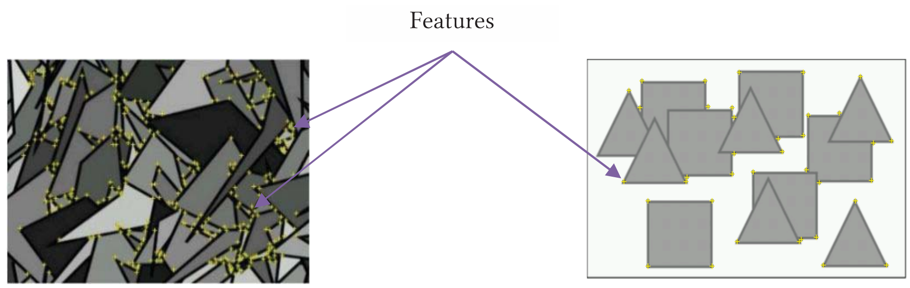


Figure 2 Pictures took from smartphone's camera that showed several amount of features which can also be used as MR marker

After defining images needed to function as markers, it is essential to understand the process to maximize features within the images. Generally, more shapes, triangles, lines, and quadrangles means more information can be stored and read on each marker. Figure 3 illustrates that imagines with more shapes, triangles, lines, and quadrangles generates higher quantity of features.



High number of shapes, triangles, lines, and quadrangles lead to having high quantity of features

Low numbers of shapes, triangles, lines, and quadrangles lead to having high quantity of features

Figure 3 difference between having high and low numbers of shapes, triangles, lines, and quadrangles in marker images

The next step is to modify the density, grid sizes, contrast, and brightness as well as to convert the image pixels into a poster that can be printed and become the marker. The objective of this step is to increase the number of triangles, lines, and quadrangles, which leads to an increased number of features (Figure 4). Modifying density, grid sizes, contrast, and brightness could be done through different software or online engines available in the market. However, this step could be optional according to the number of features obtained in the images. The following process will illustrate how to test if the number of features are enough for best tracking practices.

Figure 4 Converting images' pixels into poster style layout to increase the number of features

At this stage, files were converted from PDF to JPG using available software or online converting engines. Vuforia can only accept JPG and PNG file formats currently with less 2 MB file size.

In the Vuforia website, images were uploaded as Target Images for two reasons. First, the JPG files were converted to Unity packages to allow the Vuforia plugin to read the images as predefined Target Images in the Unity 3D environment. It is important to make sure the images have a rating of five stars, meaning there is a good number of trackable features in each marker.

Finally, the database can be downloaded as a Unity package from Vuforia Targets data set. This package includes the "Image Targets" that work on the Unity 3D editor, and will later represent images that the Vuforia SDK can detect and track. The SDK detects and tracks the features that are naturally found in the image itself by comparing these natural features against a known target resource database. Once the Image Target is detected, the SDK will track the image as long as it is at least partially in the device camera's field of view.

4.2 Development Phase

In order to begin developing an MR application, there are four main components that need to be set up in the computer: Unity 3D, Vuforia SDK, markers in the Unity package format, and model contents. The first step in this phase is to open the Unity 3D editor and create a new project. Then the Vuforia SDK package downloaded in prior steps can be opened and the Unity 3D editor will start importing the Vuforia package. The second step is to drag ARCamera and Image Target prefabs from the Assets window into the Hierarchy window. Drag multiple Image Targets if the purpose is to augment multiple components simultaneously. After that import BIM contents into the Assets window by dragging and dropping the contents (e.g. .fbx, obj) directly into the Assets window. Drag the model contents again into the Image Target prefab that was added in the prior step in the Hierarchy window. More than one Image Target can be added with different model contents. Lastly, click on the Image Target and navigate through the Image Target Behavior tab under the Inspector window to choose the pre-identified markers' names that have already developed and link those markers with model contents.

4.3 Building the MR project

Building the application can be managed in the gaming engine and different gaming engines may offer various options for compiling scripts. In this research, Unity 3D was used to develop the application, but there are several different platform options under the Platform window. The authors of this paper used the Android platform, so therefore an Andriod SDK needed to be downloaded prior to building the project. Other SDKs can be downloaded if another platform, such as IOS or Windows, is being used. However, there are additional options under the Player Setting button. The player setting allows users to change the default Bundle Identifier to a custom name. (This step is necessary for the Android platform.) The last step is to build the application by hitting Build Option and upload the app file into any mobile device.

5 Research Findings and Future Considerations

The methodology for this research included developing consistent MR environment content for the following Android devices: two different smartphones, two different tablets, two smart glasses, and one VR Box. All devices were able to depict the MR content through the same set of printed markers. Even though current mobile computer technology can run mixed reality visualization interfaces in design and constructability review sessions, the performance often fluctuates based on multiple constraints, including the cameras' resolutions, processor performance for rendering, and display quality.

Although multiple markers were used and full scale objects were augmented in different design scenarios, the number of markers dramatically influenced the tracking performance. There was a direct relationship between the object's scale and the marker's size. This was also influenced by the distance between the objects and the devices. However, despite these influences and differences in performances, all devices used in this research were able to run the exact same MR application. Therefore, this may help to identify and understand if project stakeholders may behave differently using different mobile MR interfaces.

This research was limited to marker-based MR applications related to design and constructability review sessions and used only Android devices; however, this process may also be beneficial in other use-cases.

6 CONCLUSION

While prior research has illustrated the potential for using single MR devices for design and constructability review sessions, this work presents a single methodology to enable development for various different mobile computing devices. This will allow researchers to identify the behavioural differences that may exist between users experiencing MR through different computing devices. Therefore, the contribution of this study was to help identify the developmental process that could enable the same MR design review environment to be built and run on different mobile computers including handheld and wearable devices. This paper illustrates a step-by-step procedure for leveraging existing BIM contents to generate marker-based MR environments on various commercially available computing devices. The process presented involves three main phases: the preparation phase, the development phase, and the verification phase. This may enable future developers and researchers to more easily implement MR design and constructability review sessions in the early stages of construction projects.

In addition to identifying the steps needed to develop a MR application, this study identified various challenges that may occur throughout the development process. The method used in this research to generate markers and defining factors affecting those markers' quality will help future researchers to have better tracking and localization processes and more stable objects. This study is part of a larger body of research aimed at understanding human behaviours for MR visualization approaches in design and constructability review sessions.

7 REFERENCES

A. Mohan, G. Woo, S. Hiura, Q. Smithwick, and R. Raskar, "Bokode (2009). Imperceptible visual tags for camera based interaction from a distance, *ACM Trans. Graph.*, vol. 28, pp. 98:1–98:8.

Alsafouri, S., Ayer, S. K., and Tang, P. (2015). Mobile virtual design and construction adoption in the architecture, engineering, construction and operation fields. *CONVR 2015*. p. 415

Ayer, S., Messner, J., and Anumba, C. (2014). Development of ecoCampus: A prototype system for sustainable building design education. *Journal of Information Technology in Construction*, 19, 520-533.

Bagherinia, Homayoun, and Roberto Manduchi. (2013). Robust real-time detection of multi-color markers on a cell phone. *Journal of real-time image processing,* 8.2: 207.

Bassanino, M., K. C. Wu, J. Yao, F. Khosrowshahi, T. Fernando, and J. Skjærbæk. (2010). "The Impact of Immersive Virtual Reality on Visualisation for a Design Review in Construction." In *14th International Conference Information Visualisation*, 585–89.

Collet, Alvaro, et al. (2009). Object recognition and full pose registration from a single image for robotic manipulation. *IEEE International Conference on Robotics and Automation*. ICRA'09.

D. Parikh and G. Jancke, (2008). Localization and segmentation of a 2D high capacity color barcode. In *WACV '08: Proceedings of the 2008 IEEE Workshop on Applications of Computer Vision*. Washington, DC, USA.

Dong, S., Behzadan A.H., Feng, C., and Kamat, V.R. (2013). Collaborative Visualization of Engineering Processes Using Tabletop Augmented Reality, *Advances in Engineering Software*, 55.

East, W. (1998). *Web-Enabled Design Review and Lessons Learned. Champaign*. Army Corps of Engineers Construction Engineering Research Laboratories. IL: U.S

East, W., Kirby, J.G., & Perez, G., (2004). Improved design review through web collaboration. *Journal of Management in Engineering*, 51-53.

East, W., Roessler, T.L., & Lustig, M., (1995), Improving the design-review process: The Reviewer's Assistant. *Journal of Computing in Civil Engineering*.

Gotow JB, Zienkiewicz K, White J, Schmidt DC, (2010). "Addressing challenges with augmented reality applications on Smartphones". *Proceedings of the 3rd international conference on mobile wireless middleware, operating systems, and applications*, LNCS, 48, 129–143

H. Kato and M. Billinghurst, (1999). Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *IWAR '99: Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality*. Washington, DC, USA, p. 85.

Hakkarainen, Mika, Charles Woodward, and Mark Billinghurst. (2008). *Augmented Assembly Using a Mobile Phone. In Mixed and Augmented Reality*, *7th IEEE/ACM International Symposium on ISMAR*, 167–168.

Jun Wang, Xiangyu Wang, Wenchi Shou, and Bo Xu. (2014). Integrating BIM and Augmented Reality for Interactive Architectural Visualisation. *Construction Innovation*, 14 (4): 453–76.

Kim, Changyoon, Taeil Park, Hyunsu Lim, and Hyoungkwan Kim. (2013). On-Site Construction Management Using Mobile Computing Technology. *Automation in Construction*, 35: 415–23.

Olson, Edwin. (2011). AprilTag: A robust and flexible visual fiducial system. *IEEE International Conference on Robotics and Automation (ICRA)*.

P. C. Santos, A. Stork, A. Buaes, C. E. Pereira, and J. Jorge, (2009). *A real-time low-cost marker-based multiple camera tracking solution for virtual reality applications*.

Riera, Albert Sánchez, Ernest Redondo, and David Fonseca. (2014). Geo-Located Teaching Using Handheld Augmented Reality: Good Practices to Improve the Motivation and Qualifications of Architecture Students. *Universal Access in the Information Society* 14 (3): 363–74.

Saleeb, Noha M., 2015, Discrepancies between Human Virtual and Physical Space Perception: Impact on Design Visualization. In *Proceedings of the 15th International Conference on Construction Applications of Virtual Reality (CONVR)*. Banff, Alberta, Canada.

Shin, Do Hyoung, and Phillip S. Dunston. (2010). Technology Development Needs for Advancing Augmented Reality-Based Inspection. *Automation in Construction*, 19 (2): 169–82.

Spillinger, Ralph S., 2000, Adding Value to the Facility Acquisition Process. *Best Practices for Reviewing Facility Designs*.

Stern, Robert A. M. Architects, and HLM Design (2004). *Courtroom Mock-Up Report*, Richmond, VA.

Wang X, Dunston P. (2008). User perspectives on mixed reality tabletop visualization for face-to-face collaborative design review. *Automation in Construction*, 17:399–412.

Wang, Xiangyu, and P.S. Dunston. (2011). Comparative Effectiveness of Mixed Reality-Based Virtual Environments in Collaborative Design. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*, 41 (3): 284–96.