Comparison of Virtual Communication Environment for Remote BIM Model Review Collaboration

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Abstract –

Remote building information modeling (BIM) model review collaboration is the trend in the architecture, engineering, and construction (AEC) industry. Virtual communication environment is a key factor in a successful collaboration. However, the proper environment has yet to be fully revealed. Therefore, this study aims to identify the effective environment. We identified the environment with three main types and then proposed and developed the corresponding environment namely BIM-based, PC-based virtual BIM reviewer (VBR), and VR-based VBR. A user test has been conducted to evaluate their performance and task loading in finding issues and reaching consensus. In the test, the participants were asked to find four kinds of issues and determine the top five issues and their solutions. The result shows that in finding issues, the average of issues they found in BIM-based, PC-based VBR, and VR-based VBR are 6.57, 9.77, and 9.91. The performance of PC-based VBR and VR-based VBR are no significant difference ($\alpha = 0.461462$) but both of them are significantly better than BIM-based ($\alpha = 0.000339$ and 0.004431). However, the averages of task loading in finding issues are 899.50, 813.84, 807.00 with no significant difference. In reaching consensus, the averages of seconds they used are 740.67, 682.93, and 724.40 with no significant difference. However, the averages of task loading in both of PC-based VBR ($\mu = 721.00$) and VR-based VBR ($\mu = 718.10$) are significantly lower than BIM-based ($\mu = 867.00, \alpha = 0.009610$ and 0.013879). In overall, both PC-based VBR and VR-based VBR have better performance in finding issues and lower task loading in reaching consensus.

Keywords –

Remote collaboration; Virtual communication environment; BIM model review

1 Introduction

The beginning of remote collaboration can be considered starting from the offshoring and outsourcing of services that emerged in the late 1980s and early 1990s [1]. With the rapid development of information and communications technology reduces the barriers of remote collaboration, remote collaboration has become the trend in many industries. In the AEC industry, there are also many construction teams consist of engineers and architects located in different regions or countries requires remote collaboration. For instance, the Oakland Bay Bridge is manufacturing in China and fabricating in the United States [2], Taiwan High Speed Rail Project consists of many experts from different countries including Taiwan, Britain, Denmark, India, and other countries [3], and Taiwan Taoyuan International Airport Terminal 3 is also a remote collaboration example that is joint contracted by Taiwan, Britain, and Hong Kong companies.

BIM is a novel approach in the AEC industry [4]. The concept of BIM is being a data center that integrates geometric and functional information during the building life-cycle. The information will be represented in a visualized 3D model for project participants to use. BIM supports strong spatial cognition and abundant information that can reveal most the of design issues in the early design stage through BIM model review, which is a repeated design process reviews visualized information model from various aspects, such as design, construction, specification, and safety, to decipher a proper solution [5].

Remote BIM model review collaboration is the trend in the AEC industry [6]. However, the existing common virtual communication environments, such as Skype, Hangout, Join.me, Zoom, Sococo, etc., can only help users review BIM models with a shared screen-view controlled by one of the users. This is easy to build the virtual communication environment but hard to provide the senses of teamwork and immersive exploration.

Without both of them will reduce the effectiveness of remote BIM model review collaboration. Some researchers mention that virtual avatar [7-10] and virtual reality [11] will solve these problems, but they are more focused on finding issues rather than reaching the consensus of final solutions. Although we know the communication environment is a key factor in a successful collaboration [12]. However, the proper communication environment has yet to be fully revealed.

2 Research Goals

This study aims to identify effective communication environments for BIM model review collaboration with following goals: (1) identify the main types of virtual communication environment; (2) propose and develop these communication environments; (3) evaluate their performance and task loading in finding issues and reaching consensus.

3 Virtual Communication Environment

In this study, we classified virtual communication environment types by two factors: the flexibility of exploration and the degree of immersive. The flexibility of exploration consists of passive exploration and proactive exploration. The degree of immersive consists of semi-immersive and full-immersive. Therefore, we have four kinds of type: (1) Type I: a passive exploration with semi-immersive; (2) Type II: a passive exploration with full-immersive; (3) Type III: a proactive exploration with semi-immersive; and (4) Type IV: a proactive exploration with full-immersive. Four types of virtual communication environment are listed in Table 1.

Table 1. The types of virtual communication environment

		The flexibility of exploration	
		Passive	Proactive
The degree of immersive	Semi-	Type I	Type III
	Full-	Type II	Type IV

In the existing common approaches to implementing these four types. It often uses screen-sharing-based to implement passive exploration and virtual-avatar-based to implement proactive exploration. Regard to the semi-immersive and full-immersive will often be implemented on PC devices and VR devices respectively. However, Type II is not reasonable and will not be practiced due to the dizziness issue. If users fully immersive themselves into a virtual environment but the view is controlled by others, it will cause serious dizziness to them. Moreover, in the existing VR technology, most of them already provide a virtual avatar for each user no matter it is visible or not. Therefore, this study will only focus on discussing Type I, III, and IV. We proposed and developed three environments to the Type I, III, and IV namely BIM-based, PC-based VBR [13], and VR-based VBR [13] respectively. The reviewing tool, conference tool, display device, control device, etc. they used are listed in Table 2.

Table 2. The implementation of the three main types

	BIM-based	PC-based VBR	VR-based VBR
Reviewing tool	Revit 2016	VBR (PC)	VBR (VR)
Conferencing tool	Sococo	Sococo	Sococo
Exploration type	Screen-sharing	Virtual-avatar	Virtual-avatar
Display device	Screen	Screen	VR goggles
Control device	Keyboard and mouse	Keyboard and mouse	VR controllers and VR goggles
Communication device	Microphone and headphone	Microphone and headphone	Microphone and headphone

3.1 BIM-based Environment

The BIM-based environment allows users to review BIM models by a reviewing tool, Revit 2016. Users can navigate and manipulate the models in Revit 2016 by keyboard and mouse. They can communicate with each other through a conferencing tool, Sococo. They will use microphones, headphones, and screen-sharing in Sococo. Users using the BIM-based environment is shown in Figure 1.

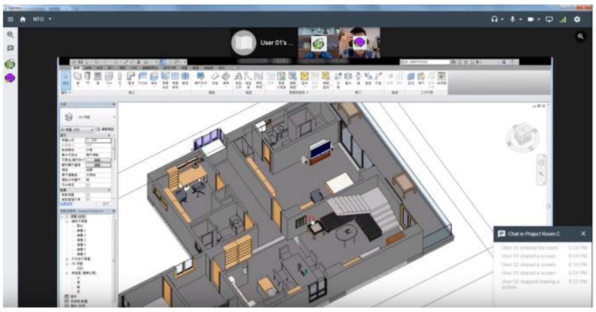

Figure 1. Users using the BIM-based environment

3.2 PC-based VBR Environment

The PC-based VBR environment allows users to review BIM models by a reviewing tool, VBR (PC). Users can navigate and manipulate the models in VBR (PC) by keyboard and mouse. They can communicate with each other through a conferencing tool, Sococo. They will only use microphones and headphones in Sococo. They do not use the screen-sharing through Sococo since they can directly interact with each other in a virtual environment through VBR (PC) by their own avatars. Users using the PC-based VBR environment is shown in Figure 2.

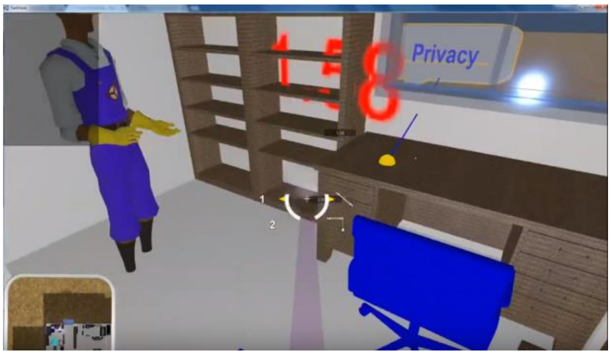

Figure 2. Users using the PC-based VBR environment

3.3 VR-based VBR Environment

The VR-based VBR environment allows users to review BIM models by a reviewing tool, VBR (VR). Users can navigate and manipulate the models in VBR (VR) by VR goggles and controllers. They can communicate with each other through a conferencing tool, Sococo. They will also only use microphones and headphones in Sococo and directly interact with each other in a virtual environment through VBR (VR) with their own avatars. Users using the VR-based VBR environment is shown in Figure 3.

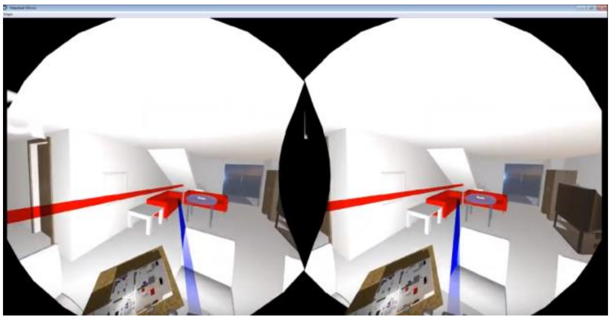

Figure 3. Users using the VR-based VBR environment

4 Evaluation

This study designed a Space Feasibility Inspection test to evaluate the performance and task loading of BIM-based, PC-based VBR, and VR-based VBR in finding issues and reaching consensus. We used Revit 2016 to build an example BIM model with four kinds of issues: usability, safety, privacy, and others. This model is a common living space including one living room, one dining room, one kitchen, one bathroom, one study room, one bedroom with bathroom, and one balcony. One example of the usability issue is that the height below the stair is too short that users are not comfortable to use the sofa. One example of the safety issue is that the table and the chair are too close to the fence. Once someone climbs on, he will be exposed to the falling danger. One example of the privacy issue is that the sliding door window would be better to have a curtain for privacy. Regarding other issues, one example of other issues is a construction problem. It is better to locate both bathrooms next to each other. So it will only require one piping space.

There are four phases in this test. The pre-phase has 3 minutes for demographics questionnaire. Then, the first phase is finding issues. It has 5 minutes for explanation and practicing, 12 minutes for finding issues, and 5 minutes for task loading questionnaire. After the first phase, the second phase is reaching consensus. It has 5 minutes for explanation and practicing, 12 minutes for reaching consensus, and 5 minutes for task loading questionnaire. Finally, the post-phase has 5 minutes for overall post-questionnaire and 8 minutes for an interview discussion. The flow-chart of this experiment is listed in Table 3.

Table 3. The procedure of user test

Phase	Description	Time (Minutes)
Pre-phase	Demographics questionnaire	3
1st phase: Finding issues	Explanation and practicing	5
	Finding issues	12
	Task loading questionnaire	5
2nd phase: Reaching consensus	Explanation and practicing	5
	Reaching consensus	12
	Task loading questionnaire	5
Post-phase	Post-questionnaire	5
	Interview discussion	8

In this test, we random recruited 90 participants and separate them into 45 groups, each environment has 15 groups and each group has 2 participants. The participants know each other before they come to the experiment to prevent the communication barriers caused by they are not familiar with each other.

At the beginning of this experiment, two participants and two research assistants meet in the same room. While all members arrive, one participant and one research assistant will go to room A. The others will go to room B. They do the same thing in the two different rooms. In the pre-phase, the research assistants will guide the participants to fill out the demographics questionnaires.

Next, the research assistant will explain the control manners of reviewing tools (Revit 2016 / VBR) and the task (finding issues) in the first phase within 5 minutes. Participant has 12 minutes to find issues as many as possible. After 12 minutes, the research assistants will guide the participants to fill out task loading questionnaires of finding issues.

Then, the research assistants will guide the participants to use a conferencing tool (Sococo) to communicate with each other. After 5 minutes of practicing, they were asked to list the top 5 issues they want to solve and also negotiate the proper solution within 12 minutes. They are also required to fill out the task loading questionnaires of reaching consensus.

Finally, they will turn off the conferring tool and fill out the overall post-questionnaires. After that, the research assistants will ask questions we designed and other questions related to the participants' 1st phase and the 2nd phase behaviors.

5 Results and Discussions

In the test, we measured (1) the average issues they found in finding issues (Table 4); (2) the average task loading in finding issues (Table 5); (3) the average time they used in reaching consensus (Table 6); and (4) the average task loading in reaching consensus (Table 7).

In the finding issues phase, the performance of PC-based VBR ($\mathbf{\mu = 9.77}$) and VR-based VBR ($\mathbf{\mu = 9.91}$) are no significant difference ($\mathbf{\alpha = 0.461462}$) but both of them are significantly better than BIM-based ($\mathbf{\mu = 6.57, \alpha = 0.000339\ and\ 0.004431}$). We further compared the performance in usability, safety, privacy, and other aspects of PC-based VBR and VR-based VBR. The results show that PC-based VBR is better in safety and privacy issues. VR-based VBR is better in usability and other issues. It may be caused by that VR-based VBR supports full-immersive experience enhancing participants more focus on simulating whether space is convenient for use. Regarding the averages of task loading in finding issues are 899.50, 813.84, 807.00 with no significant difference. We further compared the task loading in mental demand, physical demand, temporal demand, performance, effort, and frustration. All of them are no significant differences in mental demand and frustration. VR-based VBR has the greatest loading in physical demand ($\mathbf{\mu = 94.17}$) and is significantly higher than BIM-based ($\mathbf{\mu = 31.17, \alpha = 0.012771}$) and PC-based VBR ($\mathbf{\mu = 41.67, \alpha = 0.033628}$). But VR-based VBR has the lowest loading in performance ($\mathbf{\mu = 104.00}$) and is significantly lower than BIM-based ($\mathbf{\mu = 177.67, \alpha = 0.001412}$) and PC-based VBR ($\mathbf{\mu = 158.50, \alpha = 0.023266}$). VR-based VBR also has the lowest loading in effort ($\mathbf{\mu = 114.00}$) and is significantly lower than BIM-based ($\mathbf{\mu = 189.33, \alpha = 0.001212}$) and PC-based VBR ($\mathbf{\mu = 158.00, \alpha = 0.023981}$). The loading in temporal demand decreases from BIM-based to PC-based VBR and then to VR-based VBR. Among them, BIM-based and VR-based VBR have significant differences ($\mathbf{\alpha = 0.008672}$).

Table 4. The average issues they found in finding issues

Finding issues	BIM-based	PC-based VBR	VR-based VBR
Usability	3.83	4.77	5.77
Safety	1.40	2.70	1.97
Privacy	0.97	1.53	1.30
Other	0.37	0.77	0.87
Overall	6.57	9.77	9.91

Table 5. The average task loading in finding issues

Task loading in finding issues	BIM-based	PC-based VBR	VR-based VBR
Mental demand	247.17	236.67	269.83
Physical demand	31.17	41.67	94.17
Temporal demand	176.67	138.50	106.17
Performance	177.67	158.50	104.00
Effort	189.33	158.00	114.00
Frustration	77.50	80.50	118.83
Overall	899.50	813.84	807.00

In reaching consensus, the averages of seconds they used are 740.67, 682.93, and 724.40 with no significant difference. However, the averages of task loading in both of PC-based VBR ($\mathbf{\mu = 721.00}$) and VR-based VBR ($\mathbf{\mu = 718.10}$) are significantly lower than BIM-based ($\mathbf{\mu = 867.00, \alpha = 0.009610\ and\ 0.013879}$). We further compared the task loading in mental demand, physical demand, temporal demand, performance, effort, and frustration. All of them are no significant differences in effort and frustration. PC-based VBR has the lowest loading in mental demand ($\mathbf{\mu = 185.67}$) and is significantly lower than BIM-based ($\mathbf{\mu = 249.83, \alpha = 0.017308}$). PC-based VBR also has the lowest loading in physical demand ($\mathbf{\mu = 47.17}$) and is significantly lower than VR-based VBR ($\mathbf{\mu = 88.00, \alpha = 0.032764}$). VR-based VBR has the lowest loading in temporal demand ($\mathbf{\mu = 138.33}$) and is significantly lower than BIM-based ($\mathbf{\mu = 220.83, \alpha = 0.008720}$) and PC-based VBR ($\mathbf{\mu = 212.33, \alpha = 0.015529}$). VR-based VBR also has the lowest loading in performance ($\mathbf{\mu = 99.50}$) and is significantly lower than BIM-based ($\mathbf{\mu = 147.00, \alpha = 0.032007}$).

Table 6. The time they used in reaching consensus

	BIM-based	PC-based VBR	VR-based VBR
Seconds	740.67	682.93	724.40

Table 7. The task loading in reaching consensus

Task loading in reaching consensus	BIM-based	PC-based VBR	VR-based VBR
Mental demand	249.83	185.67	227.97
Physical demand	74.17	47.17	88.00
Temporal demand	220.83	212.33	138.33
Performance	147.00	111.83	99.50
Effort	142.50	128.67	125.63
Frustration	32.67	35.33	38.67
Overall	867.00	721.00	718.10

To sum up, both PC-based VBR and VR-based VBR have better performance in finding issues and lower task loading in reaching consensus. In addition, we found that VR-based VBR has the lowest loading in temporal demand no matter in 1st phase or 2nd phase. It may be caused by that participants already immersive themselves into the virtual environment. They can use less time to adapt and realize the example BIM model and then use more time to conduct the tasks we assigned.

6 Conclusions

This study aims to identify effective communication environments for remote BIM model review collaboration. We identified and implemented three kinds of virtual communication environment: BIM-based, PC-based VBR, and VR-based VBR from two factors: the flexibility of exploration and the degree of immersive. A user test with 90 participants was conducted for evaluating their performance and task loading in finding issues and reaching consensus. The result shows that in finding issues, PC-based VBR ($\mu = 9.77, \mathbf{\alpha = 0.000339}$) and VR-based VBR ($\mu = 9.91, \mathbf{\alpha = 0.004431}$) are significantly greater than BIM-based ($\mu = 6.57$). Among them, PC-based VBR is better in finding safety and privacy issues and VR-based VBR is better in finding usability and other issues. The averages of task loading in finding issues are no significant difference in overall. However, VR-based VBR has the lowest loading in temporal demand, performance, and effort but has the highest loading in mental demand, physical demand, and frustration. The result shows that in reaching consensus, PC-based VBR and VR-based VBR can use less time to reach consensus than BIM-based but are no significant difference. However, the averages of task loading in both of PC-based VBR ($\mu = 721.00$) and VR-based VBR ($\mu = 718.10$) are significantly lower than BIM-based ($\mu = 867.00, \alpha = 0.009610$ and 0.013879). PC-based VBR has the lowest loading in mental demand and physical demand. In overall, both PC-based VBR and VR-based VBR have better performance in finding issues and lower task loading in reaching consensus.

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