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Communication Effectiveness in Face-to-Face and Immersive Virtual Environment: An Initial Evaluation for Construction

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Abstract

Traditional methods of communication in the construction are changing, notably due to advancements in computer-mediated communication technologies such as immersive virtual reality (IVR), which can provide new opportunities for long-distance communication among stakeholders. Despite this, little research has examined whether or how far IVR-based visual communication can replicate the characteristics of face-to-face (FtF) communication or the relative effectiveness of these two types of communication. Accordingly, to compare the communication effectiveness of these two channels, students were selected to role-play the different construction stakeholders and compared five key aspects of FtF communication against those of remote communication with IVR support. Results indicate that IVR-based student groups experienced better communication – in terms of both quality of discussion and communicative richness – than their FtF counterparts. However, communicative appropriateness, openness, and accuracy were all higher in the FtF student groups. These results could be helpful for construction-industry stakeholders to strengthen inter-organizational communication and to deal with impediments to communication among project participants in both FtF and virtual environments.

Keywords: Communication effectiveness, Face-to-face communication (FtF), Immersive virtual reality (IVR), Construction industry, Inter-organization communication

1. Introduction

Among the many proposed applications of immersive virtual reality (IVR), new IVR-based long-distance communication methods are expected to mitigate or eliminate various limitations of face-to-face (FtF) communication (Ceenu George and Hussmann, 2017). In the construction industry, for example, IVR has been combined with building-information modeling (BIM) to create a new form of 3D visual communication, allowing stakeholders to "walk through" high-quality, immersive BIM models and, via avatars (i.e., virtual models of humans), to effectively communicate within 3D immersive environments and even to share project workspace without being physically present at the same location (Coburn et al., 2018). Another noteworthy benefit of BIM-based IVR in the same industry is that it facilitates increased involvement and interaction among various stakeholders from the design stage through to the completion of the project (Tutt et al., 2013). Moreover, Ceenu George and Hussmann (2017) have argued that communication in IVR environments is not merely equal in effectiveness to that in real-world settings, but can be superior to it in certain circumstances.

However, claims such as Ceenu George and Hussmann (2017) have hitherto remained largely untested. As such, if the potential benefits of IVR-based communication are to be fully realized in the construction industry, a much clearer understanding of the relative effectiveness of IVR-based and FtF communication is essential. To this end, the present study compared the effectiveness of IVR-based communication in a virtual environment against that of FtF communication for early design stage construction decision-making purposes. Specifically, the three students of each of eight teams were asked to role-play as an architect, construction contractor, and client, with four of the teams using FtF methods and the other four, IVR. The relative communicative effectiveness of the two experimental conditions was then compared using five criteria, i.e., discussion quality, appropriateness, richness, openness, and accuracy (Lowry et al., 2006, Roberts et al., 2006).

2. Literature Review

Effective communication is fundamental to construction projects' success but is often challenging due to the industry's interdisciplinary and dynamic work environment, in which mutually unfamiliar groups of stakeholders are expected to communicate continuously. Poor communication during construction projects may lead to time overruns (Chan and Kumaraswamy, 1997, Mydin et al., 2014), cost overruns (Sambasivan and Soon, 2007), conflict among stakeholders (Murray et al., 2006), rework and redesign (Murray et al., 2006), increased accident rates (Li, 2018), workforce demotivation (Tipili and Ojeba, 2014), and even overall project failure (Gamil and Rahman, 2017).

To address these communication challenges, the construction industry has mostly relied on FtF interaction and traditional long-distance communication channels (Cheng et al., 2001). However, FtF meetings for the purpose of group decision-making by key project participants based at different locations are often unrealistic, usually due to cost considerations (Heller, 2010). On the other hand, the amount and complexity of information that can be shared via phone calls, emails, letters, and faxes is limited. For this reason, the construction industry is continuously exploring new channels that might be capable of improving communication between project participants. Among all such channels, IVR technology has recently attracted considerable attention (Du et al., 2016). However, despite its apparent benefits, it remains unclear whether IVR-based communication is as effective as its FtF counterpart when it comes to exchanging construction project-related information, as very little research has empirically tested this specific use of IVR (Du et al., 2017).

In recent decades, researchers have developed various instruments for measuring the effectiveness of communication. Guevara and Boyer (1981), for example, utilized data from nine different construction organizations to identify four key communication-effectiveness factors: information overload, information underload, gatekeeping, and distortion. Thomas et al. (1998) proposed six such variables,

accuracy, timeliness, procedures, understanding, barriers, and completeness; and Lowry et al. (2006) and Roberts et al. (2006) subsequently identified five key factors of communication effectiveness: discussion quality, appropriateness, richness, openness, and accuracy. While Thomas et al. and Guevara and Boyer focused on communication effectiveness at the level of whole organizations, the two later studies emphasized aspects of communication at the small-group level, thus making their typology of communication-effectiveness factors more appropriate to the study of modern construction-industry working practices. In particular, *discussion quality* denotes the participants' issue understanding, knowledge sharing, feelings of satisfaction during the discussion, and overall level of group-communication effectiveness. *Appropriateness* refers to behavioral acts such as politeness and social manner. *Richness* indicates the overall quantity and comprehensiveness of information-sharing within a group. *Openness* is the inclination of group members to be open-mindedly receiving the communication of the other group members, and *accuracy* is whether the information is communicated to the right people and correctly understood by them.

3. Methodology

This study used controlled experiments to measure and compare the effectiveness of FtF and IVR communication. The participants comprised 24 undergraduate students taking building engineering and management, surveying, and property-management courses at the Hong Kong Polytechnic University. After the sample was divided into eight teams of three students each, four teams were assigned at random to each of the two experimental conditions, i.e., FtF and IVR-based communication. The goal of the experimental sessions was to simulate communication for design review, one of the common types of inter-organizational group communication in the construction field. Before the experiments began, each team member was given a specific role as a contractor, a client, or an architect, and remained in that role throughout. During the sessions, the participants were asked to decide the best design features for a project, from among options including wall materials (i.e., concrete or brick), structural materials (i.e., concrete or steel) and floor heights (i.e., low or high), with different BIM models reflecting all options being supplied by the researchers. To encourage more informed decision-making, the participants were given supplementary information regarding the costs and construction durations associated with the various options, prior to their deliberations.

In the FtF condition, all three students from a given team were gathered in the same room, in which Autodesk Revit BIM models with different design options were presented on a monitor screen, and all communication was conducted orally (Figure 1a). In the IVR condition, the same BIM models were integrated into Fuzor Virtual Design Construction software (https://www.kalloctech.com/) and shown in an immersive virtual environment. Through the assistance of HTC Vive, a head-mounted display (HMD) device equipped with an earphone and a microphone, the IVR-condition participants were able to observe one another's avatars and communicate with them through voice chat while examining the models (Figure 1b).

At the end of each experimental session, a questionnaire was used to measure the participants' communication effectiveness, in terms of the five criteria proposed by (Lowry et al., 2006, Roberts et al., 2006). All responses were provided on a five-point scale ranging from 1=strongly disagree to 5=strongly agree. The duration of each session, including the instructions, discussion, and questionnaire completion, was about 50 minutes. Each team engaged in one session.

Figure 1(a). Experimental Settings of FtF Communication

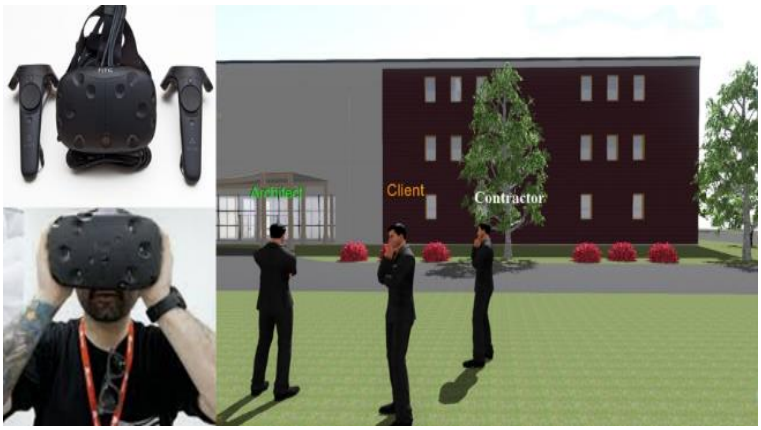


Figure 1(b). Experimental Settings of IVR-based Communication

4. Results

The internal consistency of the questionnaires completed by the participants in the FtF and IVR-based communication conditions was examined using Cronbach's coefficient alpha. The values of this coefficient for the FtF and IVR questionnaires were 0.873 and 0.816 respectively, i.e., both within the acceptable range of 0.7 and above (Zahoor et al., 2016).

The means and standard deviations of the communication-effectiveness scores for both experimental conditions are shown in Table 4.1. As the table indicates, the scores for three factors – appropriateness, openness, and accuracy – were greater in the FtF condition, whereas the other two factors, richness and discussion quality, had higher scores in the IVR condition. The following subsections discuss each factor in turn.

Table 4.1. Communication-effectiveness Questionnaire Results

Communication Methods	Communication Effectiveness Criteria				
	Quality of Discussion	Appropriateness	Richness	Openness	Accuracy
FtF Communication	4 (0.74)*	4.31 (0.57)	3.58 (0.63)	4.14 (0.67)	2.63 (0.91)
IVR-based Communication	4.25 (0.45)	4.27 (0.57)	4.14 (0.66)	4.02 (0.71)	2.16 (0.79)

*Mean (Standard Deviation)

4.1 Quality of Discussion

The IVR-based communication method scored higher on quality of discussion than FtF communication did, 4.25 vs. 4.00. This implies that, overall, IVR facilitated group discussions that enabled the team members to successfully understand the scope of the problem. More specifically, the participants rated IVR-based communication as more effective than its FtF counterpart in terms of the subfactors of issue understanding, knowledge sharing, and effective discussion (Figure 2). However, the participants' levels of satisfaction with their respective teams' solutions were almost the same across the FtF and IVR conditions, with mean values of 4.08 and 4, respectively.

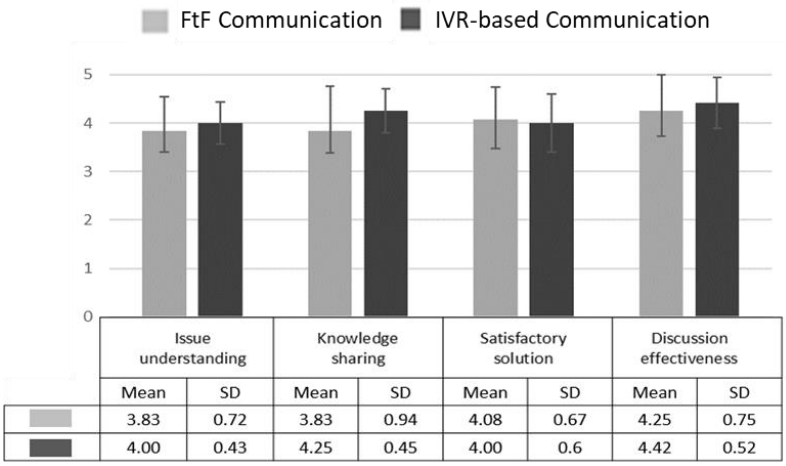
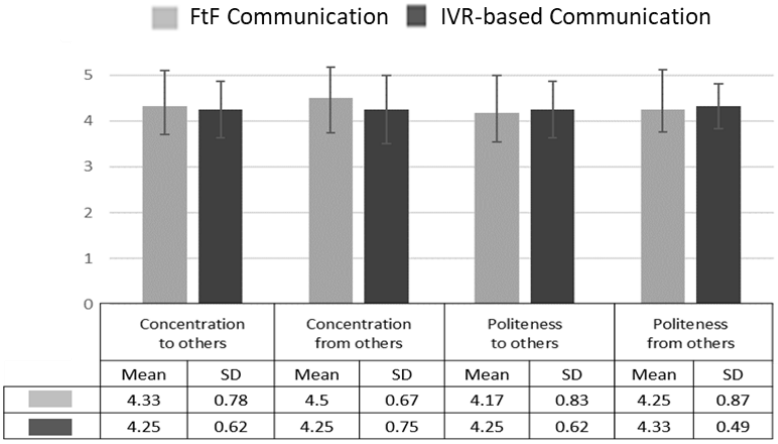


Figure 2. Group Discussion Quality of FtF and IVR-based Communications

4.2 Communication Appropriateness

The second communication-effectiveness factor, appropriateness, was rated slightly higher by the FtF participants than by their IVR counterparts, but this difference was not statistically significant (FtF: 4.31 (0.57), IVR: 4.27 (0.57)). But as shown in Figure 3, it could be observed from two of this factor's four subfactors (i.e., personal concentration and other members' concentration) that higher concentration was possible during FtF communication, i.e., that the FtF teams' members could more easily remain focused on the main topic of discussion when other members were speaking. With regard to the two politeness subfactors, members of the IVR condition appeared more likely than their FtF counterparts to behave politely to their colleagues during the discussion (IVR: 4.25 (0.62)) and to

feel that other IVR members were responding politely to the points they made (IVR: 4.33 (0.49)).

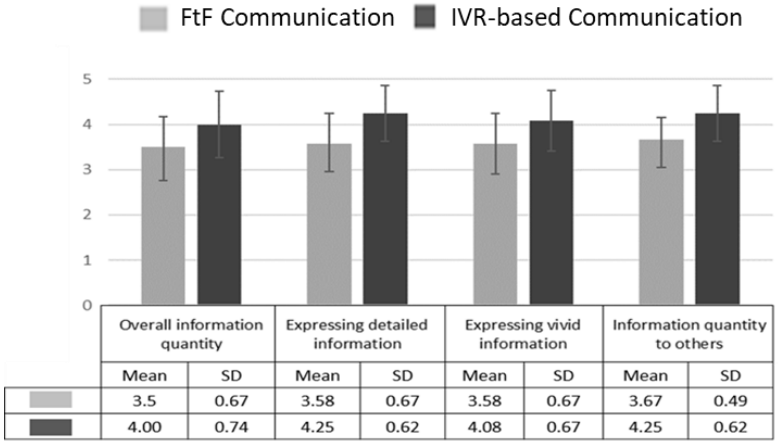


	Concentration to others		Concentration from others		Politeness to others		Politeness from others	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	4.33	0.78	4.5	0.67	4.17	0.83	4.25	0.87
	4.25	0.62	4.25	0.75	4.25	0.62	4.33	0.49

Figure 3. Communication Appropriateness of FtF and IVR-based Communications

4.3 Communication Richness

As Figure 4 illustrates, communication richness was rated as significantly higher by participants in the IVR condition than by those in the FtF condition (FtF 3.58 (0.63), IVR: 4.14 (0.66)). The IVR teams also assigned higher mean values to all four subfactors of this construct.



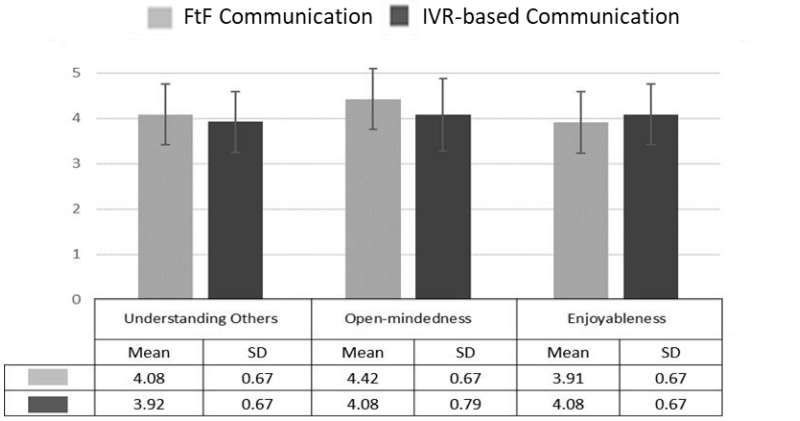
	Overall information quantity		Expressing detailed information		Expressing vivid information		Information quantity to others	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	3.5	0.67	3.58	0.67	3.58	0.67	3.67	0.49
	4.00	0.74	4.25	0.62	4.08	0.67	4.25	0.62

Figure 4. Communication Richness of FtF and IVR-based Communications

4.4 Communication Openness

The overall mean scores assigned to communication openness were higher for the FtF environment (FtF: 4.14 (0.67), IVR: 4.02 (0.71)), indicating that team members' willingness to behave hospitably toward one another was higher during FtF communication. A detailed comparison of this construct's subfactors is shown in Figure 5. The mean score of the first subfactor, understanding between members, was higher during FtF team discussions (4.08 (0.67)) than during IVR ones (3.92 (0.67)).

The higher mean score assigned by FtF participants to the second subfactor (4.42), meanwhile, indicates that they were more open to exploring their own ideas and more receptive to other's opinions than their IVR counterparts were. However, IVR-based communication was rated as more enjoyable (FtF: 3.91 (0.67), IVR: 4.08 (0.67)).

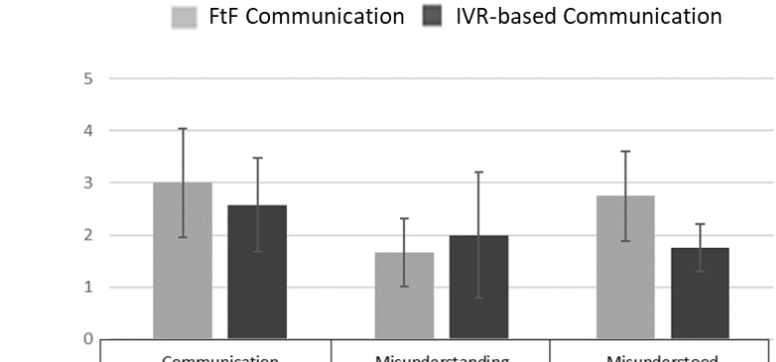


	Understanding Others		Open-mindedness		Enjoyableness	
	Mean	SD	Mean	SD	Mean	SD
	4.08	0.67	4.42	0.67	3.91	0.67
	3.92	0.67	4.08	0.79	4.08	0.67

Figure 5. Communication Openness of FtF and IVR-based Communications

4.5 Communication Accuracy

The overall mean score assigned to communication accuracy by participants in the FtF condition was significantly higher than that assigned to it by their IVR counterparts (FtF 2.63 (0.9), IVR: 2.16 (0.79)), suggesting that direct FtF communication allowed team members to share their opinions more clearly and correctly. FtF discussants also awarded significantly lower scores to the misunderstanding-others subfactor (FtF: 1.67 (0.65), IVR: 2 (1.2)), indicating that the FtF participants understood their fellow team members' ideas more clearly than IVR participants did. However, the higher mean score assigned to the misunderstood-by-others subfactor by the FtF teams (FtF: 2.75 (0.86), IVR: 1.75 (0.45)) means that FtF environments may demand a more effective explanation or clarification of discussants' own ideas than IVR environments do.



	Communication Accuracy		Misunderstanding Others		Misunderstood by Others	
	Mean	SD	Mean	SD	Mean	SD
	3.00	1.04	1.67	0.65	2.75	0.86
	2.58	0.9	2.00	1.2	1.75	0.45

Figure 6. Communication Accuracy of FtF and IVR-based Communications

5. Discussion and Conclusions

This study compared the communication effectiveness in two communication environments, FtF and IVR. The students were role-playing of various construction stakeholders and simulating eight inter-organizational construction-project meetings in the early design stage of a project. The IVR-based communication produced a higher quality of group discussions and richer communication, implying this technique's capability to exceed the discussion quality of traditional FtF meetings, in keeping with Ceenu and Hussmann's (2017) expectations. In addition, IVR-based communication provided the participants with clearer and more comprehensive visual information, suggesting that this approach could help construction stakeholders to better comprehend complex problems, and thus save them time and effort when seeking appropriate solutions. In addition, IVR-based communication is inherently useful for stakeholders who may be unable to attend FtF meetings for any number of reasons, by enabling them to examine the same visual information and provide feedback in the same virtual environment at the same time as their collaborators, thus decreasing the risk of miscommunication.

However, the results of the present study also highlight some obstacles that IVR will need to overcome if it is to be applied widely for inter-organizational communication in the construction industry. For instance, some of the participants found it difficult to perceive appropriate moments to speak, due to limitations in the system's visual representations of other team members. This led to overlapping of participants' speech with other team members' speech and actions, which could have been a major reason that they assigned IVR lower appropriateness and openness ratings than they assigned to FtF. Additionally, IVR-based communication does not yet permit users to use non-verbal forms of communication such as eye contact, facial expressions, or hand gestures. This absence of non-verbal cues is the most likely reason for the lower ratings for accuracy that IVR-based communication received. It could also undermine trust between team members and/or reduce the quantity of interaction between them, as compared to its FtF equivalent, by limiting the participants' ability to express their own feelings/mindsets and to interpret those of others.

In short, the current study is an initial step towards the examination of IVR-based communication effectiveness in the construction context that can be used as a communication method for connecting remotely located members of an inter-organizational. Based on this research results, the appropriateness, openness, and accuracy of IVR-based communication will need to be improved if it is to equal or surpass the effectiveness of FtF meetings for this purpose. It is hoped that these initial findings may assist construction-industry professionals to make necessary improvements in the effectiveness of IVR-based construction communication.

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