Effect of Immersive VR on Communication Patterns in Architectural Design Critiques

Hadas Sopher[1], John S. Gero[2]
[1]CRENAU/AAU – UMR_CNRS 1563 – School of Architecture Nantes. Design Research Laboratory Hybridlab, University of Montreal [2]University of North Carolina, Charlotte
[1]hadas.sopher@CRENAU.archi.fr [2]john@johngero.com

Immersive Virtual Reality (iVR) systems hold a promise to affect design behavior by allowing users to experience presence, as they are embodied in the digital display. However, the lack of research articulating how embodiment enabling media change design behavior limits integrating iVR systems in design pedagogy with a well-defined framework. This paper presents the preliminary results from a case study of a work in progress comparing the communication patterns of critique sessions in an architecture studio in two kinds of media: iVR and non-immersive desk-crits. We employed protocol analysis methods to track the distribution of conversational turns and the first occurrence of design issues emerging over the different media. Results show that compared to non-immersive critiques, the iVR had a lower number of conversational turns and an increase in the first occurrence generated by students, indicating support in a learner-centered activity. Elucidating the effect of the communication medium on design behavior provides an empirical foundation for its inclusion in a design theory that encapsulates embodied cognition.

Keywords: *Immersive VR, Studio, Design cognition, Critique, Virtual Reality*

INTRODUCTION

The increasing use of immersive virtual reality (iVR) systems in design pedagogy raises a significant need to examine the ways iVRs as communication media support design learning. However, a lack of studies articulating how communication in iVR learning sessions differs from non-immersive sessions limits integrating iVR systems as educational media.

In response, this exploratory case study is used to examine a research question concerning the impact of iVRs on the emerging communication in iVR studio crits, compared to non-immersive media used in conventional studio desk-crits. Explicating how communication media impact design activity provides a basis for integrating iVRs in design pedagogy as educational means to support learning.

Communication at the Design Studio

The studio forms the core environment for learning how to design. Following the situated learning approach, students learn by actively practicing design activities and generating design issues that con-

cern the development of a design artifact (Schön, 1985). In so-called "crits", or "desk-crits", the work done by the student is regularly assessed and discussed with an expert tutor and peers, an activity that supports further design progress by generating new design issues and discussing existing ones, and gaining competence (Oh, Ishizaki, Gross, & Do, 2013; Schön, 1987). Generating new design issues, also known as First Occurrences (FO), is considered an essential indicator of design progress. The ability to generate new ideas testifies to divergent thinking, an activity that includes introducing new issues or design alternatives, and is often linked with creativity and design progress (Dorst & Cross, 2001). The process repeats itself during an entire semester and supports design development from an abstract to a more concrete artifact.

Learning how to design poses no easy challenges. Design activity predominantly occurs over representations such as drawings or models that deliver a particular message (or more) concerning design issues of the artifact (e.g., a building section provides information regarding each floor's height). Representations serve as media for creating, developing, and communicating design issues between the designer and self or other participants, as happens during crits (Kalay, 2004). However, the medium of representation plays a significant role in delivering the message, as it carries a change in properties of the object in mind, such as scale, materials, or motion (McLuhan, 2006). Given that different media deliver different messages, using particular media during design activity may stimulate or hamper subsequent design activities by affecting the creation and interpretation of the message. In addition, design problems are considered to be wicked (Rittel & Webber, 1973). They have no determined solution and leave traces upon subsequent problems, characteristics which may create difficulties in assessing whether the design is satisfactory and hamper design progress, particularly for inexperienced designers such as students. These characteristics may be more challenging in the early design stages when the representations are less concrete.

These difficulties make crit communication an essential component in the learning process. Studies investigating student-tutor communication in design crits found the tutor dominant in the conversation structure by generating more conversational turns (Milovanovic & Gero, 2018), and explicating design issues (Goldschmidt, Hochman, & Dafni, 2010). A study tracking evidence of FO of design issues in design crits found that compared to the student, the teacher generated more FOs concerning the artifact's structure and expected behavior (Gero & Jiang, 2016). Since the studio encourages a learner-centered approach, such hidden hierarchy, often criticized over the years (Dutton, 1987; Wang, 2010; Webster, 2008), puts the success of the educational approach to accomplish this goal into question and indicates the need to support enhanced learner activity during crits.

Immersive Virtual Reality Media of Communication

The use of iVR systems as communication media in design practice and pedagogy has grown significantly. By allowing users to experience a sense of presence in the digital display, iVR systems hold promise to affect design learning by creating a change in crit communication. The common definition states that the two major components, immersion and presence, embedded in virtual reality, assist in allocating the communication between the system and the user. Immersion describes the physical and virtual conditions that comprise the system. Presence refers to the way the display is experienced by users (Slater, 2009). Sanchez-vives and Slater (2005) describe immersion as the extent to which a computational display is able to generate an extensive, inclusive, continuous, and surrounding illusion of reality and its capacity to provide a display, matching the user's movements with the feedback generated in the visual display. Presence is described as the illusion of being in a place, or a situation, as conveyed by an immersive system. Described by Merleau-Ponty

(1962) embodiment stands for the human-world relationship. Since humans inhabit the environment, any choice of behaviour is intertwined with their surroundings. Following Merleau-Ponty (1962), presence is a psychological state of consciousness that leads to forms of behaviour that correspond to what would have occurred if met in similar real settings (Slater, 2009). Differing from other representations that are external to the user, the interaction with iVR media occurs as the users are embodied in the display. A similarity in users' navigation was found in a study comparing design activity in an iVR and a real site during early design stages (Date, 2018).

These unique characteristics enable iVR to support situated learning by allowing the users to simulate a real-life situation and acquire desired behaviors and skills (Slater, 2017). A recent survey depicts the educational advantages of iVR systems in simulating environments and supporting training and interaction (Beck, Morgado, & O'Shea, 2020). In addition, it also identifies gaps requiring further investigation, such as the ways iVRs foster exploration and interaction, essential factors in design activity. A study investigating the current focus of research in iVR shows that few studies focus on the iVRs' capacity to support the performance of desired activities (Hamilton, McKechnie, Edgerton, & Wilson, 2020), while a different study points to the need in providing more rigorous methods to evaluate iVRs' support in situated learning (Mikropoulos & Natsis, 2011). In the studio context, iVR systems were found supportive of important factors in design learning, including increased design activity (Sopher, Kalay, & Fisher-Gewirtzman, 2017), design development and design convergence (Sopher, Fisher-Gewirtzman, & Kalay, 2018; Sopher, Fisher-Gewirtzman, & Kalay, 2019), and spatial comprehension (Zhao et al., 2020), indicating that iVR should be integrated into design syllabi. Multi-user virtual environments were found advantageous for collaboration between learners in terms of presenting their work and generating progress (Fruchter, 2014). Studies tracking collaborative ideation in iVR crits indicate the media's role in shaping crit communication (Boudhraa, Dorta, Milovanovic, & Pierini, 2019; Dorta et al., 2011; Dorta, Kinayoglu, & Boudhraâ, 2016). However, since these studies focused solely on iVR crits, further knowledge is required to articulate how communication in iVR crits differs from non-immersive crits to discuss the implications iVR media may have on design pedagogy and integrate iVRs as educational media in the studio.

ANALYZING CRIT COMMUNICATION USING PROTOCOL ANALYSIS METHODS

Protocol analysis methods are widely used to analyze cognitive processes during a design activity (Cross, Christiaans, & Dorst, 1996). By coding elements in transcribed design conversations, these methods reveal the conversations' structure and identify commonalities and saliences in communication patterns. To identify the medium's role during crit communication, we employed protocol analysis methods (Gero & Mc Neill, 1998; Kan & Gero, 2017). The coding scheme includes the tutor-learner conversational turns and FOs generated by each participant. Measurements based on the distributions of these codes assist in revealing the structure of conversations (Sacks, Schegloff, & Jefferson, 1978). Conversational turns provide information regarding the structure and the contribution of each participant to the conversation (Gero & Kan, 2009). FOs are considered essential indicators of design progress, hence the interest in measuring the number of FOs generated and their distribution over time for each medium. Studies tracking evidence of FOs in design conversations (Gero & Jiang, 2016), or patterns of collaborative ideation (Dorta, Kalay, et al., 2011) articulate how design behaviors are structured, independent from either the design process or supporting media. In this sense, these studies provide a means to assess how iVRs affect design communication during crits. In this study, the first time a design issue is mentioned in a particular crit is considered an FO and is coded as such. Repetitions of this word as the crit progresses are not coded.

CASE STUDY

In this case study, we monitored a third-year architecture studio course taught by Dr. Fisher-Gewirtzman at The Technion, Israel Institute of Technology, that used an iVR system (Figure 1) and non-immersive desk-crits (Figure 2). The iVR system is a room-sized setting containing a 7 x 2.5 meter screen and synchronized sensors that allow for single user navigation in a 3D display of digital design models. The setting affords a shared presence experience for twenty attendees. The desk-crits sessions included various representations communicated in non-immersive media. The brief required the design of a public building, including adaptive reuse of the existing context. Two weekly crits were given during a sixteen-week semester. The tutor and four undergraduates (age 22-25) with previous experience in digital modeling software formed the case that was studied. None of the students had used the iVR system before the course. The tutor had prior teaching experience in the iVR.

Three iVR and their parallel three desk-crit sessions were used as the data source for this study. Figure 3 illustrates the sessions recorded throughout the course. Two pairs of sessions were recorded at each time slot, allowing for tracking temporal differences over time. The crit duration ranged from ten to fifty minutes. The results were normalized to remove differences in the crits' durations.

RESULTS

Seven and a half hours of crit conversations were recorded, transcribed, and coded using the two coding schemes resulting in 4,152 conversational turns and 5,324 FOs. iVR crits had an average of 6.1 tutor-student conversational turns per minute (SD=1.64), while non-immersive desk-crits had an average of 9.0 turns per minute (SD=2.05). $p<0.001$. These results served as a preliminary basis for further investigation. A second analysis tracked the FOs generated by the crit participants in each medium. A t-test was used to determine if there were significant differences between the two classes of crit (Table 1).

Figure 1
A design crit taking place at the immersive VR system

Figure 2
A non-immersive desk-crit at the conventional studio

Figure 3
Sessions recorded thoughout the course

We observed no significant difference between the media in terms of the total number of crit FOs. However, an analysis conducted to separate the FOs generated by each participant revealed statistically significant differences between the two media types. As seen in Table 1, the iVR crits had a higher number of FOs generated by the students, indicating the medium's capacity in supporting this important activity. These results align with previous comparative studies concerning design activity in iVR and non-immersive crits (Sopher et al., 2017; Sopher et al., 2019) and expand them to include new understandings of the characteristics of conversational patterns supported by the media.

Examining the teacher's activity revealed that compared to the students' activity, more FOs were

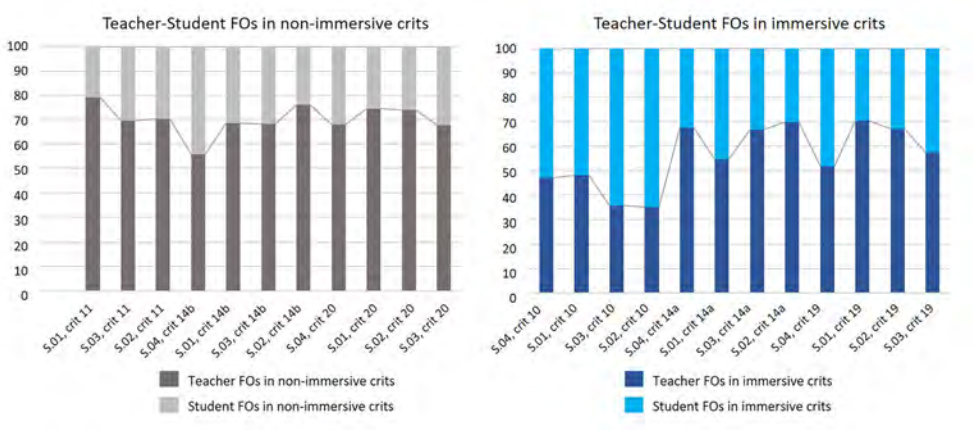

Figure 4
The distribution of First Occurrence of design issues made during student-teacher interaction in non-immersive crits (left) and immersive crits (right).

generated in both the immersive and the non-immersive media (Table 1). The teacher was dominant in generating FOs regardless of the media involved, providing preliminary evidence of teacher-centered learning taking place during the course. These results align with other studies investigating design activity in non-immersive crits (Goldschmidt et al., 2010; Milovanovic & Gero, 2018).

Despite the teacher's dominance, the iVR was found to encourage learner activity. The percentage of student-teacher FOs generated in each media is shown in Figure 4. Compared to non-immersive crits, we observed increased student FOs in iVR crits and decreased teacher FOs. This finding, if generalizable, has important implications for studio-based design pedagogy, as it implies that it encourages a learner-centered learning approach.

Table 2 presents the percentage of FOs generated by each student over the two media. Revealing each student's activity allows a teacher to personalize the use of a certain medium to support design progress. For example, student S.03 had 65% of FOs generated in iVR, clearly showing that the student has benefited from the medium, in terms of introducing new issues, and should be encouraged to use it when a decrease in activity is identified.

Table 1
The distribution of First Occurrence of design issues in immersive and non-immersive crits

FOs per minute	Communication media	Mean (SD)	P values
Crit FOs (generated by both students and teacher)	Immersive VR	9.9 (2.58)	p>0.1
	Non-immersive	10.1 (2.3)	
Student FOs	Immersive VR	4.3 (1.61)	p<0.1
	Non-immersive	3.1 (1.17)	
Teacher FOs	Immersive VR	5.6 (2.06)	p<0.1
	Non-immersive	7 (1.41)	

Table 2
The percentage of FOs generated by different students in immersive and non-immersive crits

Students	FOs (%) in immersive VR crits	FOs (%) in non-immersive crits
S.01	59	41
S.02	54	46
S.03	65	35
S.04	56	43

Temporal changes in crit activity

Figure 5 presents the variation in the distribution of FOs at each media throughout the course. A difference is observed in the first pair of sessions (10 and 11), where the iVR session had a higher number of student FOs compared to the following non-immersive session. Of note, the session also had the highest number of all student activity. Since generating FOs faces difficulties, particularly in the early design stages (Dorta, Lesage, Pérez, & Bastien, 2011),

these results provide evidence of the support the iVR lends to cope with this educational challenge.

The number of FOs largely decreases (over both media) from the early sessions to mid-course sessions, followed by a marginal decrease until the final sessions, indicating convergence, an expected behaviour as the design progresses. As seen in Figure 5, the teacher's activity complements the students' activity by introducing a high number of FOs when a poor student FOs occurs, indicating the teacher's role in the process. The variations seen in the teacher's activity over the media indicate the need to further investigate the impact iVR systems may have on design teaching.

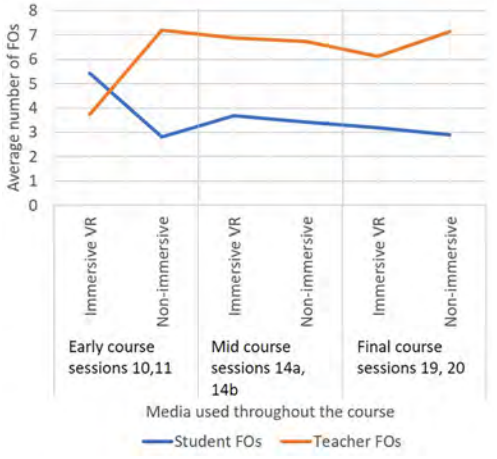

Figure 5
Distribution of the average number of FOs per minute, generated in immersive and non-immersive crits throughout the course

DISCUSSION

This exploratory case study demonstrates how the introduction of computational support, in the form of iVR, to the teaching of architectural design in the studio affects communication during design crits. The results show that compared to non-immersive crits, iVR crits have a lower frequency of conversational turns while being similar in generating FOs, results that indicate the iVR's capacity to support design progress. A significant salience between the media was found in the students' FOs, revealing a higher frequency of FOs generated in iVR crits. These results align with existing studies concerning design learning in iVR media (Boudhraa et al., 2019; Dorta et al., 2016; Sopher, Kalay, and Fisher-Gewirtzman, 2017; Sopher, Fisher-Gewirtzman and Kalay 2018, 2019) and expand them to include the communication patterns emerging in iVR crits. Despite the teacher's dominance in generating FOs in both media, an increase in students' FOs was observed in iVR crits, indicating the medium's role in supporting enhanced learner activity. While similar teacher dominance was previously found in non-immersive crits (Goldschmidt et al., 2010; Gero & Jiang, 2016; Milovanovic & Gero, 2018), this study opens the way to rethink the teacher's profile in different kinds of media. Preliminary evidence found the iVR's capacity to support student activity in early design stages in terms of generating FOs, provides ground for further research under the aim of integrating iVR in future syllabi within a well-defined framework.

CONCLUSIONS

This paper examines the impact of iVR systems on design crits by comparing the communication patterns in iVR and non-immersive crits. The findings show preliminary evidence that iVRs affect design crit activity in terms of conversational structure and ideation patterns. The iVR was found to have a lower frequency of conversational turns and a higher number of FOs generated by students, particularly in the early design stages. An increased frequency of student FOs followed by a decreased teacher FOs indicates the important role the iVR plays in fostering learner-centered communication. No significant differences were found in the emergence of the total number of FOs due to the teacher's complementary behaviour to reduced student activity. Future research will expand this corpus by further detailing the ways iVR systems impact learners' cognitive activities.

This study has several limitations. The small number of subjects limits the ability to draw representative conclusions. The study ameliorates this limitation by focusing on the numerous FOs gener-

ated by the participants. An additional limitation is that the analyses related to teaching performance are based on a single teacher. Further investigation is needed to determine how iVRs affect different teacher profiles.

IVR systems stimulate embodied cognition in ways that the non-immersive media do not. This study provides a foundation for integrating iVRs in design pedagogy as the means to enhance a learner-centered approach.

ACKNOWLEDGEMENTS

The authors wish to thank Associate Professor Dafna Fisher-Gewirtzman and the students for their participation. This study is supported by the West Creative Industries grant.

REFERENCES

Beck, D., Morgado, L. and O'Shea, P. 2020, 'Finding the gaps about uses of immersive learning environments: a survey of surveys.', *Journal of Universal Computer Science*, 26, p. 1043–1073

Boudhraa, S., Dorta, T., Milovanovic, J. and Pierini, D. 2019, 'Co-ideation critique unfolded: an exploratory study of a co-design studio 'crit' based on the students' experience', *CoDesign*, 17, pp. 1-20

Cross, N., Christiaans, H. and Dorst, K. (eds) 1996, *Analysing design activity*, Wiley, Chichester

Date, K. 2018, *Immersion in Early Architectural Design in the Age of Computing.*, Ph.D. Thesis, University of California, Berkley

Dorst, K. and Cross, N. 2001, 'Creativity in the design process: co-evolution of problem–solution', *Design Studies*, 22(5), p. 425–437

Dorta, T., Kalay, YE, Lesage, A. and Pérez, E. 2011, 'Design conversations in the interconnected HIS', *International Journal of Design Sciences and Technology*, 18(2), p. 65–80

Dorta, T., Kinayoglu, G. and Boudhraâ, S. 2016, 'A new representational ecosystem for design teaching in the studio', *Design Studies*, 47, pp. 164-186

Dorta, T., Lesage, A., Pérez, E. and Bastien, JMC 2011, 'Signs of Collaborative Ideation and the Hybrid Ideation Space Signs of Collaborative Ideation and the Hybrid Ideation Space', in Taura, T. and Nagai, Y. (eds) 2011, *Design Creativity 2010*, Springer

Dutton, T. 1987, 'Design Studio Pedagogy', *Journal of Architectural Education*, 41(1), pp. 16-25

Fruchter, R 2014 'Transformative 3D immersive collaboration environment in support of AEC global teamwork', *Computing in Civil and Building Engineering - Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering*, p. 1425–1432

Gero, JS and Jiang, H. 2016, 'Exploring the Design Cognition of Concept Design Reviews Using the FBS-based Protocol Analysis', in Adams, RS and Siddiqui, JA (eds) 2016, *Analyzing Design Review Conversations*, Purdue University Press

Gero, JS and Kan, JW 2009 'Learning to collaborate during team designing: some preliminary results from measurement-based tools', *ICORD 09: Proceedings of the 3rd International Conference on Research into Design Engineering*, pp. 560-567

Gero, JS and Mc Neill, T. 1998, 'An approach to the analysis of design protocols', *Design Studies*, 19(1), pp. 21-61

Goldschmidt, G., Hochman, H. and Dafni, I. 2010, 'The design studio "crit": Teacher–student communication', *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 24, p. 285–302

Hamilton, D., McKechnie, J., Edgerton, E. and Wilson, C. 2020, 'Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design', *Journal of Computers in Education*, 8, pp. 1-32

Kalay, YE 2004, *Architecture's new media: principles, theories, and methods of computer-aided design*, MIT press, Cambridge, Massachusetts

Kan, JWT and Gero, JS (eds) 2017, *Quantitative Methods for Studying Design Protocols*, Springer, Dordrecht

McLuhan, M. 2006, 'The Medium is the Message', in Durham, MG and Kellner, DM (eds) 2006, *Media and cultural studies*, Blackwell Publishing Ltd, Oxford, pp. 100-107

Merleau-Ponty, M. 1962, *Phenomenology of Perception (Landes, Donald A., Trans.).*, Routledge, New York

Mikropoulos, TA and Natsis, A. 2011, 'Educational virtual environments: A ten-year review of empirical research', *Computers & Education*, 56(3), p. 769–780

Milovanovic, J. and Gero, JS 2018 'Exploration of cognitive design behaviour during design critiques', *Proceedings of International Design Conference, DESIGN*, p. Vol. 5, pp. 2099–2110

Oh, Y., Ishizaki, S., Gross, MD and Do, E.YLD. 2013, 'A theoretical framework of design critiquing in architec-

ture studios', *Design Studies*, 34(3), p. 302–325
Rittel, HWJ and Webber, MM 1973, 'Dilemmas in a general theory of planning', *Policy Sciences*, 4(2), pp. 155-169
Sacks, H, Schegloff, EA and Jefferson, G 1978, 'A Simplest Systematics for the Organization of Turn Taking for Conversation', in Schenkein, J (eds) 1978, *Studies in the Organization of Conversational Interaction*, Academic Press, pp. 7-55
Sanchez-vives, MV and Slater, M 2005, 'From Presence Towards Consciousness', *Nature Reviews Neuroscience*, 6(10), p. 332–339
Schön, DA 1985, *The design studio: an exploration of its traditions and potentials*, RIBA Publications, London
Schön, DA 1987, *Educating the Reflective Practitioner. Toward a new design for teaching and learning in the professions*, Jossey-Bass, San Francisco
Slater, M. 2009, 'Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, p. 3549–3557
Slater, M. 2017, 'Implicit Learning Through Embodiment in Immersive Virtual Reality', in Liu, D., Dede, C., Huang, R. and Richards, J. (eds) 2017, *Virtual, augmented, and mixed realities in education*, Springer, Singapore, pp. 19-33
Sopher, H., Fisher-Gewirtzman, D. and Fisher-Gewirtzman, YE 2018 'Use of Immersive Virtual Environment in the Design Studio.', *Proceedings of the 36th eCAADe Conference*, Lodz, p. Vol 2, 853–862
Sopher, H., Fisher-Gewirtzman, D. and Kalay, YE 2019, 'Going immersive in a community of learners? Assessment of design processes in a multi-setting architecture studio.', *British Journal of Educational Technology*, 50(5)(10.1111/bjet.12857), p. 2109–2128
Sopher, H., Kalay, YE and Fisher-Gewirtzman, D. 2017 'Why Immersive? - Using an Immersive Virtual Environment in Architectural Education.', *Proceedings of the 35th eCAADe Conference*, Rome, p. 313–322
Wang, T. 2010, 'A new paradigm for design studio education', *International Journal of Art and Design Education*, 29(2), p. 173–183
Webster, H. 2008, 'Architectural Education after Schön: Cracks, Blurs, Boundaries and Beyond', *Journal for Education in the Built Environment*, 3(2), pp. 63-74
Zhao, J., Sensibaugh, T., Bodenheime, B., McNamara, TP, Nazareth, A., Newcombe, N., Minear, M. and Klippel, A. 2020, 'Desktop versus immersive virtual environments: effects on spatial learning', *Spatial Cognition and Computation*, 20(4), pp. 328-363