EXPLORING THE EFFECT OF IMMERSIVE VR ON STUDENT-TUTOR COMMUNICATION IN ARCHITECTURE DESIGN CRITS

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Abstract. Using digital tools like immersive Virtual Reality (iVR) reduce the carbon footprint by providing collocated and remote communication through virtual design studios. By providing a sense of presence in a digital display, iVR systems impact student-tutor communication during design critiques or crits. Research lacks studies articulating how iVRs change crits' communication to increase the ability to integrate iVRs as educational media and promote a quality education in inter-university studios. To this end, this study explores the cognitive structure of student-tutor communication during collocated architecture crits using iVR and non-immersive media. We employed protocol analysis to analyze divergent thinking by tracking the distribution of First Occurrences of design issues. Combining protocol analysis with Natural Language Processing, we explored the size of the design space generated during the crits. Results from a case study that includes twelve crits from three students show an increase in students' exploration of the design space and divergent thinking in the iVR crits, providing evidence that iVR enhances learners' communication. iVRs can be integrated to support remote design studios without the generation of carbon due to physical travel.

Keywords. Immersive VR; Design Cognition; Architecture Studio; NLP; First Occurrence; Design Networks; SDG 4.

1. Introduction

Immersive Virtual Reality (iVR) systems provide a uniform setting for collocated and remote communication through virtual design studios that enables tutors and learners to be immersed in life-scale virtual design representations, and reduce the need to physically travel. Design representations are key to support design communication in situated pedagogic settings known as "crits" (Schön, 1985) and design progress (Goldschmidt and Smolkov, 2006; Goldschmidt, 2014). Following the situated learning approach (Lave and Wenger, 1991), the studio encourages a learner-centered

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learning through enhanced learner engagement during crit sessions (Oh, et al., 2013). In the case of architectural design studios, iVR offers the possibility of experiencing designs at a real scale, demonstrating relevance to architecture learning that mostly relies on scaled representations. Shifting between 2D and 3D types of representations has the potential to alter learners' experiences (Milovanovic and Gero, 2020) and design development (Sopher et al., 2019). If the use of iVR systems in design crits is to become a pedagogical tool, we need a better understanding of its impact on students' learning. We should examine how these representation systems impact communication during the learning process in design crits. More studies are necessary to understand how communication in iVR crits differs from non-immersive ones to move toward integrating iVR systems in studio pedagogy. Integrating immersive systems into design courses can accomplish a sustainable design goal (SDG) quality education that foresees updated education facilities that provide inclusive and effective learning environments for all. This exploratory case study examines how iVRs impact student-tutor communication in iVR crits, compared to commonly used non-immersive media. It provides insights on the benefit of using iVR to support communication between students and tutors during design crits.

1.1. IMMERSIVE VIRTUAL REALITY SYSTEMS AS CARBON FREE COMMUNICATION MEDIA

iVRs are not restricted to collocated activity and can be used remotely without any change in functionality. This provides the opportunity to reduce the carbon footprint of users as they do not need to travel to be physically in a single location. Further, it creates novel opportunities to engage tutors from geographically dispersed locations. iVRs are characterized by immersion and presence, principal components that lead the interaction between the system and the users. Immersion refers to the system's hardware, and software components that provide for a surrounding and continuous display synchronized with the user's movement (Sanchez-vives and Slater, 2005). Presence refers to the user's experience of being in a situation as conveyed by the system (Slater, 2009). Despite the awareness of the situation to be less than real, presence experience leads to behaviours similar to ones that would occur in a similar real situation (Ibid).

These characteristics enable iVRs to support situated learning that relies on gaining desired skills through handling simulated real-life situations (Slater, 2017). Prior studies highlighted the advantages of iVRs as carbon-free educational media through supporting spatial comprehension of 3D models (Gómez-Tone et al., 2021; Zhao et al., 2020), increased design performance (Sopher et al., 2017) and design convergence (Sopher et al., 2019). Using iVRs in crits tends to increase the number of newly generated design issues introduced by students (Sopher and Gero, 2021), providing evidence for the medium's capacity to support a learner-centred education desired in situated pedagogy (Slater, 2017). iVRs support collocated and remote communication through using conversational elements considered to support collaborative ideation from abstract to concrete ideas (Boudhraa et al., 2019; Dorta et al., 2016) and in achieving creative design solutions (Hong et al., 2019). This demonstrates iVRs' role in shaping communication in a carbon-free educational setting. Surveys report a lack of rigorous methods able to track progress in situated learning (Mikropoulos and

Natsis, 2011), and few studies focusing on design education (Milovanovic et al., 2017; Ummihusna and Zairul, 2021) and related objectives such as interaction during exploration (Beck et al., 2020). More research is needed to determine how iVRs change student-tutor communication to take advantage of iVR systems as educational media and provide a carbon-free SDG4 quality education.

1.2. COMMUNICATION DURING STUDIO CRITS

Studio crits form the core setting for learning how to design. Learning requires the development of a solution to a design problem. During crits, students present their work and discuss it with tutors and peers to accomplish progress (Schön, 1985). Following the situated learning approach, the studio fosters a quality education by encouraging a learner-centred activity framed in tutor-student discussions (Oh, et al., 2013). Crit-communication comprises divergent thinking that expands the design space by generating new design issues and convergent thinking in which existing issues are refined (Goel, 2014). Divergent thinking is a cognitive behaviour indicating design progress (Dorst and Cross, 2001). Crits' activities are recurring as the course progresses until a more converged solution is achieved towards the course's final phase. Links between issues, or connectivity, testify to designers' capacity to account for multiple issues during the design process (Goldschmidt, 2016). Divergent thinking and connection between concepts, particularly the ones generated by students, serve as important indicators in supporting high-quality learning aimed at enhanced learner engagement (Oh, et al., 2013). Considered wicked (Rittel and Webber, 1973), design problems have no determined solution, creating difficulties in assessing whether further development in the form of new design issues is required. This activity tends to be particularly challenging for inexperienced designers such as students.

Representational media are embedded in design activity (including crits), as these support communicating information about design artifacts or their components (Kalay, 2004). Prior works show the role of representations in stimulating ideas and design progress (Goldschmidt and Smolkov, 2006; Goldschmidt, 2014). Interaction over representational media poses a challenge for learners. Considering that the medium plays a significant role in delivering the information (McLuhan, 2006), as it differs from the object in mind (E.g., scale), communication may be affected. Consequently, altered communication can enhance or hinder design activity. Early design phases may confront more challenges as the representations carry little or unclear information. Most representational media used in architectural design provide static and scaled representations, which lack the life-scale and surrounding context of the built environment, making iVRs particularly relevant for architecture students.

These challenges make crit communication an essential educational means in supporting SDG quality education. Crits tend to be tutor-dominated (Goldschmidt, et al., 2010; Milovanovic and Gero, 2018) and in generating new design issues (Gero and Jiang, 2016). Tutor-lead crits are criticized as they can hinder students' generation of alternative ideas and learners' engagement (Wang, 2010). In such crits, students can find tutors' feedback ambiguous (Salama, 2015), raising a need to find educational means that support crit communication to better achieve a learner-centered education. iVR systems appear as an interesting tool to support such an approach.

1.3. RESEARCH QUESTIONS

Explicating how iVRs impact the design activity during crits provides a basis for integrating these systems in design pedagogy as means to support learning. Demonstrating whether and how iVRs positively change student-tutor communication can promote integration of iVR systems as educational tools and promote inter-university design studios. This exploratory study articulates how iVR affects communication in design crits. The research questions are:

- Does iVR better support divergent thinking during design crits?
- Does using iVR impact students and tutors' exploration of the design space during design crits?

2. Method

2.1. CASE STUDY

We examined communication patterns in studio crits in a case study involving both iVR and non-immersive crits. Tutor and student natural verbalizations are compared between the two types of crit. The case study involves a studio course, taught by Associate Professor Fisher-Gewirtzman at the Faculty of Architecture and Town Planning, Technion, that alternately used immersive and non-immersive media on a weekly basis. Two weekly crits were given during a sixteen-week semester. The brief required the adaptive reuse of an existing electricity station, that was inaccessible to visitors. Data collected for this study includes twelve crits from three students (aged 22-25) in their third year of studies. Six crits were given in the early course phase, and the other six occurred towards the end of the course (Figure 1), allowing for tracking differences as the course progressed. The iVR system (Figure 2, left) is a 35sqm room, equipped with a 7 x 2.5 meter screen and synchronized sensors that allow single user navigation in a 3D display of digital design models, done in Sketchup, Revit, and Rhino types of digital modeling software. The system enables a shared presence for twenty attendees. The desk-crits sessions took place at the collocated studio workshop using various non-immersive media (Figure 2, right). The tutor had prior teaching experience in the iVR, whereas the students had no such experience prior to the course.

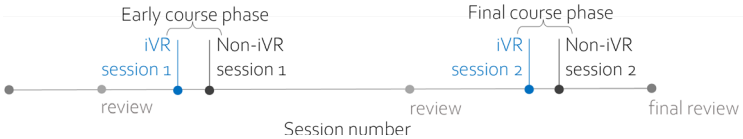

Figure 1. Sessions recorded during the course

Figure 2. A crit using the iVR system (left) and a non-immersive desk-crit (right).

2.2. MEASURING DIVERGENT THINKING IN DESIGN CRITS

We employed protocol analysis techniques to produce evidence of divergent thinking and used results to measure the size of the design space generated. 4.6 hours of crit discussions were recorded, transcribed, and segmented based on conversational turns. The transcripts, originally in Hebrew, were translated into English using Google Translate. Divergent thinking is analyzed by tracking the distribution of First Occurrence (FOs) of design issues generated during design activity (Gero and Kan, 2016). FO is the introduction of an idea for the first time in the design session. The number of FOs in a session is a measure of the size of the design space. FOs generated when using a given medium provides evidence for that medium's capacity in supporting this activity. Using Natural language processing (NLP) on design protocols, we automatically identified FOs generated by each participant. We used statistical testing to compare the number of FOs for each participant and each medium. We also analyzed the cumulative occurrence of FOs over time (Gero and Kan, 2016). The slopes of the cumulative FOs are a measure of the rate of divergent thinking. We normalized the time and the number of FOs to overcome different crits' durations.

2.3. ANALYZING THE DESIGN SPACE EXPLORED IN DESIGN CRITS

To assess how iVR is used for the exploration of the design space, we used a network to represent unique ideas generated by each participant. We used the FOs as concepts and generated connections between FOs based on a syntactic approach. To represent the network of FOs, we used the Networkx and Holoview Python libraries. The network of concepts generated by all the participants in a session represents the design space explored, allowing assessment of the medium's capacity to support this activity.

3. Results

3.1. DIVERGENT THINKING IN DESIGN CRITS

The analysis resulted in 2,398 FOs. For most crits, the occurrence of FOs over time is uniform as the curve of the cumulative occurrences is linear. The average value of the slope of the students' cumulative FOs in the iVR is higher compared to the non-immersive media (Table 1). A paired t-test determined that there was a significant difference between the two media types ($t(5) = -3.54$, $p = 0.016$). The tutor's average slope of cumulative FOs is higher in the non-immersive environment compared to the iVR (Table 1), with no significant difference ($p > .05$).

Table 1. Average slope of the cumulative FOs generated in immersive and non-immersive crits

FOs per segment	Communication media	Mean (SD)	Significant difference (P values)
Student FOs	Immersive VR	0.69 (0.32)	0.016
	Non-immersive	0.24 (0.06)	
Tutor FOs	Immersive VR	0.58 (0.19)	0.280
	Non-immersive	0.66 (0.06)	

The average cumulative occurrence of FOs generated by students is shown in Figure 3 (left) and by tutors in Figure 3 (right) in iVR and non-immersive media. iVR crits result in an increase in students' divergent thinking over time (Figure3 (left)), indicating the medium's capacity to foster an increased activity. The opposite behaviour is seen as the tutor's cumulative FOs shows a higher slope when using the non-immersive media. This suggests that these media supported enhanced teaching activity. The graphs in Figure 3 also represent the variance between cases (shaded areas). The variance of the cumulative FOs over time using non-immersive media is smaller than in the one using the iVR. It accounts for more individual differences in the iVR that could imply differences in individual abilities to use the iVR, which were seen in a former study (Sopher and Fisher-Gewirtzman, 2020). Such feedback can support tutors in integrating different media to support individual competences and promote custom-tailored teaching. Examining the early and final phases of the course reveals a decrease in the slope of the cumulative occurrence of FOs generated in both media types during the final phase (Table 2). This is an expected behaviour, considering that the design solution converges as the course progresses. In this sense, the decrease in the slope value in iVR crits, compared to non-immersive ones, may be interpreted as the system's capacity to better support convergence.

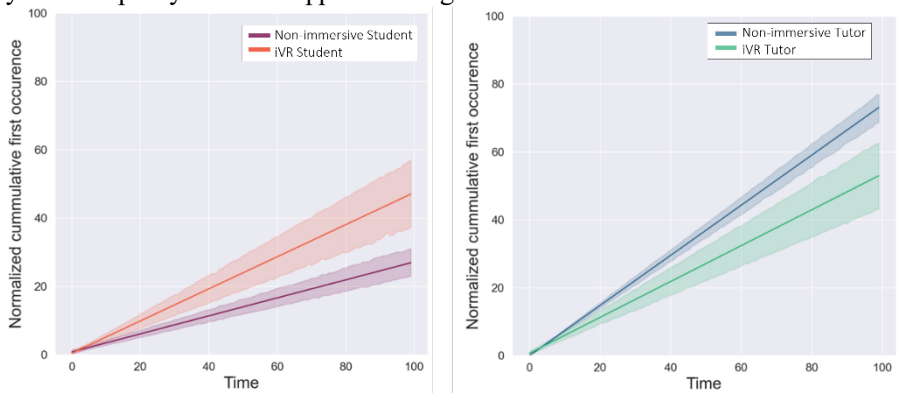

Figure 3. Cumulative occurrence of the FOs generated with immersive and non-immersive media by students (left) and tutors (right).

Table 2. Average slope of the cumulative occurrence of FOs generated during early (session 1) and final (session 2) phases for immersive and non-immersive media.

	Session 1-Early phase	Session 2-Final phase
iVR	0.94	0.43
Non-immersive	0.25	0.23

3.2. EXPLORATION OF THE DESIGN SPACE

The effect of different media on tutor-student exploration of the design space is illustrated in the network of FOs' concepts. Figure 4 presents the network of FOs for crits given to student S1. The networks show concepts generated during each session.

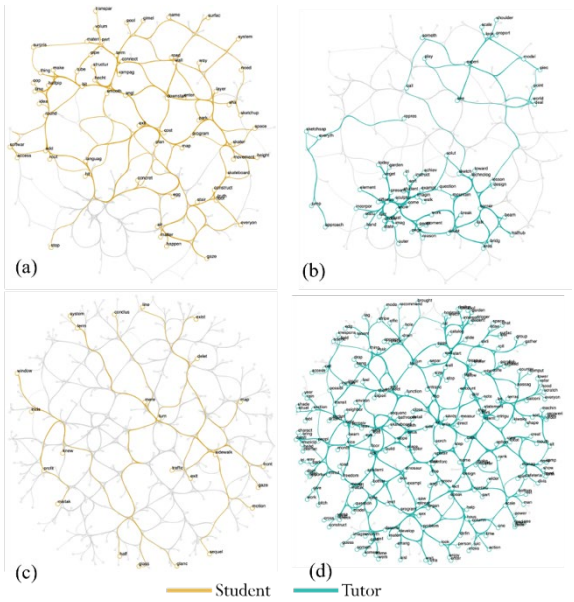

Figure 4. The design space explored by Student S1 in the early course phase: (a) Student's network in the iVR, (b) Tutor's network in the iVR, (c) Student's network in a non-immersive crit, and (d) Tutor's network in a non-immersive crit. The networks are presented against the backdrop of the full design space.

In the early phase iVR crit (Figure 4(b)) we observed a hub of highly connected ideas in the tutor's design space. This could indicate a topic that invoked feedback during this crit. In the iVR crit, the student's exploration of the design space is higher (see Figures 4(a) and (c)). The networks generated in the non-immersive early phase (Figure 4(d)) show a tutor dominance in the exploration of the design space. Using networks of FOs reveals differences regarding how participants explored the design space with the medium used. Non-immersive crits are observed with more tutor FOs (Figures 4(b) and 4(d)). The iVR had more student FOs and a greater connectivity during the iVR, indicating the medium's capacity to benefit the activity.

4. Discussion

This case study demonstrates how iVR systems, flagged as supportive of SDG, affect communication during architecture studio crits through measurements of the design space and learner activity, considered important in achieving a quality education. The results show that iVR crits have a significantly higher frequency of FOs generated by students, indicating the medium's capacity in supporting a learner-centred activity, considered a challenge as the studio is commonly tutor-dominated (Gero & Jiang, 2016; Goldschmidt et al., 2010; Milovanovic & Gero, 2018).

The increase in student FOs in iVR compared to non-immersive media, demonstrates the iVR's capacity in supporting divergent thinking, defined as a quality educational objective. These results provide quantitative support for results of former studies (Dorta et al., 2016; Sopher et al., 2017; Sopher et al., 2019; Sopher & Gero,

2021) and expand them to account for the syntactical and temporal characteristics of the conversations exhibited in the media, information that can support the integration of iVRs in studio pedagogy.

The tutor generated more FOs with non-immersive media, while achieving a smaller variance between the two media, which may imply a greater competence regardless of the medium used. The non-immersive crits had more tutor-student imbalance in the generation of FOs, indicating a stronger tutor dominance, found in other studies investigating design activity in non-immersive crits (Goldschmidt et al., 2010; Milovanovic & Gero, 2018).

Evidence showing differences in activity in iVR during early and final course phases provides ground for further research to increase the ability to integrate iVR in future courses. No significant differences were found in the tutor's FOs over the media, indicating that the tutor was less affected by the medium involved. More research is needed to study how iVRs affect teaching behaviours.

Exploring the connections generated by students shows that the iVR supports greater connectivity between design issues, particularly during the early course phase, which is considered more challenging. Using NLP to track FOs and networks to represent the design space enabled conducting automated quantitative and qualitative analyses. This may be useful in providing detailed feedback to support individually tailored teaching approach, known to lack in the studio (Salama 2015).

This study has several limitations. As a case study, the small number of subjects limits the ability to generalize conclusions. Since the study has a single tutor, further investigation is needed to determine how iVRs affect teaching behaviours.

5. Conclusions

Aiming to increase the possibilities of SDG quality education through carbon free inclusive educational means, this explorative study examined how an iVR system affects communication during design crits by comparing it with non-immersive crits. The results show evidence that iVR increases student engagement in design crits as they generate more FOs and connections between concepts, while potentially reducing carbon emissions. The iVR medium enhanced students' engagement in the crits during the early course phase that is more challenging. No significant differences were found in the tutor's FOs over the media, implying that the tutor is less affected by the medium used. Since only one tutor participated, more research is needed to determine how iVRs affect teaching activities. In addition, since this was a case study, further research is needed to determine whether these results are generally applicable.

The study results provide insights for integrating iVRs in design studios to support remote and collocated communication in inaccessible situations, without generating carbon due to physical travel. This could be extended to inter-university iVR design studios that can enrich learning by engaging with tutors and peers from diverse backgrounds and accomplish an SDG4 quality education with updated education facilities that provide inclusive and effective learning environments for all.

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