IMMERSIVE GAZE SHARING FOR ENHANCING COMMUNICATION IN DESIGN EDUCATION: AN INITIAL USER STUDY IN THE CONTEXT OF ARCHITECTURAL DESIGN CRITIQUES

Kahlon, Yuval (1);
Maurya, Santosh (2);
Fujii, Haruyuki (1)

1: Tokyo Institute of Technology;
2: Hitachi Ltd.

ABSTRACT

Gaze sharing is an emerging technology which can enhance human communication and collaboration. As such, it is expected to play an important role in future educational practices. To date, its application was not explored in the context of design education. Additionally, it was mainly implemented in non-immersive environments, which are limited in their potential for engaging learners. Acknowledging the growing interest in immersive learning, as well as the promise made by gaze sharing technology, we strive to develop an immersive gaze sharing environment, to support design education. As a first step, we have implemented and tested an immersive gaze sharing system for supporting design learners. The system was then tested by focusing on a scenario of architectural design, with the aim of collecting valuable user feedback regarding its usability and potential. Our initial user study informs developers of such systems regarding potential issues that may be encountered during deployment in a real-world setting and proposes concrete ways to address these. These insights can help to pave the way for integrating gaze sharing system into design education practices in the near future.

Keywords: Design education, Communication, Gaze sharing, Immersive learning, Computer Aided Design (CAD)

Contact:
Kahlon, Yuval
Tokyo Institute of Technology
Israel
kahlon.y.aa@m.titech.ac.jp

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1 INTRODUCTION

How will we learn to design in the future? Digital systems are already being used ubiquitously by design learners worldwide. For instance, in design prototyping and documentation activities. However, there's much room for a deeper integration of such systems into educational practices, for the benefit of design learners and educators. One aspect of design education which can be further supported by digital tools is that of communication among students and instructors. As a key example for a communicative activity in design education, consider design critiques. Simply put, critiques consist of meeting between students and instructors, in which ways to improve students' work are discussed. The authors believe that such discursive activity can greatly benefit from recent advances in the general field of technology-facilitated communication.

Technology facilitated communication is a rapidly growing research field. A promising emerging technology for enhancing human communication is that of gaze sharing (Brennan *et al.*, 2008), which in turn draws on eye tracking technology. Eye tracking technology enables us to track a person's eye movements and make inferences regarding changes in his/her attention, objects of interest and more (Holmqvist and Andersson, 2017). Digital systems which visualize gaze information of one person and display it to another are generally referred to as shared gaze systems, or simply gaze sharing. We build upon these important achievements, as well as on recent developments in immersive technologies, and develop a digital system for supporting communication in design education. The result is a platform for immersive real-time gaze sharing (iRTGS) which targets design students and educators (Figure 1). By collecting initial feedback from potential users, we draw insights for integrating such systems into design education in the near future.

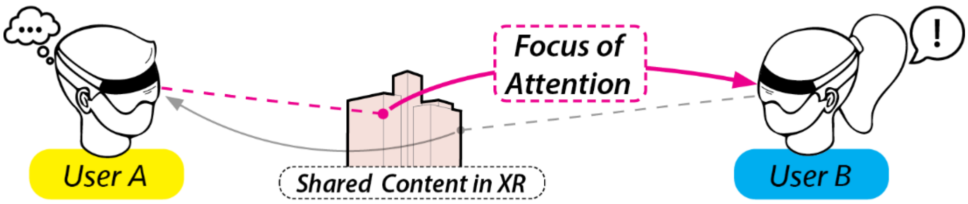

Figure 1. Vision - enabling iRTGS for enhancing communication in design education.

2 BACKGROUND

We begin with a concise review of existing studies concerning immersive environments for design education. Next, we review relevant work on collaboration and communication using eye tracking technology. On the basis of these, we lay out the main claims regarding the potential of iRTGS to contribute to future design education practices.

2.1 Immersive design education

Immersive technologies enable to create experiences that merge the physical world with virtual content. Two principal types of these technologies are Augmented Reality (AR) and Virtual Reality (VR). In the former, the physical world is partially overlaid with virtual content, while in the latter the virtual content covers the whole visual field of the user. As these technologies extend reality in various manners, they are also often grouped under the label of Extended Reality (XR), which also includes additional technologies, such as Mixed Reality (MR). While each XR technology offers different degrees of immersion, they all enable users to intuitively experience and interact with 3D content. Accordingly, they have shown to benefit designers by supporting design processes in various manners. For example, by easing the comprehension of products (Tang, Au and Leung, 2018), by aiding in the different phases of design prototyping (Kent et al., 2021) or even by facilitating end-users participation in co-creation (Maurya et al., 2019).

Researchers from various fields are interested in exploring the potential of XR for enhancing our future educational practices ("immersive education"). For instance, an XR environment that enabled science, technology, engineering and mathematics (STEM) learners to interact with content and with their peers improved learning outcomes (Birchfield and Johnson-Glenberg, 2010). Similarly, XR was found useful in learning factories (Juraschek *et al.*, 2018) and even in distance learning (Peña-Rios,

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Callaghan and Gardner, 2017). Immersive learning thus bears a great promise for our future educational practices.

Expectedly, immersive learning is now seeping into engineering & design education as well. In one study, an AR system had helped to promote students' understanding of geometric relations when exploring the structure of products (Tang, Au and Leung, 2018). Relatedly, utilizing XR for visualizing educational content in a spatial design task contributed to student engagement (Birt and Cowling, 2017). Further, it was recently reported that a VR environment has contributed to an increase in divergent thinking and encouraged exploratory activity among students during a design critique (Sopher, Milovanovic and Gero, 2022). Finally, its potential to benefit design education in remote settings has also emerged as a topic for research (Kahlon *et al.*, 2022). These studies points to its potential impact on the ways in which we will teach and learn to design in the future, thus rendering it as an important topic for research and development.

2.2 Real-time gaze sharing (RTGS) for enhancing communication in design education

Eye tracking (ET) technology enables us to study attention by recording the behaviour of a human subject's eyes as he/she engages in various activities. Frequently used measurements include gaze fixation (moments in which the eyes are focused on an object for a certain duration), pupil dilation and more (Holmqvist and Andersson, 2017). As such data offers insights into changes in visual interest, ET is a powerful tool for studying visual-design-related phenomena, such as the visual experience of products (Kukkonen, 2005; Guo *et al.*, 2016), architecture (Nguyen-Tran *et al.*, 2022), scenery (Kiefer *et al.*, 2014) or art (Massaro *et al.*, 2012). Further, it is useful for studying human communication as well. Gergle and Clark, for instance, have utilized it for studying communicative acts of referring to objects in space and have related the posture of the participants with the quality of communication - e.g., seated pairs had higher gaze overlap than mobile ones (Gergle and Clark, 2011). Interestingly, ET is recently being used not only for studying visual attention and communication in visual tasks, but also for facilitating these when engaging in real-time collaborative activities.

A prominent approach for utilizing ET to enhance communication is to enable real-time gaze sharing (RTGS). In RTGS, data regarding the gaze of one subject is visualized and shared with another subject. In a pioneering study, Brennan et al. demonstrated that RTGS can facilitate better collaboration between participants in a visual search task (Brennan et al., 2008). Further, in a remote setting, Gupta et al. have reported that RTGS, with the addition of a pointer for a remote helper, contributed to improved task performance. These also contributed to a sense of human co-presence, which is of great value in itself (Gupta, Lee and Billinghurst, 2016).

Recently, researchers have begun exploring the value of RTGS for educational activities. Schneider and Pea have observed that RTGS has facilitated better collaboration among students engaged in joint problem-solving in the context of neuroscience (Schneider and Pea, 2013). Relatedly, in a remote education setting, informing the instructor of students' attention by overlaying gaze information onto video data was found to contribute to learning quality (Sung, Feng and Schneider, 2021). On the basis of the above, it is assumed that RTGS can contribute to communication between stakeholders in design education as well.

One limitation of current RTGS implementations is that they are done in non-immersive environments. Simply put, one person needs to read another person's gaze data off a screen. While this may be useful in certain settings, gaze visualization on a flat display has certain demerits with respect to teaching/learning in a physical space. For one, it requires us to shift our gaze between our interlocutor, the physical objects around us and the screen, as well as coordinate our perceptions of these. This burden may be mitigated by sharing spatial content in an immersive environment, which removes the screen from the equation, thus simplifying the task of coordinating our perceptions.

Wang et al. (2021) have developed an immersive VR environment which enabled several users to efficiently manipulate objects in space, by automatically transferring control to the user with the best vantage point at a given instance. In this, they have proposed to augment their system by adding the possibility of RTGS, as a future step. Inspired by their work, we aim to enable iRTGS, for facilitating better communication in design education.

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3 AIM & OBJECTIVES

This research aims to enhance our ability to communicate when engaging in design education, via iRTGS. Under the assumption that iRTGS may benefit both students and instructors, the goal of this paper is to explore its potential in realistic educational scenarios and collect user feedback. Such feedback may prove valuable in directing the efforts of developing interactive design support systems, for enhancing collaboration and communication in educational setting in the near future.

To reduce the complexity of working with multiple users, we focus on a minimal scenario of 1-1 interaction between two interlocutors. The following objectives are set:

1. Implement a system that enables iRTGS among two users
2. Test the system in the context of architectural design education, as a case study
3. Collect positive and negative feedback from potential users
4. Draw conclusions regarding the future development of iRTGS for enhancing design education

4 THE PROPOSED SYSTEM

4.1 System outline

A system for facilitating iRTGS was designed and implemented. The outline of the system is given below in Figure 2. Two users are wearing head-mounted displays (HMDs; a,b) and are viewing some shared content in XR (c) which is displayed within two identical 3D environments running in parallel (a',b'). The gaze position recorded by each HMD is shared with the other by uploading it to a cloud-based server (f), and then visualizing it (i) in the immersive environment. The could server runs on local workstation (e), which is connected to a wireless router (d). Both HMDs (a,b) are connected to the same network via Wi-Fi. Gaze sharing is essentially the transfer of gaze data described by the path (a'→f→i→b'). Notice that here gaze data is transferred from HMD1 to HMD2. For simplicity purposes, we have not drawn the opposite path from HMD2 to HMD1. However, the system was designed in a symmetrical manner, such that gaze data is also shared from HMD2 to HMD1. Therefore, the system enables dual gaze sharing (as opposed to uni-directional sharing). The recorded data is also stored for later use (g) - mainly for purposes of visualization conducted offline after the session is finished (h), which is outside the scope of this study.

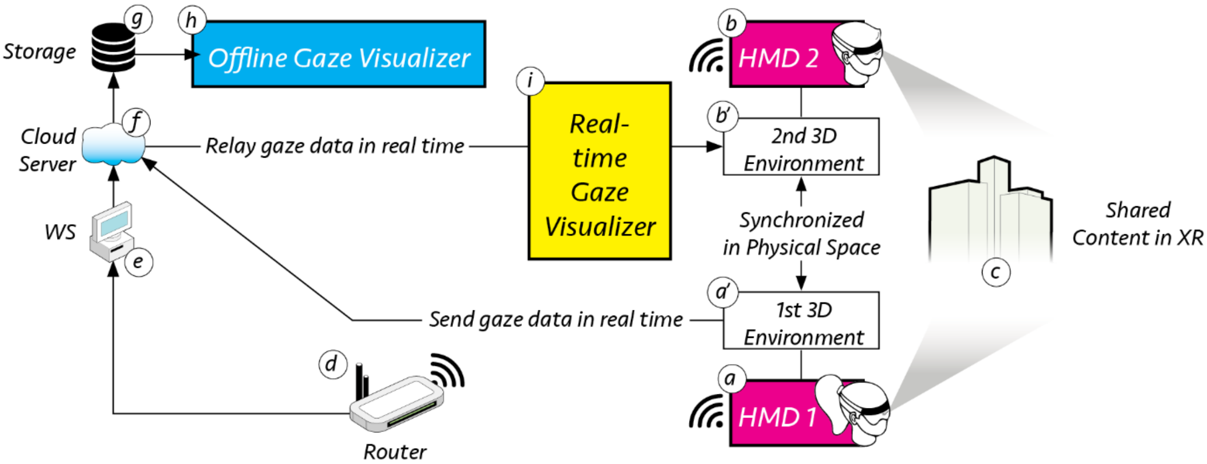

Figure 2. System outline.

4.2 Implementation

As a proof-of-concept (PoC), the proposed system was implemented in an Augmented Reality (AR) setting, by integrating a real-time development platform (Unity3D, https://unity.com/) with two HMDs (Microsoft HoloLens 2, https://www.microsoft.com/en-us/hololens) and a local server (JSON server). The latter was set up to enable sharing content between users and to maintain consistency across the individual user scenes. A key datum which was harvested and shared across users (through visualization) was the wearer's gaze point, which provides useful information regarding one's visual attention at a given instance. This was achieved by utilizing Microsoft HoloLens's Eye Tracking API,

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which provides access to the wearers' gaze point (origin, direction), at a rate of 30Hz. Details about visualization of gaze points are given below.

4.3 UX and system behaviour

Pairs of participants who use the system experience the following: (1) both see an identical visualization of a spatial model prepared in advance, albeit from different angles based on their location in the physical space; (2) each sees a visualization of the other user's current and recent gaze points. The latter was realized by developing a real-time gaze visualizer (Figure 2,i). The real-time gaze visualizer first derives the current gaze point from each user through their HMD and stores its coordinates on the server (Figure 2, f). Then, it utilizes these to create a 3D gaze marker in the form of a sphere, to represent the user’s visual focus. The markers are visualized in the other user's HMD, to make them aware of their peer's focus in real-time. The size and colour of the gaze marker are relative to the cumulative time one gazes at a certain location. Thus, longer gaze results in larger size and higher colour saturation. The maximally saturated colour was set to a strong red (255,0,0, alpha = 255), due to its salience against the background of the physical environment and the virtual model. The marker gradually grows at a constant rate according to a pre-set growth parameter, until a new fixation is detected. It then begins to shrink, its colour saturation is reduced and finally it disappears from the display. This visual behaviour was designed to offer additional information regarding the other user's recent focus of attention (similar to a Gaze Trail; Rahman et al., 2020) while reducing visual clutter that may be caused by accumulating many gaze markers on the display (Figure 3).

Figure 3. Dual gaze sharing setting.

5 INITIAL USER STUDY

5.1 Participants

To test our system and evaluate its potential to support design education, a small-scale user study was executed. Students (N=6) and instructors (N=2) of architectural design were invited to test the system and provide constructive feedback. With respect to the former group, since participants were recruited at a minimal level of 4th year bachelors, all possessed fundamental knowledge in architectural design and have experienced communication in design critiques many times. The same applies for the latter group, of course, as both instructors regularly teach several design studios in each academic year. Collecting user feedback from these two groups is valuable as it may help to facilitate a user-centred development process in future steps.

5.2 Task and user experience

To enable our participants to experience the system and imagine its potential value for communication in architectural studios, a simple scenario was designed and implemented using Augmented Reality (AR). Essentially, the scenario consisted of two participants co-located in a lab setting, viewing and discussing virtual content as their gaze was being shared in real time. The choice of an AR setting was due its similarity with traditional studios with respect to presence in a physical space (as compared to VR) as well as its relative technical simplicity (as compared to MR).
A scale model of a residential neighbourhood in Tokyo (recently completed student work) was scanned using a desktop 3d scanner and prepared in advance. Our system was implemented and

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deployed on two HMDs, using the above model as the shared visual content (Figure 2,c). The content was presented to two participants simultaneously, and their gaze was shared in a dual manner (i.e., both could see their peer's gaze, as opposed to a uni-directional setting). In each trial, two participants wore HMDs (Microsoft HoloLens 2) and had a short discussion about the virtual content presented to them, while commenting on their user experience. The procedure for collecting, processing and analysing the data is given below.

5.3 Procedure, data collection and analysis

Participants worked in pairs (student-student, instructor-instructor) such that a total of 4 feedback sessions were held. Sessions were conducted as follows: (1) a short explanation was given about the concept of gaze sharing and regarding the purpose of the system; (2) both participants were asked to wear an HMD and view the model in AR as their gaze was being shared; (3) a few minutes were allocated for to walk freely around the model and experimenting with the system, by conversing with their partner and confirming that their gaze is indeed being shared; (4) on the basis of this experience, each participant was asked to imagine that the system is implemented in a future architectural design studio, and comment freely regarding potential advantages and disadvantages, based on his/her impressions and experience; (5) users were allowed to continue and use the system while commenting on it, for as long as they saw fit. The duration of the last phase ranged between 5-15 minutes. Sessions were terminated by the moderator when topics for discussion and feedback on the system were clearly exhausted.

Notes were continuously taken by a moderator throughout the session. The moderator occasionally asked clarification questions and requested participants to provide further detail regarding their feedback, as required. The collected comments were then used to identify categories and sub-categories of user feedback, as follows: each comment was first labelled as either negative or a positive judgement made by the user. Second, general categories were discovered by: (1) taking each comment and identifying the specific topic or aspect of the system which was focused on by the user, (2) using it to create a label, and (3) applying this label for all other relevant comments. For instance, a comment such as "the colours are too bright" expresses sub-optimal visual experience and would thus be classified under the label "issue with visualization" along with comments such as "the gaze markers disappear too fast"; (4) finally, the resulting categories were segmented into sub-categories, based on recurring topics (e.g., the above two comments can be seen as "issues with visualization" in terms of either colour or speed, accordingly). Categories, representative comments and their importance for the future development of iRTGS are presented and discussed below.

6 RESULTS AND DISCUSSION

Comments made by participants are divided into two main categories: negative comments (denoting aspects of the system which hindered their experience) and positive comments (denoting aspects which should be preserved or that may be added to enhance the system in the future). These are presented and discussed below. In 6.1 we present the issues which were raised by participants (6.1.1, 6.1.2, 6.13) and their positive comments or features requests (6.1.4). In 6.2 we reflect on further reflect on these and draw insights for the future design of iRTGS systems.

6.1 Results

6.1.1 Legibility of visualization issues

All participants expressed concerns regarding the obstruction of their field of view. The main sources of such issues were: (1) the size of the gaze markers, (2) the opacity of the gaze markers, and (3) the accumulation of past gaze marker. With respect to (1), the size of gaze markers was found to be problematic in two senses: first, since gaze markers' size reflected gaze duration, they occasionally grew beyond the size of the object of interest. Second, when approaching the model, the participants looked at the markers from up-close, which meant that they filled a large portion of their field of view. This negative effect was augmented by (2). With respect to (3), most participants have found the number of gaze markers to be too large and somewhat overwhelming. Large number of sphere-like markers resulted in undesired visual clutter, which did not serve them in their conversation. On the

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contrary, this form of over information made it hard to focus and resulted in obstruction of large parts of the model, as mentioned above.

Relatedly, participants also expressed concerns regarding their ability to interpret the markers that were displayed. For example, one instructor asked - "am I seeing my own eye tracking data?", which reflected her confusion regarding the meaning of the markers that were present on her display at that time. Similarly, several students reported that they did not understand the meaning of the white gaze markers, which represented past gaze points of their peers. This implies that the current mode of display (i.e., colour scheme etc.) does not intuitively communicate such information, and that users would need training in order to use it effectively. One instructor also reported of difficulties to distinguish new gaze markers from old ones, which precluded the possibility of using the visual history of the gaze for discussion purposes.

Finally, extending the above point, one participant had pointed out that current markers are less suitable for pointing to specific objects, since they cover a portion of the model. For instance, if one looks at a window in a wall, it is hard to know if the marker refers to the window itself or the wall as a whole. Simply put, the shape of the markers and size have decisive consequences for communication, and therefore should be designed purposefully, in accordance with the needs of the users.

6.1.2 User control issues

Several concerns were raised regarding the users' inability to control the flow of gaze data. Both students and instructors reported that they do not feel comfortable with sharing all gaze information with their peers. A proposal to add a button for regulating the flow of gaze data elicited different reactions from the participants. On the one hand, several students and one instructor thought that this may be effective in at least two ways - in reducing visual clutter, and in helping the peer to focus on certain things at given moments in time (i.e., activating the sharing mechanism can signal - "look here now"). On the other hand, another instructor had pointed out that gaze behaviour itself is very hard to control, so that such a control mechanism cannot prevent the "leakage" of gaze information. In other words, since we often do not intend to glance at something but do it naturally, an additional mechanism would be needed to filter the shared gaze data and remove unintended/irrelevant gaze fixations.

6.1.3 Technical issues

Various technical issues were pointed out and should be addressed to make the system usable in a real studio setting. First, several participants evaluated the quality of the model that was presented as unsatisfactory and lacking in detail. Second, when facing each other, gaze markers appeared and blocked their view of their peer's face, which had a negative impact on the quality of communication, as it discouraged them from trying to face each other and communicate naturally. Third, while participants found the gaze markers useful in reflecting their peer's gaze and successfully identified their objects of interest, occasional imprecisions in the position of gaze markers were reported.

Beyond these, participants also expressed dissatisfaction with certain limitations posed by current technology. For example, one student explained that the size of the HMDs display (visor) is not large enough to create an experience which is highly immersive in their opinion, and that it places constraints on the size of architectural models which can be used for discussion.

6.1.4 Suggestions & features requests

Useful suggestions regarding the improvement of the system were made by our participants. First, with respect to the mode of display of gaze markers, one student pointed out that the use of 3D gaze markers may cause confusion with other 3D objects such as the model under discussion, and that therefore it would be better to distinguish the marker from the model in a clearer manner. Another participant proposed an alternative strategy of completely replacing the spherical markers with dynamic object textures which are commonly used in game development (called "decals"). For instance, if one looks at a roof, a light tint may colour it to reflect the fact that it is currently an object of interest. By using these we can keep the original texture of a given 3D object and overlay it with another texture to highlight the object underneath it, as needed. This can both contribute to the immersivity of the experience and reduce the need for searching for the referent object of a gaze marker.

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Additional suggestions were made regarding the type of information that is displayed. For instance, one instructor pointed out that he would like to see his own gaze point, which may help to increase one's awareness of their current object of interest. Also, a request was made for viewing the direction of their peer's gaze, which may be more intelligible when the virtual model is rich in information. Another participant requested that her peer's hand will be displayed as a hologram as well. In other words, gaze information did not seem to be sufficient for discussion (perhaps also due to the difficulties in its interpretation at the moment), and therefore many hand gestures were made. However, the hologram that is displayed on each participants HMD prevented them from seeing their peer's hand, and thus did not enable to pick up such information.
Other features which participants found essential for integrating the system as an effective tool for studio discussion were the ability to move objects in space and to add notes on the model, as they go. In a traditional studio, students and instructors can manipulate the model (to a certain extent), sketch etc. These possibilities for action seem integral to communication in a critique setting.

6.2 Reflection on user feedback and important considerations for future GS systems

On the basis of the above, key insights and for the design of future iRTGS systems are discussed. First, while we have argued for the necessity of effective communication in an educational context (Section 2), it is important to further consider the concrete manners in which communication be enhanced by an iRTGS system. One important way in which an iRTGS system may contribute to communication is by visualizing referents in discourse, thereby helping to coordinate the interlocutors. As explained by our users, such a visualization is expected to not only to be visually intelligible, but also to intuitively correspond to the content which is being referred to. For instance, if one refers to a physically large area, a point-shaped marker would be sub-optimal, since it may be interpreted as denoting a small visual area from the user's perspective. Therefore, iRTGS systems are expected to allow adaptability to various circumstances, preferably by adjusting their mode of presentation in accordance with the contents of the discourse. Valuable findings with respect to specific modes of presentation can be found in works such as (Rahman *et al.*, 2020). These can guide the design of future iRTGS systems, while keeping in mind the need to develop them further as to fit various circumstances and contexts, and while considering the complex, multimodal nature of human communication.
Second, reflecting on the general similarities and differences between instructors and students in terms of user feedback is fruitful as well. Naturally, both students and instructors expected the system to clearly reflect the visual information regarding their peer's gaze in a clear and intelligible manner. However, instructors were more explicit regarding what the system might *do* to support better communication. We view this as a call to reframe our conception of iRTGS systems - from passive visualization tools to active support systems. Realizing such active support capabilities may require drawing on advances in artificial intelligence (AI). One concrete example for an application of AI in this context may be the usage of predictive models to evaluate gaze behaviour (Kiefer *et al.*, 2014), which can then allow to respond accordingly. Prior to selecting a specific computational method, however, it is essential to further explore the manners in which users may be actively supported effectively, potentially via an extended user study in the context of an educational activity.
Finally, to reliably evaluate the potential of iRTGS systems to support communication in real-world scenarios, such as design discussion and critiques, it is important to embed them within larger digital environments. These are expected to include a minimal set of features which are fundamental to discursive activity in traditional settings and are thus inseparable from this practice at the moment. A key example may be the ability to leave visual marks on the model or drawing, as an act of commenting as well as documenting one's thoughts. While these do not have to take the same form as in traditional communicative settings, they are expected to cater for similar user needs. This will strengthen the reliability of the findings gathered from experimental studies with respect to their validity for real-world scenarios, in which communicative activity is facilitated by such tools and practices.

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7 CONCLUSION

A system for sharing gaze information across participants in an immersive environment was deployed and tested. Several of our main insights for the future development of such systems, in the context of design education, are summarized below:

- Gaze markers should be carefully designed so that they reflect the object/area of interest with greater/lesser ambiguity, in accordance with the specific goals of the participants in the discussion. For example, a discussion of general issues may benefit from larger markers that refer to areas of the model, while more specific points can be put, across using smaller ones that pinpoint specific objects or their parts, etc.
- Extending the above, fixed-sized marker should be avoided in immersive environments. Preferably, marker size would be dynamic (change in accordance with one's changing position in space) and easily distinguishable from non-marker objects. Marker colour may be dynamic as well, such that its contrast with differently coloured parts of the model is maintained.
- A gaze sharing system would benefit from a sub-system which filters gaze information, such that over information and visual clutter are avoided, and that essential information is transferred between interlocutors.
- The successful implementation of iRTGS systems in design education practices depends on their integration with additional systems which offer essential functionalities, such as note-taking, sketching etc., potentially in a modified form that makes use of the advantages of XR environments.

The authors strongly believe in the importance of deepening our awareness of user needs in design education, and that such awareness is essential for reaping the benefits of gaze sharing technologies in our design studios in the near future.

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