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Design Reviews in Immersive and Non-Immersive Collaborative Virtual Environments: Comparing Verbal Communication Structures

N. Horvat ✉, M. Brnčić, M. M. Perišić, T. Martinec, N. Bojčetić and S. Škec

University of Zagreb, Croatia

✉ horvatn@fsb.hr

Abstract

The paper explores the differences between immersive and non-immersive collaborative virtual environments (CVEs) during design reviews. Based on ten reviews with one designer and two reviewers, the study shows that CVEs affect verbal communication structure. More specifically, teams usually talked less, and reviewers exchanged significantly more turn sequences in immersive than in non-immersive CVEs. Regardless of the environment, most turn sequences were related to the designer, who usually talked the most. These findings contribute to the understanding of CVEs in virtual teams.

Keywords: collaborative design, virtual reality (VR), design review, verbal communication structure, virtual teams

1. Introduction

Design reviews are one of the main control mechanisms in product development (Liu et al., 2018), where many design decisions are made (Huet et al., 2007). In addition, they help designers improve their proficiency, design process, and design outcomes by reflecting on the current situation (Reymen et al., 2006). While design reviews can be conducted internally by designers themselves, they also offer an opportunity to include various stakeholders (Lauff et al., 2020). Hence, it is not surprising that they are usually conducted as a team activity (D'Astous et al., 2004).

Teams are a basic working structure in today's organisations, and they are used in both collocated and virtual settings. The advancements of information-communication technologies (ICTs) enabled organisations to switch more and more work to virtual settings (Gilson et al., 2015). Virtual teams, as compared to collocated teams, can utilise specialists around the world without their physical presence. Moreover, their performance is less affected by lockdowns such as the ones caused by the COVID-19 pandemic. However, these benefits of virtual teams might not result in better team performance, as such teams are prone to issues related to the lack of face-to-face communication (Dulebohn and Hoch, 2017; Gilson et al., 2015). Understanding virtual teams and how ICTs affect their behaviour might thus have significant implications for future research and practice.

While a number of different ICT tools can support virtual work, it remains unclear how they can be leveraged to their full potential (Gilson et al., 2015). Recently, researchers started investigating the use of collaborative virtual environments (CVEs), in which team members share the same digital space while occupying remote physical locations. These CVEs were incorporated for various activities in the design field, including design reviews (Bassanino et al., 2014; Horvat et al., 2021). As a result, design researchers often analysed various technologies used to represent and interact with CVEs, commonly comparing low immersion technologies such as 2D screens with high immersion virtual reality (VR)

technologies. However, despite the high potential of CVEs and the high interest of design researchers, these studies resulted in contradictory findings related to the immersion effect on design review outcomes. More specifically, the use of immersive CVEs sometimes resulted in higher (Tea et al., 2021; Wolfartsberger, 2019) and sometimes in lower (Liu et al., 2020) review performance as compared with non-immersive CVEs. A possible way forward that might have great potential to better understand these differences is to analyse mediators through which technology affects design review outcomes. These mediators can be broadly categorised into affective, behavioural, and cognitive mechanisms (Dulebohn and Hoch, 2017). While all these mediators might affect review performance, this work investigates the relationship between technology and team behaviour.

As one aspect of team behaviour, design researchers often study verbal communication - the most dominant mode of communication in design (Eris et al., 2014). Such studies might focus on the semantics or the structure of verbal communication, using a unit of analysis that is either semantically determined or unrelated to the communication content. While both approaches were used to understand designing (Bierhals et al., 2007; Lauff et al., 2020), design researchers focused more on semantic analysis and rarely studied the communication structure. However, previous research has linked the verbal communication structure to team creativity (Leenders et al., 2003) and the formation of sub-teams (Bierhals et al., 2007). Moreover, the analysis of verbal communication structure with a content-independent unit of analysis yields similar results to a content-dependent unit of analysis (Jiang and Gero, 2017), thus making it easy to execute. Hence, analysing verbal communication structure is a powerful methodological tool to identify related aspects of team behaviour within design reviews.

Given the importance of analysing virtual teams' behaviour while using various ICTs, this study compares verbal communication structures between non-immersive and immersive CVEs during design reviews. Furthermore, this research is a step towards understanding how virtual teams can leverage the emerging technologies. More specifically, this article answers the following research question: *How do different CVEs affect verbal communication structure in design review activities?*

The following section introduces design reviews and CVEs that can be used for this activity. Section 3 introduces and describes the conducted experiment, while Section 4 compares verbal communication structures of the observed samples. The results are then discussed in Section 5.

2. Design reviews

Design reviews are reflection periods involving members who verify the design and recommend future actions (BS EN 61160, 2005; Huet et al., 2007; Liu et al., 2018). They can be conducted internally by designers, externally by reviewers (members who did not work on the design), or as a mix between the two (Lauff et al., 2020). Team composition might have a significant impact on the internal review activity, as designers already know the requirements and structure of the design. On the other hand, external members might give alternative views on the design but might take more time to understand the design (Liu et al., 2020). Therefore, to utilise the advantages of internal and external review types, design reviews commonly consist of mixed members (i.e., designers and reviewers).

The execution of design reviews usually follows three cycles: understanding the design, evaluating the design, and planning future actions (Huet et al., 2007; Liu et al., 2018). When going through these cycles, a review team often has a current design representation (e.g., sketches, drawings, 3D models, physical prototypes). These representations serve as boundary objects (Bassanino et al., 2014; Chandrasegaran et al., 2013) and aid in the communication and the development of shared understanding among various product stakeholders (Lauff et al., 2020). Since the development of shared understanding is important for the successful review (D'Astous et al., 2004), several researchers suggest conducting an understanding cycle before the reviews (Tea et al., 2021; Wetmore et al., 2010). This understanding of the design and requirements might help the team proceed more efficiently as they already share review-related information (Wetmore et al., 2010). Finally, planning future actions usually involves feedback about identified issues and proposed changes (Huet et al., 2007; Liu et al., 2018). Since much information is lost during these reviews, meeting templates are suggested to help teams in summarising the review findings (Huet et al., 2007).

While these cycles are typical to a wide range of design reviews, the contextual focus of these activities might differ, such as functionality, manufacturing, or ergonomics (BS EN 61160, 2005). Hence, in order

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to guide the review according to its aim, the review team can have checklists based on standardised requirements (BS EN 61160, 2005) or requirements developed throughout the product development.
Studies of the design review process rarely utilise virtual team settings. Hence, it is unclear how the design review process looks in a virtual setting and how virtual teams can leverage the CVEs. Therefore, the following subsection provides an overview of CVEs and previous work investigating their effect on some aspects of design reviews.

2.1. Collaborative virtual environments (CVEs) for design reviews

Review teams can use various CVEs, which differ in the content they present and the supported social awareness and depth cues. Since design reviews typically occur in the later product development phases (BS EN 61160, 2005), the content available during these activities often includes computer-aided design (CAD) models (Chandrasegaran et al., 2013). Indeed, previous research identified CAD models as the main boundary objects during mixed design reviews (Bassanino et al., 2014). However, when reviews are conducted with only internal members, CAD models are still used, but the focus is more on the other documents, such as a list of requirements (Horvat et al., 2021).
Social awareness cues of CVEs often relate to the communication modality that CVEs enable, such as verbal, gestural, and textual (Eris et al., 2014). Even the subtle social awareness cues (e.g., sharing viewpoint) affect user performance, usability, and subjective preferences (Wolfartsberger, 2019). While personal interactions with a review content facilitate members' contribution to team activities (Bassanino et al., 2014), shared views help team members in developing shared understanding, generating alternatives, and problem-solving (Bassanino et al., 2014; Dossick, 2014). Hence, teams benefit from both the personal and shared views of the work under review (Bassanino et al., 2014; Dossick, 2014).
CVEs also differ in the sensory cues stimulated by the visualisation technology used to represent the virtual environment. Both immersive (e.g., collaborative VR) and non-immersive technologies (e.g., collaborative CAD) can support several participants who individually control their viewpoint but could also see where the others are looking. However, CVEs with immersive technologies such as VR (e.g., head-mounted displays) sometimes have only one active participant that controls the viewpoint while other members are passive observers. Although restricting individual interactions, even this setup enabled participants to perceive the benefits of immersive environments. For example, teams in immersive environments reported a better understanding of product assembly steps and spatial relationships between parts compared to traditional reviews with a desktop computer (Berg and Vance, 2016). Moreover, review teams suggested that immersive VR has a positive effect on the communication within the design review teams (Wolfartsberger, 2019) and results in higher participation of individuals (Berg and Vance, 2016) compared to traditional approaches. However, the objective measures suggest that this type of immersive CVE does not improve review performance (Liu et al., 2020).
Few studies compared immersive and non-immersive CVEs where both environments would have more than one active participant. Zaker and Coloma (2018) compared two-member collaboration and reported that immersive CVEs are perceived beneficial for internal and mixed design review. Furthermore, Tea et al. (2021) compared these two CVEs for the understanding cycle of the design review. They found that using immersive CVE in this cycle resulted in a slightly higher number of identified errors in a real-world building inspection. They also suggest that reviews within immersive CVEs result in improved collaboration and better spatial understanding (Tea et al., 2021). Most recently, Horvat et al. (2022) compared issue identification using two CVEs with different immersion levels. Contrary to prior work, they identified that collaborative design reviews in non-immersive CVEs result in a higher number of issues than the reviews in immersive CVEs.
Previous studies that investigated the effect of CVEs usually focused on the review outcomes, neglecting its effect on the review process. Moreover, these studies rarely focused on CVEs with multiple active participants. Therefore, analysing the effect of various CVEs with multiple active participants on the verbal communication structure can have important implications for both research and practice.

3. Methods

The study is designed as a matched-pair experiment aimed at unravelling the subtle differences between different types of CVEs. In the experiment, participants worked on a design review task in two

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conditions: immersive CVE (i.e., collaborative VR) and non-immersive CVE (collaborative CAD). These two conditions were chosen because they support the visualisation of CAD models - a typical design representation in the later design phases (Chandrasegaran et al., 2013).
To investigate the effect of CVEs on team behaviour, the dependent variables that describe the communication structure were collected from the experimental design review activities using a protocol analysis approach. More specifically, all the reviews were segmented into speaking and non-speaking portions for each review team member. To ignore the short pauses while speaking, turn ends with either the next person starting speaking or with a silence longer than one second (Eris et al., 2014). Two dependent variables have been derived from the turn-taking model of conversation (Sacks et al., 1974) and include the total duration of turns and 1st order turn sequences between team members. The total duration of turns is defined as the speaking time throughout the whole session. Furthermore, to identify the differences amongst the two conditions, the total duration of turns has been normalised by calculating the ratio of a member's total duration of turns to the team's overall speaking time. The 1st order turn sequences between team members are defined as the total number of cases when a team member started speaking after another member. They have also been normalised with regards to the total number of 1st order turn sequences in a design review session.

3.1. Experimental task and sample

The experimental task was to review the design and report issues regarding requirements, ergonomics, manufacturing, assembly, safety, maintenance, functionality, and strength. During the reviews, the suggested procedure was to take a screenshot with an optional markup of the identified issue. After the review session, the review team complemented each screenshot with comments to create a review report. In total, ten design review sessions were analysed, five in non-immersive and five in immersive CVE.
The designs under review were devices that use only human energy and have one or more user interface elements. More specifically, designs include five different devices (foldable wheelchair, weightlifting equipment, foldable baby stroller, foldable baby tricycle, and office chair), each designed by two teams (Figure 1). The devices were designed by ten three-member design teams randomly composed from a sample of 30 undergraduate mechanical engineering students (10 female and 20 male). Each team was randomly assigned a design brief and a patent as a source of inspiration. The design teams participated in the project-based CAD course and had two months to create a design in CAD software.
The review teams were composed of one internal (i.e., designers) and two external (i.e., reviewers) members. Each design team selected their representative, while researchers sampled the two reviewers following several criteria. Firstly, they had to be independent of the course as the teaching staff's authority might influence the students' behaviour. Furthermore, the reviewers had to have masters' degree and previous design experience. For participation in the experiment, each reviewer received financial compensation.

Figure 1. Designs reviewed in the experiment

3.2. Experimental setup and procedure

During the experiment, review team members were located in three separate rooms. These physically distant members met in a CVE to review the design (Figure 2). In both immersive and non-immersive CVEs, the review team verbally communicated using *Microsoft Teams* and had the same basic set of available tools: screenshot, measure, marker, and section view. For the non-immersive CVE condition, the *Onshape* software has been chosen. *Onshape* is a cloud-based CAD that enables synchronous work on the same CAD model. Like other CAD tools, *Onshape* enables navigation by grabbing and moving (i.e., pan, rotate, zoom) within a CVE. Furthermore, its viewing mode has functions similar to the toolset in the immersive CVE, supporting the control of this variable between the two conditions. Moreover,

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Onshape enables several social cues such as seeing whether anyone else is online on the same document and following others to see their viewpoints (see Figure 2 top for an example of shared view between Reviewer 1 and Designer). To ensure consistency, all the members in this condition had the same model of a monitor (22" with the resolution of 1920x1080 pixels), keyboard, mouse, and office chair.
The review in immersive CVE has been conducted using *Autodesk VRED 2021 Pro* software and either *HTC Vive* or *HTC Vive Pro* headset. Team members could navigate the viewpoint by moving in a virtual room (4x3 meters). In addition to the available tools, team members could see the position and orientation of the participants' heads and controllers in the form of avatars (see Figure 2). Besides virtual environments, the review team had available two documents commonly used during design reviews: the requirements list and the review checklist (Huet et al., 2007; Wetmore et al., 2010). After the review session, the reporting session was conducted in an online document editing tool (*Microsoft Word Online*), regardless of the condition. During this phase, the review team had screenshots that they had taken, the design review checklist, and the list of requirements.

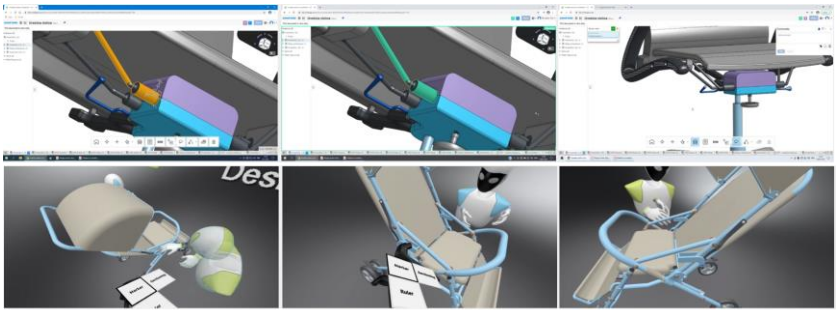

Figure 2. Viewpoint of each participant in non-immersive (top) and immersive CVE (bottom)

The experimental procedure consisted of five steps: 1) Preparation and introduction to the equipment, 2) First design review session, 3) Reporting the first review session, 4) Second design review session, 5) Reporting the second review session. The review session has been split into two parts according to the suggestions for the experimental protocols using immersive VR equipment (Mastrolembo Ventura et al., 2020). The preparation and equipment introduction were differently conceptualised for reviewers and designers. Reviewers received an introduction (about 1 hour per condition) through a pilot experiment. This timing is considered sufficient to tackle the issues related to lower experience in technology (Horvat, Martinec, Lukačević, et al., 2022). Furthermore, a few days in advance, they were given a preparation package that included a checklist for creating requirements, patents similar to those given to students, a design review checklist, a review template, and a set of *Design for X* guidelines. The guidelines included designing practices related to casting and injection moulding, machining (turning, drilling, milling, grinding), sheet metal, welding, assembly, maintenance, safety, and ergonomics. One day before each experiment, reviewers were given the requirements of the design under review. A design team representative was given a brief introduction to the equipment by explaining each tool (screenshot, measure, marker, and section view) and how to manipulate and navigate in a CVE. After the introduction, the team had 30 minutes to review the design. During this phase, the review team had available a design representation, a review checklist and a list of requirements. The researcher then instructed them to move to the reporting of the first session. For this experimental step, review teams had no time restrictions. However, this part of the session usually lasted for 15-20 minutes. Once the review team finished reporting on the first session, they continued reviewing for an additional 30 minutes and then reporting the second review session. Each review team could decide themselves on the review process and its distribution over the two sessions. The participants' audio and the content displayed on each screen were recorded during the experiment using *OBS Studio*.

4. Results

On average, the total duration of turns in a review team (i.e., speaking time) was 76% of the session time in non-immersive CVE and slightly less (around 68%) in immersive CVE. This time has been used

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to normalise the data and identify the ratio of the team members' total turns duration (Figure 3). In all the sessions, except the wheelchair and multipurpose gym equipment in non-immersive condition, the designer (D) had the highest ratio of total turns duration, i.e., spoke the most. Moreover, the highest ratio in both conditions happened while reviewing foldable baby strollers (0.7 in non-immersive and 0.48 in immersive CVE). The lowest ratio has been found for the first reviewer (R1), again while reviewing the foldable baby stroller (0.1 in non-immersive and 0.13 in immersive condition).
Furthermore, the review teams had on average 659 turn sequences between team members in non-immersive and 609 in immersive conditions. These sequences have been used to calculate the ratio of the team members' 1st order turn sequences in the review session. The highest ratio of the sequences was always between the designer (D) and the second reviewer (R2), i.e., R2→D and D→R2 sequences, ranging from 0.2 for wheelchair in immersive CVE to 0.35 while reviewing baby stroller in immersive CVE. The lowest ratio of the sequences within sessions was usually amongst reviewers (the exception was wheelchair in immersive condition), with only 0.03 for the baby stroller in non-immersive CVE.
The following subsection presents a more detailed comparison of the turns duration ratio and the turn sequences between the two conditions. Before statistical testing for the group differences, the normality of the data was tested using the *Shapiro-Wilk* test, while the homogeneity of variances was tested using *Levene's* test. All the analysis has been conducted in *R* using the *car* library.

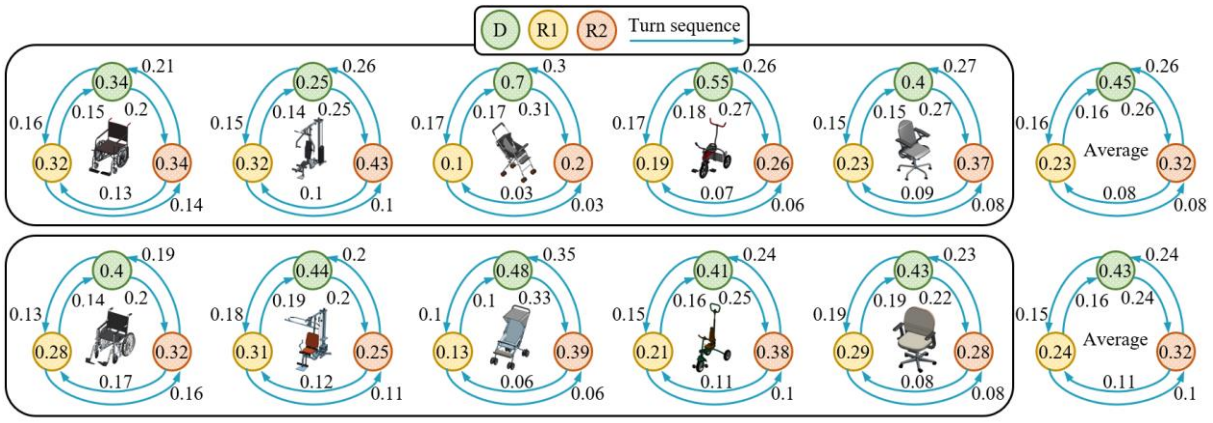

Figure 3. The ratio of total turns duration (in circles) and 1st order turn sequences (on arrows) for non-immersive (up) and immersive condition (down); D - designer, R - reviewer

4.1. Comparing the ratio of total turns duration and 1st order turn sequences

While the designers verbally dominated the sessions in both environments, the comparison of the means revealed that they had a slightly lower average ratio of turns in immersive compared to non-immersive CVE (Figure 4). However, paired *t*-test did not reveal significant differences ($p = 0.84$), and the effect size was small (Cohen's $d = 0.1$). Comparison amongst reviewers suggests that, on average, R2 had a higher ratio of total turns duration than R1. Furthermore, both reviewers had a higher average ratio of total turns duration in immersive condition. However, these differences were not significant, neither for the R1 ($p = 0.59$) nor the R2 ($p = 0.94$). The effect sizes were also small, i.e., Cohen's d is 0.26 for R1 and 0.04 for R2. Finally, the designers' total turns duration ratio had lower variation in immersive compared to non-immersive conditions. The same is true, although less apparent, for both reviewers.
Most turn sequences happened between two members with the highest verbal communication ratio (D and R2 - see Figure 5). This finding is true for both directions (D→R2 and R2→D). Similarly, the lowest ratio of 1st order turn sequences was between the two reviewers in both directions (R1→R2 and R2→R1). Furthermore, a comparison between the two conditions shows that the ratios of 1st order turn sequences with designers (D→R1, R1→D, D→R2, and R2→D) had higher means in non-immersive than in immersive CVE. However, these differences were not significant, p(D→R1) = 0.79, p(R1→D) = 0.93), p(D→R2) = 0.27, and p(R2→D) = 0.36. In addition, the effect size was small for sequences between D and R1, with Cohen's d being 0.12 for D→R1 and 0.04 for R1→D. On the other hand, the effect size of D and R2 sequence differences in the two environments were moderate, i.e., 0.58 for D→R2 and 0.46 for

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the R2→D type of sequence. Opposite to the turn sequences between a designer and a reviewer, a comparison amongst reviewers (R1→R2 and R2→R1) shows that they had a higher ratio of 1st order turn sequences means in immersive than non-immersive conditions. Indeed, these differences were significant for both the R1→R2 sequence (p = 0.065) and the R2→R1 sequence (p = 0.044). Moreover, the effect sizes were large for both sequence types, i.e., Cohen's d is 1.13 for the R1→R2 sequence and 1.29 for the R2→R1 sequence. Finally, the results concerning the sequences with designers suggest that those sequences vary less in non-immersive than in immersive CVE.

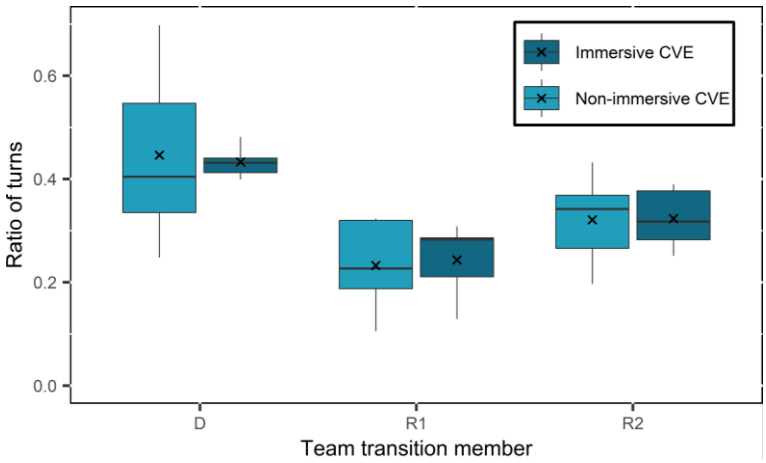

Figure 4. Comparing verbal communication in the two environments

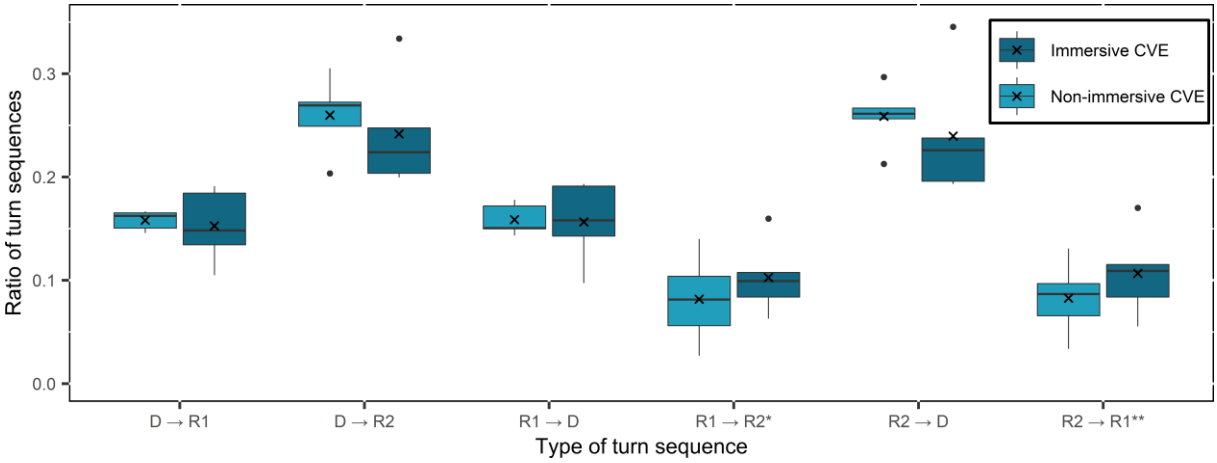

Figure 5. Comparing turn sequences in the two environments (* - p < 0.1; ** - p < 0.05)

5. Discussion

Results suggest that the review teams had less verbal communication in immersive than non-immersive CVEs, with designers dominating both environments. Furthermore, reviews within immersive CVE had a more uniform communication structure than reviews in non-immersive CVEs. This section discusses these findings (Section 5.1.) and presents implications and limitations of the study (Section 5.2.).

5.1. The effect of CVEs on verbal design review communication structure

The presented results show that CVEs affect communication structures in design reviews. For example, the lower average proportion of verbal communication suggests that team members communicate less in immersive CVEs. These results might be because of different social cues in the two environments since the immersive CVEs display the position and orientation of the participants' head and controllers. Hence, it might be that review teams used other communication modes to replace the portion of the verbal communication in non-immersive CVE. Another explanation might be that team members in

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immersive CVEs were always in a shared space which might resulted in higher awareness of members' actions (Bassanino et al., 2014; Dossick, 2014), thus requiring less verbal communication.
Although the designer usually talked the most, the ratio of turns durations did not differ in the two conditions. These results suggest that CVEs do not affect this aspect of communication structure. Furthermore, turn sequences between reviewers and designers were higher than turn sequences amongst reviewers. Hence, review sessions had dyadic sequences between one of the reviewers and a designer. Indeed, the turn sequence proportions were similar in any two directions. These results align with the theoretical assumptions of the mixed review team and understanding cycle being part of the review session (Huet et al., 2007; Liu et al., 2018) rather than conducted in advance (Tea et al., 2021; Wetmore et al., 2010). Furthermore, the central role of a designer in verbal communication during reviews is in line with the qualitative findings, as designers explain the progress of their work and often try to persuade the external members during design reviews (Lauff et al., 2020).
While both conditions resulted in differences amongst review team members in the ratio of 1st order turn sequences, these differences were less pronounced in immersive CVE (Figure 5). As reviewers also had the lowest portion of turn sequences, these results suggest that immersive CVEs might equalise the engagement of review team members. The possible explanation is again related to the higher number of social awareness cues and the use of shared space in immersive conditions, as team members might be more aware of each other. Consequently, reviewers might have collaborated more in immersive CVE than in non-immersive CVE, suggesting that reviewers provide more cohesive feedback (i.e., agreed upon on a team level) to team members in an immersive CVE. Indeed, these results are aligned with the previous studies, which suggests that immersive CVE resulted in better communication (Wolfartsberger, 2019), fuller participation (Berg and Vance, 2016), and improved collaboration (Tea et al., 2021; Zaker and Coloma, 2018). These findings might partially explain the lower number of identified errors in immersive CVE (Horvat, Martinec, Perišić, et al., 2022), as the use of private spaces in non-immersive CVEs might facilitate privacy and self-exploration for finding solutions (Bassanino et al., 2014). However, future studies should explore this interplay between personal and shared spaces as well as the relationship between the immersion level of CVE and feedback type.

5.2. Implications and limitations

The here-presented results have various implications for researchers and design practitioners. First, design and virtual team researchers can use the findings to better understand the differences between CVEs in the design review context. The study suggests that the effect of different CVEs is identifiable at the team behaviour level, more specifically at the communication structure. Hence, besides analysing the effect on the review outcomes (e.g., number of identified issues), design researchers should also investigate the effect of CVEs on a team affect, behaviour, and cognition. Second, design researchers might use presented findings to develop new collaboration technologies that elicit desired team behaviour, depending on the situation.
Virtual teams could use these results to help them in choosing the CVE for the review-based task. For example, during the design review process, they should use non-immersive CVE (e.g., collaborative CAD) if they would like to facilitate verbal interaction with a designer. On the other hand, if the team wants to equalise verbal communication between review team members, they should use immersive CVE (e.g., collaborative VR). Furthermore, software developers could use the study findings to tailor future developments of CVEs. More specifically, they should carefully assess the development decisions as they might have significant side effects on the team behaviour.
While providing insights for researchers and practitioners, the results have several limitations. First, the presented study is focused on the design reviews that occur during the detailed design phases. However, the other phases often use two-dimensional representations (Chandrasegaran et al., 2013) whose visualisation in immersive CVEs might elicit different team behaviour. Hence, additional studies are necessary to explore how immersive CVEs can support other reviews throughout product development. Second, findings have limited generalisation to other settings, such as those related to the different communities (e.g., educational reviews such as design critiques), different team types (i.e., internal, mixed, external) and sizes. While these settings are based on similar cycles (understand, evaluate, plan), some differences between these settings must be explored. For example, in educational settings, the

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authority of the course staff over students should be considered. Third, the generalisation to other CVEs with different toolsets must be investigated because the relationship between CVEs' immersion level and verbal communication structure might not be linear. Fourth, the study is limited in sample size. Hence, future studies should be conducted with a larger and more heterogeneous sample. Finally, the results should be carefully extrapolated to other designs of different sizes and complexities (Horvat et al., 2019; Liu et al., 2020). These limitations are common in experimental settings, and they should be used as a guideline for exploring CVEs' effect on virtual teams.

6. Conclusions

This paper investigates the effect of immersive and non-immersive CVEs on the verbal communication structure during design reviews. The results show that teams usually talked more in a non-immersive CVE. On the other hand, the ratio of total turns duration did not differ between the two groups. Regardless of the environment, the results show that the designer talked the most during three-member mixed design reviews. Moreover, most of the turn sequences are related to the designer, suggesting a dyadic communication amongst each reviewer and designer. Finally, results show that the immersive condition resulted in a significantly higher number of 1st order turn sequences among reviewers than the non-immersive group. Taken altogether, these findings show that different CVEs elicit different team behaviour in terms of verbal communication structure.

The results have several implications for researchers and practitioners. First, researchers should also consider process variables in addition to the outcomes when investigating design reviews. Furthermore, researchers can utilise the findings to understand the use of CVEs, either in the design field (e.g., design reviews) or in the management field (e.g., after-action meetings). Finally, virtual teams should use these results to support the decision for the tool they will be using.

Future studies should replicate presented findings with a larger sample and analyse the effect of the various cues on team behaviour. In addition, these studies should identify other variables that might be affected by different CVEs, thus fostering a better understanding of the different CVEs on the design reviews. Another stream should investigate generalisation to different settings (e.g., educational reviews), team types (internal, mixed, and external reviews), design contexts (different sizes and complexity), and other reviews that happen during product development (e.g., requirements review). Finally, researchers should also augment the findings with content-dependent analysis.

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