Title:
Approach to Analyse the Use of Virtual Prototypes in Distributed Design Reviews

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Introduction and related work:
Design teams use prototypes to communicate with stakeholders, identify design issues, learn from failures, make decisions, etc. [1]. An example of activities where design team members (TMs) commonly use prototypes are the design reviews [2] - inspection periods in which the team has to understand design intent, validate requirements, and resolve design issues [3]. During these periods, design teams use various prototypes to explain ideas and receive feedback from other TMs to iterate and improve the design [2]. Throughout these iteration cycles, design teams quickly develop new versions of the product and gain knowledge on the solutions that work. This puts prototypes in the centre of design review, as they provide the ability to have similar mental models of a design within the review team [2]. While both physical and virtual prototypes (VPs) can be used during design reviews, the latter are more flexible as VPs support more rapid testing at a lower cost than physical prototypes. Given the flexibility and low cost of VPs [4], it is not surprising that, in design review meetings, VPs are the main boundary objects [5]. The benefits of VPs are even more emphasised in distributed teams – a common team setting in today's product development organisations [6] – since all the members have access to an up-to-date version of the prototype.

During design reviews, teams benefit from both personal and shared views of a prototype [7,8]. Personal viewing of the prototype provides an opportunity for the TMs to personalise the viewpoint and hence supports their understanding of the prototype [9]. Indeed, in a collocated educational environment, Groen et al. [10] showed that all the reviewers interact with the physical prototype to understand and evaluate the design. However, prototypes' sturdiness and functionality affected this personal interaction and, consequently, the review process, as more developed prototypes facilitated more constructive feedback and decreased power relations between designer and reviewer [10]. Hence, personal interactions with prototypes facilitate TMs' contribution to team activities [7]. On the other hand, shared views help members to develop shared understanding [8], generate alternatives [7], and solve problems [8]. While the focus on a prototype during reviews supports the team agreement on the issues discovered by individuals [8], reviewers use other documents (e.g., analyses, requirements) that help them during the review. The simultaneous use of a VP with additional documents supports engagement and knowledge exchange among reviewers [8]. Therefore, in distributed design reviews, TMs change their views between the personal view of VPs, shared view of VPs, and other documents (e.g., list of requirements).

Researchers explored the overall use of prototypes during design reviews and emphasised the importance of both personal and shared views of VPs. While some computer-aided design (CAD) tools already support the transitions between personal and shared views of VPs (e.g., synchronous collaborative CAD tool such as Onshape [11]), none of the researchers focused on the prototypes' use dynamics throughout the session. Consequently, the frequency of these transitions and the dynamics of their occurrence is still unclear. This limited understanding of VP use in design review context might delay the implementation of new tools that might help reviewers in the review process. To fill this gap, this paper proposes a methodology to design and analyse the use of VPs in distributed design reviews.

Empirical study description:
We present the approach in a single design review session. Although a single-case empirical study prevents generalisability, our aim was not to give a general understanding of VPs' use but rather propose a procedure for gaining a better understanding of distributed design reviews. The studied case is a 40-minute design review session of a student subteam.

The review subteam consisted of four members out of an eight-member design team who collaborated virtually in a semester-long project-based course, with two members from Slovenia and one from each Croatia and Italy. The course aimed to develop a solution for reusing water from the washing machines' rinsing cycle. An academic coach facilitated the work of the team throughout the course. Besides, two companies tracked the students' progress through formal reviews (presentation of students + discussion) after each phase.

In preparation for the distributed design review, participants installed a screen recording software (e.g., OBS Studio). In addition to the screen recording software, the participants used a familiar video conferencing tool (Microsoft (MS) Teams) as well as a synchronous collaborative CAD software (Onshape) in which the team developed their design. The use of collaborative CAD software enabled both personal and shared views, as TMs could individually manipulate the CAD model and follow the view of other TMs. For example, in Figure 1, TM1 and TM4 follow TM2 (indicated by examination of screen recordings), and they have the same viewpoint. On the other hand, TM3 has a different viewpoint since they do not follow anyone. The team also had a list of requirements (represented in MS Excel Online) developed by the design team and a review template (represented in MS Word Online) inspired by Huet et al. [3]. The review preparation included also a brief introduction of the session goal and files to be used during the review. A researcher was present at the conference call at the beginning and the end of the session in order to provide instructions, start voice recording, and collect data necessary for synchronising participants' screen recordings. We instructed participants to check whether the assembly and the subassemblies meet the requirements. They were allowed to modify the requirements list developed by the team during the course. After the review session, the researcher re-joined the conference call and asked the participants a few questions about their reviewing approach.

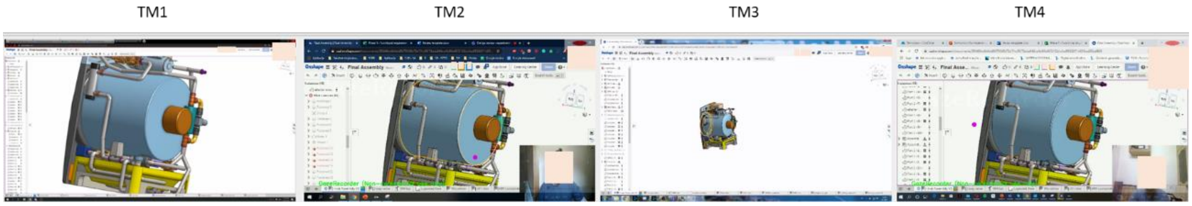

Fig. 1: Personal (TM3) and shared view of the VP (TM1, TM2, TM4).

Analysing the use of VPs:
This section describes the approach for analysing VP use (Figure 2) through the above-mentioned empirical study. We processed the screen and audio recordings by using a video annotation software (e.g., ELAN). More specifically, we synchronised the recordings and annotated whether the TMs looked at the VP or not. We also annotated periods when TMs looked at the VP personally or followed other members (having shared view of VP). Although this process is laborious due to the manual annotation, it provides quantitative data as a baseline for understanding the use of VPs during design reviews.

Using these results, we firstly analysed the time that TMs spent viewing the VP, by distinguishing the personal and shared views (Figure 1). We then provided insight into the dynamics of viewing the VP throughout the session (including personal and shared viewpoints). We used moving window analysis, with the window size corresponding to the average duration of TMs viewing the VP (22 seconds). This window size was selected to filter the data and get insight on the brief and long views of VPs. Finally, we analysed whether TMs usually viewed the VP one-by-one (such as turn-taking) or simultaneously. To support insights from quantitative analysis, we also provide qualitative data gathered from the post-session interview.

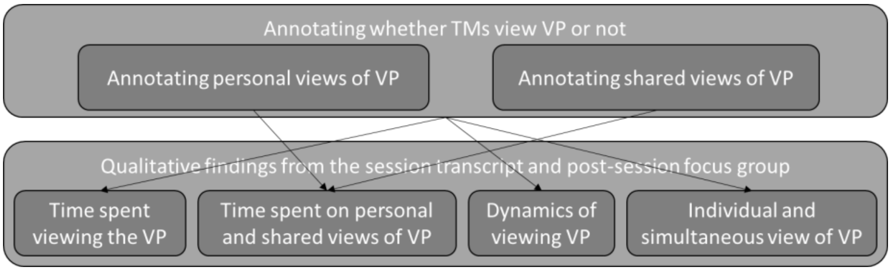

Fig. 2: Results obtained using the analysis approach.

TMs spent 18.9% to 31.9% of the session time viewing the VP (Table 1). TMs, on average, spent from 16.7 to 25.1 seconds looking at the VP, suggesting that the viewing of VP is typically brief. These results suggest that TMs focused primarily on the other windows they had available, such as the requirements list window. The reason for the low percentage of viewing VP may lie in the composition of the review team, as they already had an understanding of the design under review. Another reason could be the type of requirements that the team checked, as not all of them could be verified using the VP (e.g., power of the machine pump). Post-session interview supports these suggestions:

"Let's say for the storage space or something, for that kind of things, we went to the CAD models. Apart from that, we already knew the topics and the things which covered in requirements." – TM4

"For example, washing machine pump has maximum headlift. You were not going to get it from the CAD file." – TM3

TM	Viewing VP – total		Personal view of VP	Shared view of VP		
	Share of the session time [%]	Average duration of occurrence [sec]		Followed by others [%]	Following others [%]	Total public view [%]
TM1	18.9 %	16.7	15.5 %	0 %	3.4 %	3.4 %
TM2	31.9 %	23.1	17.6 %	12.8 %	1.5 %	14.3 %
TM3	21.7 %	21.5	16.5 %	5.1 %	0 %	5.1 %
TM4	24.2%	25.1	10.2 %	0.5 %	13.6 %	14.1 %

Tab. 1: Descriptive statistics of viewing VP.

TMs utilised both personal and shared views of VP (Table 1). Viewing the VP in personal viewpoint mode was fairly consistent and ranged from 10.2 % to 17.6 % of the session time. On the other hand, the extent of the shared viewpoints ranged from 3.4 % to 14.3 %. Furthermore, the use of shared viewpoints differed between TMs, with some of TMs usually following others (TM1 and TM4), and some being followed by others (TM2 and TM3). Such use of shared viewpoints was discussed in the interview:

"When I was in CAD, I followed the members who actually tried to explain something. I did it a lot by myself because while we were discussing about potential improvements and everything, I was still searching in CAD and tried to figure something new or maybe look at the component or subsystem from the other perspective." – TM2

"I also didn't follow anyone. I just checked it on my own. Because I knew what the others were talking about if that was the case, cause there is not many components. So its like: okay, we're talking about filter, you know where the filter is." – TM3

The dynamics of viewing the VP is shown in Figure 3. The VP viewing time was generally brief, since the above-average duration of viewing VP occurred only a few times throughout the session. On the other hand, periods when TMs viewed other windows (e.g., requirements list, review template) were often longer than the average (indicated by the flat line on the bottom of Figure 3). These results suggest that reviewers viewed the VP briefly throughout the session. Post-session interview supports this observation, as one of the participants said that they viewed the VP to assess some of the requirements:

"The only time I opened CAD was if I wanted to check something, so like if all the components fit into the design. I checked that real quick, just to double-check." – TM3

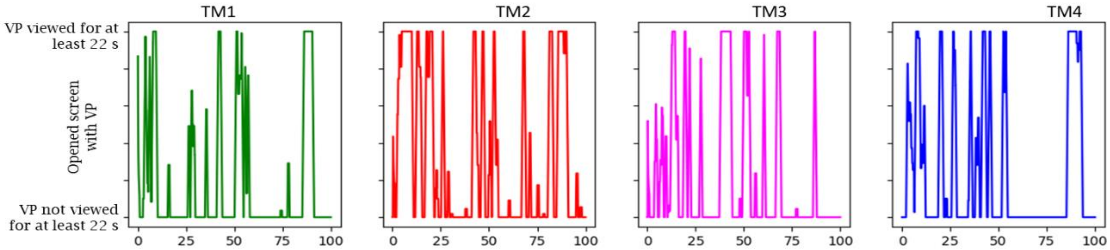

Fig. 3: Moving average (22s) of the combined VP's view (both personal and shared viewpoint).

The distribution of viewing the VP shows that most often (24.7% of session duration) only one member viewed the VP (Figure 4). The individual percentages of viewing ranged from 2.9% (TM1) to 9.6% (TM2). As for the VP's simultaneous view (i.e., two or more members viewed the VP at the same time), the portion of session time equals 13.4% for two members, 9.2% for three, and 4.3% for all the members. Such distribution suggests that as the number of simultaneous viewers of VP increases, the corresponding share in session duration decreases. Therefore, although the individual view of VP is the most prevalent one, a significant share of session time involves viewing of VP by more than one member simultaneously. These results support the previous suggestions that all individuals should have accessibility to the 3D model [9] or a physical prototype [10]. In both individual and simultaneous use cases, the highest portion of session time is consistently related to TM2. This member was a team leader during the last phase of the course, which might affect their use of the VP. However, further research is needed to delineate the effect of team structure on the viewing of VPs during distributed design reviews.

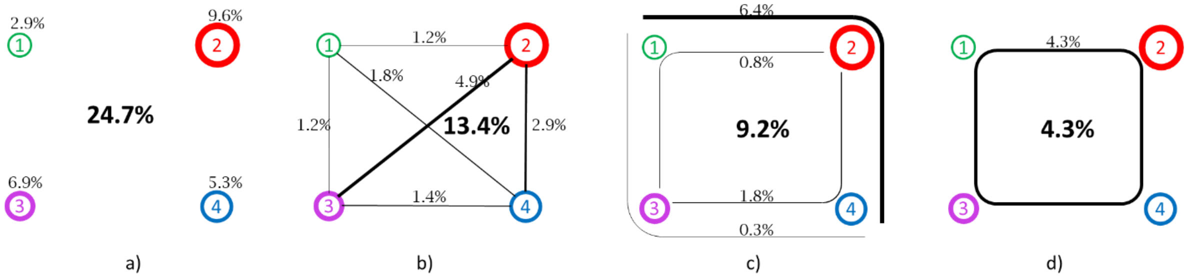

Fig. 4: Distribution of (a) Individual, and (b) – (d) Simultaneous view of VP.

Conclusions and future work:

This paper presents an approach for analysing the use of VPs in distributed design reviews. The approach distinguishes personal and shared, as well as the one-at-a-time and simultaneous viewing of VPs. The preliminary results based on the proposed approach suggest that all TMs viewed VP throughout the session. The viewing of VP varied between the personal and shared viewpoints, as well as between viewing by one TM at a time and simultaneous view by two or more TMs. However, their use was usually short in duration. Furthermore, even though for a significant share of the session time only one member viewed the VP, there were also occasions when the VP was viewed simultaneously by two or more members. Taken altogether, these results suggest that CAD tools should incorporate a feature to follow other members. Furthermore, due to a large number of transitions from VP to requirements and review template windows, these collaborative CAD tools should incorporate also a list of requirements within the CAD environment.

Scholars and practitioners should use this approach to assess the goodness of VP-based interaction among TMs. These results could be used to elicit requirements for the development of new technologies that might support design reviews or other types of design activities that involve the use of VPs. For example, the initial results suggest that the tools for viewing VPs (e.g., collaborative CAD, virtual reality) should allow enough flexibility for TMs.

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