INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED23
24-28 JULY 2023, BORDEAUX, FRANCE

IS IT BETTER? EXPLORING THE EFFECT OF TRANSITION GOAL AND VIRTUAL REALITY ON TEAM PERFORMANCE

Horvat, Nikola;
Martinec, Tomislav;
Brnčić, Marko;
Škec, Stanko

University of Zagreb

ABSTRACT

Transition activities, such as design reviews, are often utilised in product development to evaluate the conducted work and plan future actions. While key decisions are made during these activities, they are still underexplored. This paper studies the effect of transition goals and virtual reality (VR) on transition team performance. In an experimental study, four-member teams conducted two transition-related experimental tasks (validation and verification) working in one of the two conditions (VR or desktop interface). The results show that transition goals and VR affect performance. More specifically, the validation-oriented transition was more efficient but less effective than the verification one. Furthermore, the performance of the validation-oriented transition compared to the verification one was increased in VR and decreased in a desktop interface. Finally, the high-performing teams consistently discussed new issues, while low-performing teams had prolonged moments of not discussing anything new. These findings suggest that desktop interface and VR are not substitutable but rather complementary technologies.

Keywords: Virtual reality, Evaluation, Teamwork, Transition processes, collaborative CAD

Contact:
Horvat, Nikola
University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Croatia
nikola.horvat@fsb.hr

Cite this article: Horvat, N., Martinec, T., Brnčić, M., Škec, S. (2023) 'Is It Better? Exploring the Effect of Transition Goal and Virtual Reality on Team Performance', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.239

1 INTRODUCTION

While developing products, designers often seek feedback from various stakeholders, such as end-users, managers, and designers (Deininger et al., 2019; Lauff et al., 2020). Feedback helps evaluate the conducted work and plan future actions (Huet et al., 2007; Liu et al., 2018), thus providing a means for transitioning between different states of the product design. In order to get feedback, design practitioners and educators utilise various transition activities, such as design reviews (Huet et al., 2007) and educational design crits (Sopher et al., 2022). Yet, transition activities are rarely studied in both design (Cash et al., 2013; Wynn & Maier, 2022) and management (Bush et al., 2018) literature. However, there are many potential benefits in studying transition activities, given that they represent core design activities (Cash et al., 2013) where key decisions are made (Huet et al., 2007; Wynn & Maier, 2022).

As the participation of both designers and stakeholders is important for transitions, many researchers have suggested that influencing their way of interacting with the current design representation (e.g., concepts, 3D models) might affect the execution of transitions (Lukačević et al., 2020). Similarly, influencing how the transition team[1] (TT) members interact with each other might also affect transitions (Horvat, Brnčić, Perišić, Martinec, et al., 2022). In this context, the recent proliferation of virtual reality (VR) showed great potential to change the way transitions are executed (Berg & Vance, 2017). VR seeks to perfect a sensory illusion of being present in another environment by alternating interaction and navigation modes and by affecting sensory and social cues. Given these characteristics, it is not surprising that VR has been actively used in the industry to support transitions (Berg & Vance, 2017).

Although having large potential, the effect of VR technologies on TT performance is still inconclusive. While subjective evaluations of team members suggest that using VR positively affects teamwork (Wolfartsberger, 2019), objective measures of TT performance have provided contradictory evidence. For instance, the effect of VR on the number of identified issues was found to be positive (Tea et al., 2022) and negative (Horvat, Martinec, Perišić, et al., 2022; Liu et al., 2020). Hence, while VR technologies influence transitions, the exact effect remains unclear.

The oversimplification of measuring TT performance might be the cause for the contradictory results regarding the effect of VR on transitions. For example, researchers usually measured the number of reported issues (Tea et al., 2022; Wolfartsberger, 2019) or the time needed to complete the transition (de Casenave & Lugo, 2017; Satter & Butler, 2015). However, these indicators largely depend on the inputs, such as the initial quality of the design. Therefore, performance indicators should not consider only outcomes but also the transition itself (Kozlowski & Ilgen, 2006). Furthermore, as transitions happen throughout product development (Liu et al., 2018) and involve various stakeholders (Lauff et al., 2020), they might be distinguished by their goals (e.g., manufacturability, ergonomics, customer values). While the goal of transitions might affect TT performance (Deininger et al., 2019) and is often accounted for in performance indicators (O'Donnell & Duffy, 2002), the effect of the goal is often neglected when measuring TT performance. In order to fill these gaps, this paper studies the effect of a transition goal and VR on TT performance, guided by the following questions:

- How does a transition goal affect TT performance?
- How does a VR affect TT performance?

The rest of the paper provides background on transitions (Section 2), describes the conducted experimental study (Section 3), presents the results of the conducted study (Section 4), and discusses the results around the two research questions (Section 5).

2 BACKGROUND ON TRANSITIONS

Transitions serve teams to verify the design solution by considering the defined design problem (e.g., list of requirements) or to validate it by considering the undefined design problem (e.g., end-user preferences that come from their experience) aspects. These two goals might be suited for different TT compositions. For example, Yilmaz and Daly (2016) suggested that mechanical designers often focus on convergent feedback types, while industrial designers focus on both convergent and divergent types. Therefore, to get the feedback that is the most relevant to the transition goal, various stakeholders might be employed throughout the product development (Lauff et al., 2020).

[1] Transition team (TT) is used to depict the team that executes transition. TT sometimes differ from the product development team, as its members might be outside the organisation (e.g., users).

https://doi.org/10.1017/pds.2023.239 Published online by Cambridge University Press

Regardless of the goal, transitions consist of three intertwined actions: understanding, evaluation, and planning (Huet et al., 2007; Liu et al., 2018). The understanding action refers to sharing information about current design work and aims to comprehend any aspect of the design, either through the interaction within the TT (Liu et al., 2018) or interaction with the design artefact (Horvat, Martinec, Lukačević, et al., 2022). Although the understanding does not contribute directly to the outcomes of the transitions, it is a prerequisite for successful evaluation (D'Astous et al., 2004). The evaluation action relates to assessing the current solution in regard to the design goal and the utility assessment of these goals (Huet et al., 2007; Liu et al., 2018). Finally, planning relates to discussing a future version of the design, which involves proposing new changes, understanding these changes by other team members, and evaluating these changes (Huet et al., 2007; Liu et al., 2018). As a support, various design artefacts are commonly utilised (Lauff et al., 2020), and their characteristics (e.g., level of detail) might significantly affect the transition (Deininger et al., 2019). As another support, meeting templates are used to reduce the information loss of decisions made (Huet et al., 2007). Besides being useful for design teams, these templates are often used to measure outcome-oriented TT performance.

2.1 Transition team (TT) performance indicators

Studies focused on TT performance mainly focus on the outcomes of transition. More specifically, researchers observed the time spent identifying the issues (de Casenave & Lugo, 2017; Satter & Butler, 2015) or the number of reported issues (Tea et al., 2022; Wolfartsberger, 2019). Furthermore, Astaneh Asl and Dossick (2022) measured performance by assessing their final decision and by assessing the shared understanding of the decisions. Liu et al. (2020) developed metrics to assess the transition value by considering who benefits from the action and how significant the action is, i.e., whether actions contribute directly to the design solution (direct value) or they contribute to the larger design process (indirect value). While TT performance studies exist, they are mainly oriented towards the transition outcomes and rarely consider the process aspects of transitions.

In the context of the design activities, O'Donnell and Duffy (2002) suggested two parameters to assess performance: efficiency and effectiveness. Efficiency corresponds to the produced output from the activity (e.g., explored issues) per unit of resource (e.g., people, time), while effectiveness is the extent to which the results (e.g., explored issues) meet the activity goal (e.g., manufacturability, customer values). In the transition context, the number of reported issues and the time spent corresponds to the efficiency metric, and it has been partially addressed by the transition literature (Tea et al., 2022; Wolfartsberger, 2019). On the other hand, transition researchers rarely focused on effectiveness, such as the number of explored issues related to the transition goal. Therefore, investigating this aspect might be necessary in order to better understand team performance in transitions.

2.2 The effect of the VR on TT performance

The effect of immersion on TT performance is still not uniquely determined. For example, previous studies reported a decrease (Satter & Butler, 2015) and an increase (de Casenave & Lugo, 2017) in time spent on transition using VR compared to a desktop interface (DI). Similarly, the number of feedback items might also be increased (Tea et al., 2022) or decreased (Liu et al., 2020). Furthermore, researchers have also investigated the context of issues reported during transitions. In this context, Rigutti et al. (2018) found that immersion helps identify affordance errors (e.g., door handle on the same side of the hinges), but it does not support recognition of perceptual errors (e.g., misaligned handrail). Next, Wolfartsberger (2019) suggested that the VR supported the identification of design- and ergonomic-related issues, while it did not support the identification of circuit logic issues. Hence, while studies on the effect of the VR exist, it remains unclear how immersion level affects TT performance.

3 METHODS

In order to investigate the effect of transition goal and VR on TT performance, an experimental study has been conducted in which participants worked in one of the two conditions (DI or VR) and conducted two transition-related experimental tasks with different goals.

3.1 Experimental task and sample

There were two experimental tasks for each TT. The first task was to review the design regarding the fulfilment of the product (i.e., functional), process (i.e., manufacturing and assembly), and people (i.e., human factors) requirements (Dong et al., 2009). The goal of this task was to assess and improve the solution based on the given requirements and constraints, thus referred to as verification. The second task involved reviewing the design regarding the fulfilment of the essential customer jobs (what customers are trying to get done), gains (concrete benefits that customers seek), and pains (bad outcomes, risks, and obstacles that customers would like to avoid) - a common framework for the value proposition design (Osterwalder et al., 2014). The goal of this task was to assess and improve the solution based on the values customers have, which is thus referred to as validation. For each task, the TT was given a three-item checklist that covered the above-mentioned aspects.

The designs reviewed during transitions were baby strollers (Figure 1) that needed to have the following characteristics: foldable, wheels rotation lock, sun protection, storage for things, and a safety handle for the baby. In addition, the strollers were supposed to meet several requirements, such as maximum dimensions and the baby weight they should carry. These reviewed strollers were designed by three-member student teams during a two-month period. Besides the required characteristics, the design team was asked to consider the manufacturing, assembly, ergonomics, and safety aspects.

In total, 16 participants (8 designers and 8 reviewers) took part in the experiment. The designers were two members that the design team chose to represent the team during the transition. Their professional background was very similar, with all designers being undergraduate 3rd-year mechanical design students enrolled at the same university. The reviewers were industry professionals with at least two years of working experience. They all had a similar background, as they were the same university alumni and held a master's degree in Mechanical Design (Module: Engineering Design). These participants were distributed across 4 four-member TTs, two in VR and two in DI. Each team consisted of two designers and two reviewers (Figure 1). In order to tackle issues related to the internal validity of the experiment, both team composition (assigning reviewers to designs) and condition (assigning each team to the condition) were randomised.

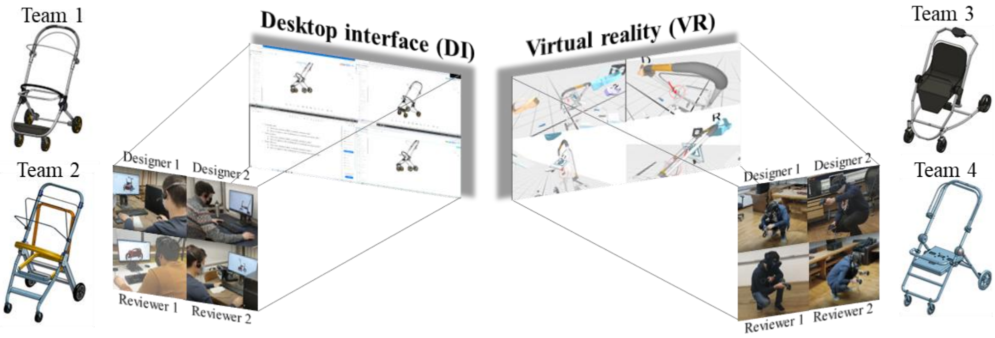

Figure 1. Transition snippet in DI and VR

3.2 Experimental setup and procedure

For the DI condition, four rooms were equipped with a working station, monitor (22", 1920x1080 pixels), headphones, keyboard, mouse, and office chair. Participants verbally communicated using Microsoft Teams, while a cloud-based CAD (i.e., Onshape) was used to visualise the design solution on a computer screen. Onshape enables synchronous work on the same CAD model (pan, rotate, zoom, screenshot, measure, marker, section, move parts, and hide parts) and provides a *follow* mode for sharing viewpoints. In addition, a checklist related to the transition goal was visualised using a PDF viewer.

For the VR condition, four rooms were equipped with a VR-ready working station, monitor (22", 1920x1080 pixels), VR headset (3 x HTC VIVE Pro, 1 x HTC VIVE Cosmos Elite), VR controllers (HTC VIVE), headphones, keyboard, mouse, and office chair. Participants verbally communicated using Microsoft Teams, while the design solution was visualised in the form of a 3D model using a VR-enabled CAD system (i.e., Siemens NX). Siemens NX VR enables synchronous work on the same model using similar functions as in DI (screenshot, measure, marker, section, move, and hide parts) (Horvat, Kunnen, Štorga, Nagarajah, et al., 2022), moving around the virtual room (3x3 meters), and seeing each other's avatars (i.e., VR helmets), controllers, and laser pointers. A checklist related to the transition goal was also visualised using a PDF viewer, which could be accessed within the VR.

The experimental procedure consisted of several steps. In the first step, the information package was sent two weeks in advance. The package included the design brief, checklist with transition goals, consent form, and equipment tutorials (presentation and video). The goal of the information package was to familiarise participants with the design problem, transition goals, transition procedure, and environment (VR or DI) used during the experiment. In the second step, all three design team members were invited to test the setup at least one day before the experiment. The third step included preparing the TT for the transition. In this step, each member was in one physical room and joined the Microsoft Teams call. They were then instructed to follow the environment tutorial until they were ready to start (usually 30-45 minutes). Since participants only had to grasp a few functionalities, this timing was considered sufficient to tackle the issues related to lower experience in an environment (Horvat, Martinec, Lukačević, et al., 2022). Moreover, designers had already learned functionalities in Step 2 and could help reviewers get acquainted with the equipment. After the participants got familiarised with the environment, researchers started the screen recording, and the team proceeded to the first transition-related experimental task. This task lasted for 30 minutes and focused on verifying whether the solution met the requirements. The participants were instructed to record screenshots that would later be available to the TT as a basis for writing the feedback. The first task was followed by a reporting period, during which all participants wrote textual feedback for each screenshot taken during the first transition-related task. After the verification transition had been finished, a 15-minute break was given to the participants. The second transition (validation) focused on assessing and suggesting improvements to the solution based on undefined customer values. This transition also lasted 30 minutes and was followed by another set of reporting. The procedure lasted around three hours per experiment.

3.3 Data collection and analysis

The data for the analysis were collected following the protocol analysis approach. Firstly, video and audio recordings were transcribed and segmented. The segmentation step was based on actions at the team level, considering the three types of actions (understanding, evaluation, planning) common for transitions. Secondly, in order to depict whether each action was related to the goal of the experimental task, a binary variable (Goal-related) was coded. The goal-relatedness was assessed by considering whether the issue discusses functionality, manufacturability, assembly or human factor aspects (verification) or whether it is focused on customer values in terms of essential jobs, gains, and pains (validation). Thirdly, an Issue variable has been coded to depict the discussed issues during the transitions. For this purpose, an issue has been defined as the set of reviewers' actions (understanding, evaluation or planning) focusing on only one instance of the design problem and only one instance of the design solution. The issue variable consists of four codes, depending on whether an action deals with the new issue (New), the same issue as the previous action (Previous), the issue different from the one in the previous action but already discussed in the session (Repeated), or does not deal with any issue (Without). To test the reliability of the goal-related and issue coding, a second coder analysed 25% of the data (about one hour in total). The agreement between the coders on this sample was substantial, as the interrater reliability calculated using Cohen's Kappa (Cohen, 1960) was 0.79 for coding goal-relatedness and 0,72 for coding the issues. An excerpt with the coded data is shown in Table 1.

Data were analysed by comparing discussed and goal-related issues in the two environments and across two goals (verification and validation). Furthermore, three indicators of TT performance are utilised: efficiency, effectiveness, and goal-related efficiency. Efficiency has been operationalised as the number of issues per unit of time, effectiveness as the proportion of goal-related issues, and goal-related efficiency as the number of goal-related issues per unit of time.

Table 1. Coded excerpt from the validation transition in a VR

Discourse	Goal-related	Issue
I took the [screenshot of the] shade, [and] the wheel / I did I did [take a screenshot]/ …and the handle, and I also took the wheel for the breaking, I would	0	Without
And for that same mechanism, regarding thickening the cylinders, that would make it easier, so to speak, for everything to stay in the breaking position / yeah / I mean it would be more functional / yes / if it was [thicker]	0	Repeated
Another thing, this part on top for folding it, it really seems awkward to use, it looks robust and / yeah / and I don't like that it has right angles / yeah, alright	1	New
So it should be more like / again, in that rod	1	Previous

https://doi.org/10.1017/pds.2023.239 Published online by Cambridge University Press

4 RESULTS

Teams discussed between 21 and 29 issues in the verification and between 24 and 34 issues in the validation task (Table 2). The results show that, on average, the validation tasks had a higher number of discussed issues. However, the differences between the two tasks were not significant ($t(3) = -1{,}47$, $p = 0{,}24$), although a medium to large effect size was found ($d = 0{,}74$). Moreover, the difference between the two transition goals might depend on the environment (VR or DI). More specifically, while teams in the VR had a much higher number of discussed issues in the validation (13 and 8 more) than in the verification task, teams in the DI had a similar number of discussed issues in their tasks (see Table 2).
Most of the issues in the verification transition were also related to the goal (Table 2), and the differences between all and goal-related issues were not significant ($t(3) = -1$, $p = 0{,}39$) with the medium effect size ($d = 0{,}5$). On the other hand, in the validation transition, both DI and VR teams had a lower number of goal-related issues (Table 2). Moreover, the differences between discussed and goal-related issues were significant ($t(3) = -2{,}85$, $p = 0{,}065$), and the effect size was large ($d = 1{,}43$). Therefore, the validation transition had fewer goal-related issues than the verification transition.

Table 2. Outcomes of the observed transitions

Team	Discussed issues		Discussed goal-related issues	
	Verification	Validation	Verification	Validation
Team 1 - DI	23	24	23	23
Team 2 - DI	29	27	29	19
Team 3 - VR	21	34	20	24
Team 4 - VR	25	33	25	29

4.1 Efficiency, effectiveness and goal-related efficiency of transitions

The efficiency was calculated by dividing the number of discussed issues and the duration. As expected, TT usually had lower efficiency in the verification than in the validation. However, the difference was not significant ($t(3) = -1{,}58$, $p = 0{,}21$), although a large effect size was found ($d = 0{,}8$). Moreover, while there was not a clear difference regarding the TT efficiency in the verification task, the TT efficiency in the validation was higher in VR (1,09 and 1,1) than in DI (0,8 and 0,88).
The TT effectiveness was around 1 in the verification task and slightly lower (from 0,7 to 0,96) in the validation task (Table 3). More specifically, the differences in TT effectiveness between the two tasks were significant ($t(3) = 3{,}04$, $p = 0{,}056$), and the effect size was large ($d = 1{,}5$). Furthermore, there was no clear difference related to the differences between the two environments.
Finally, the goal-related efficiency in the verification and validation tasks did not significantly differ ($t(3) = 0{,}03$, $p = 0{,}98$), and the effect size was small ($d = 0{,}01$). However, the difference in goal-related efficiency between the two tasks might depend on the environment (Table 3). More specifically, the goal-related efficiency in the validation task (0,76 and 0,62) conducted in a DI was lower than the goal-related efficiency in the verification (0,77 and 0,93). On the other hand, the goal-related efficiency in the verification task (0,63 and 0,81) conducted in a VR was lower than the validation (0,77 and 0,97).

Table 3. Performance measures of the observed transitions

Team	Efficiency (issues/min)		Effectiveness (-)		Goal-related efficiency (issues/min)	
	Verification	Validation	Verification	Validation	Verification	Validation
Team 1 - DI	0,77	0,8	1	0,96	0,77	0,76
Team 2 - DI	0,93	0,88	1	0,7	0,93	0,62
Team 3 - VR	0,66	1,09	0,95	0,71	0,63	0,77
Team 4 - VR	0,81	1,1	1	0,88	0,81	0,97

4.2 Dynamics of discussed issues

Observing the dynamics of the discussed issues can provide additional insights into the effect of transition goals and environments. Figure 2 shows that the goal-related issues appeared along the

https://doi.org/10.1017/pds.2023.239 Published online by Cambridge University Press

transitions. The only prolonged periods without discussing goal-related issues occurred in the validation transition of Team 2 - Low. Despite these differences, no clear difference in patterns of goal-related issue distribution exists between the two transitions. When comparing the distribution of goal-related actions in DI and VR, there was a higher frequency of alternation between the goal-related actions and actions unrelated to the goal in VR than in DI.

Furthermore, Figure 2 shows that the discussed issues were not always uniformly distributed across the transitions. The polar sampling of the two tasks (see Table 2) with the lowest goal-related efficiency (validation of Team 2 - Low and verification of Team 3 - High) and two tasks with the highest TT goal-related efficiency (verification of Team 2 - Low and validation of Team 4 - High) suggests some distinctive patterns. The low-performing teams fixated on several issues for much longer than the high-performing ones. This fixation is depicted by the horizontal lines in the graphs, often wider in low-performing tasks than in high-performing ones. Finally, higher-performance teams consistently worked on new issues without prolonged periods of working on one issue.

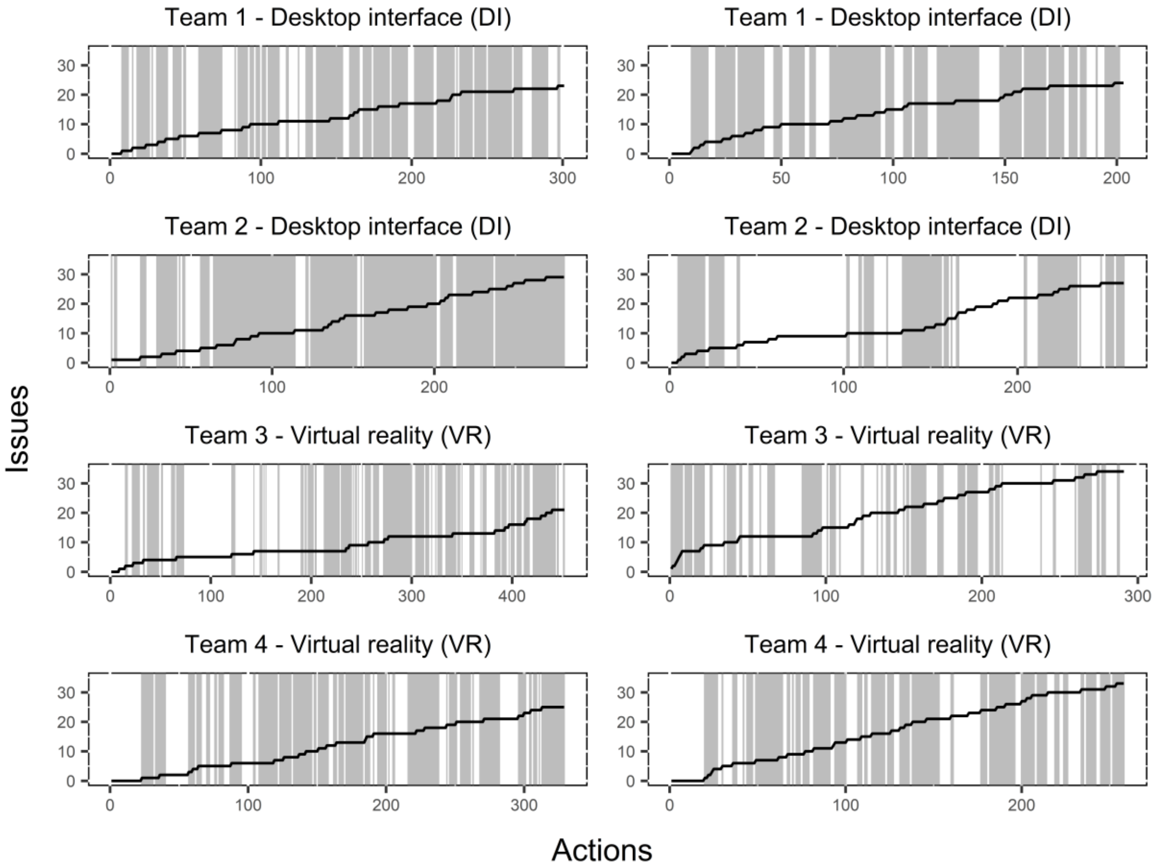

Figure 2. Cumulative number of discussed issues; a grey area depicts goal-related actions

5 DISCUSSION

The results show that the high-performing teams consistently discussed new issues and had regular periods of work on the previous and repeated issues in between. On the other hand, low-performing teams had prolonged periods without discussing any new issues. This difference in the low- and high-performing team is in line with the finding that regular pauses in doing specific actions were related to shared understanding (Cash et al., 2020). Furthermore, the low-performing teams might have suffered from fixation, which consequently reduced the efficiency of the transition.

5.1 The effect of transition goal

The higher efficiency of the validation suggests that the transition goal might trigger teams to think about more issues. This finding is in line with the broadness of the validation transitions, as they are more open-ended than verification ones. More specifically, validation transitions are often focused on issues that require relating to customers, which can be at least partially understood by most people. On

https://doi.org/10.1017/pds.2023.239 Published online by Cambridge University Press

the other hand, verification transitions require relating to specific requirements (e.g., manufacturability) that require specific expertise. Given that the validation transition requires general expertise, it might be also easier to find new issues. Hence, it is not surprising that participants with less or no design experience (e.g., end users) are often part of the transitions (Lauff et al., 2020; Liu et al., 2018).

The lower effectiveness of the validation suggests that this goal might not fit mechanical designers as the verification one. Specifically, transition is affected by team expertise (Deininger et al., 2019), and mechanical designers might be more suitable for verification problems (Yilmaz & Daly, 2016). Therefore, it is not just the goal that affects transition but the fit between the goal and background of the TT. For example, mechanical designers often work with more defined problems than industrial designers, suggesting that they might be more suited for verification transitions. This difference confirms findings that transitions are conducted with stakeholders that have various backgrounds (Lauff et al., 2020).

5.2 The effect of VR

The results show that the VR is more suitable for validation transitions, as teams had higher performance than in DI validations and increased performance than verification in the same environment. On the other hand, DI might be more suitable for the verification transitions due to higher performance as compared to validation in the same environment. These results are in line with the finding that VR might support divergent thinking (Sopher et al., 2022). Divergent thinking is an important aspect of validations as these transitions require interpretation of customer jobs, gains, and pains before evaluating and planning the design. Furthermore, the results also support the finding that this environment might help people with less expertise (Horvat, Martinec, Lukačević, et al., 2022), as the mechanical design background of the team might be more suitable for the verification transition (Yilmaz & Daly, 2016). Finally, these results suggest that the analysis of design artefacts does not only depends on the goal of transition (Deininger et al., 2019; Lauff et al., 2020) but also on the environment in which this artefact is represented.

These findings might be explained by the more natural interaction and navigation in VR than in DI, resulting in users feeling a stronger sense of presence in VR (Eftekharifar et al., 2020). These characteristics of VR might improve spatial (Lukačević et al., 2020) and contextual (Horvat, Martinec, Lukačević, et al., 2022) understanding of designs under transition - a prerequisite for evaluation (D'Astous et al., 2004). Consequently, users in VR might become more aware of the context in which the design is used. This easier interpretation might leave more mental capacity for evaluation and planning actions. Furthermore, natural interaction and navigation in VR might, through priming, trigger previous experiences in the real world (Liu et al., 2020). In this context, TTs in VR might focus more on real-world scenarios, such as use cases and assessment of the design problem. Through the same priming effect, DI might trigger previous experience regarding work in CAD, which is common for mechanical designers. More specifically, mechanical designers usually utilise CAD tools in later design phases, suggesting that working in this environment might prime TTs to think more about the later phase aspects, thus supporting convergent thinking (Yilmaz & Daly, 2016). Altogether, the results shed new light on the conflicting findings related to the effect of the environment on the transitions (de Casenave & Lugo, 2017; Liu et al., 2020; Satter & Butler, 2015; Tea et al., 2022; Wolfartsberger, 2019).

5.3 Limitations

Although the presented results provide new insights, some limitations prevent the generalisation of the findings. Most notably, a small sample size prevents the generalisation to other contexts (e.g., different team sizes). Nevertheless, the goal of the paper was not to provide the general relationship amongst the variables but rather to establish new relationships - a case in which small samples provide the possibility for an in-depth analysis. Related to that, although the analysis provides in-depth quantitative analysis and expands commonly used indicators in transitions, they might be explained by considering the discussion elaboration level of the issues (i.e., how detailed the team was in discussing the issue) and the context of the issues (e.g., to which problem and solution aspects issue relate to). This extension might provide a new set of indicators for the transitions that can provide a more detailed description of their performance.

https://doi.org/10.1017/pds.2023.239 Published online by Cambridge University Press

6 CONCLUSIONS

This paper investigates the effect of goals and VR on transitions (e.g., design reviews). The results show that the validation-oriented transition was more efficient but less effective than the verification-oriented transition. The performance of validation-oriented transition compared to verification-oriented transition was increased in a VR and decreased in a DI. Furthermore, the validation-oriented TT performance was higher in VR than in the DI. Finally, the high-performing teams consistently discussed new issues, while low-performing teams had prolonged moments of not discussing anything new. These findings suggest that DI and VR are not substitutable but rather complementary technologies. Finally, both v and goal affect TT performance, and it is necessary to consider them when deciding on the team composition and the environment used to gather feedback.

The results have several implications for researchers and practitioners. Firstly, researchers should consider process-related indicators of performance and include the goal of the transitions in these metrics. Secondly, researchers can utilise the findings as a starting point to understand the relationship between environment, goal, and transitions. Finally, design teams and educators should consider both team composition and environment while planning the next transition.

Future studies should replicate presented findings with a larger sample and expand the performance measurements. For example, studies might analyse the depth of the discussed issues or analyse the context of the issues, i.e., to which problem and solution aspects they related. In addition, future work should investigate generalisation to different types of transitions.

ACKNOWLEDGEMENTS

This paper reports on work funded by the Croatian Science Foundation project IP-2018-01-7269: Team Adaptability for Innovation-Oriented Product Development (TAIDE) and Erasmus+ project 2021-1-SI01-KA220-HED-000027506 Product Hackathons for Innovative Development (Pro Hackin'). The authors would like to thank Dr Phillip Cash and the CADLab research group for their help with preparing and executing the experiment. Furthermore, the authors would like to thank the Regional Centre of Excellence for Robotic Technology (CRTA), Dr Tomislav Stipančić, and ITCR d.o.o. for providing additional virtual reality hardware and software. Finally, the authors thank the industry experts and students for their participation in the experiment.

REFERENCES

Astaneh Asl, B., & Dossick, C. S. (2022). Immersive VR versus BIM for AEC Team Collaboration in Remote 3D Coordination Processes. Buildings 2022, Vol. 12, Page 1548, 12(10), 1548. https://doi.org/10.3390/BUILDINGS12101548

Berg, L. P., & Vance, J. M. (2017). Industry use of virtual reality in product design and manufacturing: a survey. Virtual Reality, 21(1), 1–17. https://doi.org/10.1007/s10055-016-0293-9

Bush, J. T., LePine, J. A., & Newton, D. W. (2018). Teams in transition: An integrative review and synthesis of research on team task transitions and propositions for future research. Human Resource Management Review, 28(4), 423–433. https://doi.org/10.1016/j.hrmr.2017.06.005

Cash, P., Dekoninck, E., & Ahmed-Kristensen, S. (2020). Work with the beat: How dynamic patterns in team processes affect shared understanding. Design Studies, 69, 100943. https://doi.org/10.1016/j.destud.2020.04.003

Cash, P., Hicks, B., & Culley, S. (2013). A comparison of designer activity using core design situations in the laboratory and practice. Design Studies, 34(5), 575–611. https://doi.org/10.1016/j.destud.2013.03.002

Cohen, J. (1960). A Coefficient of Agreement for Nominal Scales. Educational and Psychological Measurement, 20(1), 37–46. https://doi.org/10.1177/001316446002000104

D'Astous, P., Détienne, F., Visser, W., & Robillard, P. N. (2004). Changing our view on design evaluation meetings methodology: a study of software technical review meetings. Design Studies, 25(6), 625–655. https://doi.org/10.1016/j.destud.2003.12.002

de Casenave, L., & Lugo, J. E. (2017). Design Review Using Virtual Reality Enabled CAD. Volume 1: 37th Computers and Information in Engineering Conference, V001T02A067. https://doi.org/10.1115/DETC2017-67878

Deininger, M., Daly, S. R., Lee, J. C., Seifert, C. M., & Sienko, K. H. (2019). Prototyping for context: exploring stakeholder feedback based on prototype type, stakeholder group and question type. Research in Engineering Design, 30(4), 453–471. https://doi.org/10.1007/S00163-019-00317-5

Dong, A., Kleinsmann, M., & Valkenburg, R. (2009). Affect-in-cognition through the language of appraisals. Design Studies, 30(2), 138–153. https://doi.org/10.1016/J.DESTUD.2008.12.003

Eftekharifar, S., Thaler, A., & Troje, N. F. (2020). Contribution of Motion Parallax and Stereopsis to the Sense of Presence in Virtual Reality. Journal of Perceptual Imaging, 3(2), 20502-1-20502–20510. https://doi.org/10.2352/J.Percept.Imaging.2020.3.2.020502

Horvat, N., Brnčić, M., Perišić, M. M., Martinec, T., Bojčetić, N., & Škec, S. (2022). Design Reviews in Immersive and Non-Immersive Collaborative Virtual Environments: Comparing Verbal Communication Structures. Proceedings of the Design Society, 2, 211–220. https://doi.org/10.1017/pds.2022.23

Horvat, N., Kunnen, S., Štorga, M., Nagarajah, A., & Škec, S. (2022). Immersive virtual reality applications for design reviews: Systematic literature review and classification scheme for functionalities. Advanced Engineering Informatics, 54, 101760. https://doi.org/10.1016/j.aei.2022.101760

Horvat, N., Martinec, T., Lukačević, F., Perišić, M. M., & Škec, S. (2022). The potential of immersive virtual reality for representations in design education. Virtual Reality. https://doi.org/10.1007/s10055-022-00630-w

Horvat, N., Martinec, T., Perišić, M. M., & Škec, S. (2022). Comparing design review outcomes in immersive and non-immersive collaborative virtual environments. Procedia CIRP, 109, 173–178. https://doi.org/10.1016/j.procir.2022.05.232

Huet, G., Culley, S. J., McMahon, C. A., & Fortin, C. (2007). Making sense of engineering design review activities. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 21(3), 243–266. https://doi.org/10.1017/S0890060407000261

Kozlowski, S. W. J., & Ilgen, D. R. (2006). Enhancing the Effectiveness of Work Groups and Teams. Psychological Science in the Public Interest, 7(3), 77–124. https://doi.org/10.1111/j.1529-1006.2006.00030.x

Lauff, C. A., Knight, D., Kotys-Schwartz, D., & Rentschler, M. E. (2020). The role of prototypes in communication between stakeholders. Design Studies, 66, 1–34. https://doi.org/10.1016/j.destud.2019.11.007

Liu, Y., Castronovo, F., Messner, J., & Leicht, R. (2020). Evaluating the Impact of Virtual Reality on Design Review Meetings. Journal of Computing in Civil Engineering, 34(1), 04019045. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000856

Liu, Y., Messner, J. I., & Leicht, R. M. (2018). A process model for usability and maintainability design reviews. Architectural Engineering and Design Management, 14(6), 457–469. https://doi.org/10.1080/17452007.2018.1512042

Lukačević, F., Škec, S., Perišić, M. M., Horvat, N., & Štorga, M. (2020). Spatial Perception of 3D CAD Model Dimensions and Affordances in Virtual Environments. IEEE Access, 8, 174587–174604. https://doi.org/10.1109/ACCESS.2020.3025634

O'Donnell, F. J., & Duffy, A. H. B. (2002). Modelling design development performance. International Journal of Operations & Production Management, 22(11), 1198–1221. https://doi.org/10.1108/01443570210450301

Osterwalder, A., Pigneur, Y., Bernarda, G., & Smith, A. (2014). Value proposition design : how to create products and services customers want. Wiley.

Rigutti, S., Stragà, M., Jez, M., Baldassi, G., Carnaghi, A., Miceu, P., & Fantoni, C. (2018). Don't worry, be active: how to facilitate the detection of errors in immersive virtual environments. PeerJ, 6, e5844. https://doi.org/10.7717/peerj.5844

Satter, K., & Butler, A. (2015). Competitive Usability Analysis of Immersive Virtual Environments in Engineering Design Review. Journal of Computing and Information Science in Engineering, 15(3), 031001. https://doi.org/10.1115/1.4029750

Sopher, H., Milovanovic, J., & Gero, J. (2022). Exploring the effect of immersive VR on student-tutor communication in architecture design crits. Proceedings of the 27th International Conference of the Association for Computer- Aided Architectural Design Research in Asia (CAADRIA) 2022, 315–324.

Tea, S., Panuwatwanich, K., Ruthankoon, R., & Kaewmoracharoen, M. (2022). Multiuser immersive virtual reality application for real-time remote collaboration to enhance design review process in the social distancing era. Journal of Engineering, Design and Technology, 20(1), 281–298. https://doi.org/10.1108/JEDT-12-2020-0500

Wolfartsberger, J. (2019). Analyzing the potential of Virtual Reality for engineering design review. Automation in Construction, 104(March), 27–37. https://doi.org/10.1016/j.autcon.2019.03.018

Wynn, D. C., & Maier, A. M. (2022). Feedback systems in the design and development process. Research in Engineering Design, 33(3), 273–306. https://doi.org/10.1007/S00163-022-00386-Z

Yilmaz, S., & Daly, S. R. (2016). Feedback in concept development: Comparing design disciplines. Design Studies, 45, 137–158. https://doi.org/10.1016/j.destud.2015.12.008