



Friction situations in real-world remote design reviews when using CAD and videoconferencing tools

Francisco Garcia Rivera^{1,*}, Maurice Lamb^{1,2}, Dan Högberg¹, Beatrice Alenljung²

¹School of Engineering Science, University of Skövde, Högskelevägen, 54128 Skövde, Sweden.

²School of Informatics, University of Skövde, Högskelevägen, 54128 Skövde, Sweden.

***Correspondence to:** Francisco Garcia Rivera, School of Engineering Science, University of Skövde, Högskelevägen, 54128 Skövde, Sweden.
E-mail: francisco.garcia.rivera@his.se

Received: July 23, 2024 **Accepted:** December 07, 2024 **Published:** December 25, 2024

Cite this article: Rivera FG, Lamb M, Högberg D, Alenljung B. Friction situations in real-world remote design reviews when using CAD and videoconferencing tools. *Empath Comput.* 2025;1:128. <https://doi.org/10.70401/ec.2025.0001>

Abstract

Aims: Recent world events have resulted in companies using remote meeting tools more often in design processes. The shift to remote meeting tools has had a notable impact on collaborative design activities, such as design reviews (DRs). When DRs depend on computer-aided design (CAD) software, the lack of direct support for CAD functionalities in videoconferencing applications introduces novel communication challenges, i.e. friction. This study investigates friction encountered in real world remote DRs when using a combination of standard CAD and videoconferencing applications. The objective was to understand the main sources of friction when carrying out DRs using a combination of CAD and videoconferencing applications.

Methods: At a single Swedish automobile manufacturer, 15 DRs of a fixture component were passively observed. These observations were subjected to a qualitative thematic analysis to identify categories and sources of friction during these DRs. The DRs were carried out using a combination of CATIA CAD software and Microsoft Teams for videoconferencing.

Results: The analysis of the 15 remote DRs identified four recurring friction categories: requesting specific viewpoints, indicating specific elements, expressing design change ideas, and evaluating ergonomics. Each category highlights specific challenges that were observed during the DRs and emerged due to constraints imposed by existing methods and technologies for remote meetings.

Conclusion: This study provides a framework for understanding the current sources of friction in remote DRs using videoconferencing tools. These insights can support the future development of DR software tools, guiding the integration of features that address these friction points. Additionally, the results serve as a guideline for organizations to implement methods that reduce friction in remote DRs and improve DR quality and efficacy.

Keywords: Design review, product development, remote collaboration

1. Introduction

Design reviews (DRs) are central to many organizations' product design processes^[1]. DRs can be carried out at different stages of the PDP, and they serve as an evaluation activity where different aspects of design proposals are evaluated against defined requirements^[2]. Hence, a core activity of DRs is to evaluate the design proposals to ensure they meet a pre-defined set of requirements. These requirements are typically formulated as specifications that must be fulfilled, i.e. constraints, and as criteria used to assess the superiority of design proposals. When this evaluation is successfully passed, a DR can act as a gate activity that allows product designs to advance to subsequent stages in the PDP^[3]. DRs also serve as a platform for bringing together multiple stakeholders, who might have different roles, opinions, and interests, to make collective decisions on design proposals, thus facilitating early identification and resolution of design issues and saving time and costs in the long run^[4].

Traditionally, DRs have been conducted in physical settings, where teams collectively gather to discuss and evaluate design proposals. Initially supported by physical drawings^[4], the introduction of digital tools, particularly computer-aided design (CAD) software, expanded the scope of design factors considered during DRs, allowing more aspects of products to be considered and reviewed earlier in the PDP^[5,6]. Recently, companies have begun transforming their work practices due to various factors, including economics, climate change, travel restrictions, and the growing tendency of remote work^[7]. This shift has led to greater adoption of



videoconferencing applications in the PDP, including Teams and Zoom^[8-10]. These videoconferencing applications facilitate remote DRs by allowing designers to hold online DRs by screen-sharing 3D models of their design proposals, typically using their CAD software in combination with a videoconferencing app.

While a combination of videoconferencing applications with CAD applications enables remote collaboration in product design teams, there are also instances where technology gets in the way, hindering communication and causing interruptions^[11]. Hindered communication and interruptions in DRs can be related to both the structure of remote DRs and software limitations introduced by the tools used to support remote DRs. While discussions of enhancing remote DRs often center around software and technical advancements, such as the creation of virtual reality (VR) tools for DRs^[6,8], there is a lack of systematic studies exploring the challenges faced in remote DRs when utilizing current videoconferencing applications in conjunction with CAD software. While VR tools offer advantages, including increased immersion and even enhanced collaboration, they are not yet fully integrated into industry-standard software and most studies of VR tools in DRs focus on prototypes in experimental settings^[12]. The lack of standard VR integrations with CAD common tools makes it challenging to investigate VR tools within established workflows at many companies, which heavily rely on traditional software solutions. Thus, we will identify challenges in existing workflows where videoconferencing tools are familiar to all involved. We expect that the results from this study will be useful in guiding future integrations of VR in real-world remote DRs to address existing challenges.

Along with proposals for technological solutions to solve challenges in remote collaborative design work, several frameworks have been proposed to describe and categorize what is needed for effective remote collaboration in design teams^[13,14]. These frameworks are important tools that can guide the reorganization of existing remote design teams or the formation of new workflows. However, before identifying and developing a technological or organizational solution to real-world challenges in design workflows, it is necessary to understand the challenges as they emerge in typical workflows involving experienced design professionals. Thus, we engaged with the production design team of a Swedish automotive manufacturer to observe their remote DRs and evaluate where and how the flow of these DRs was hindered. These instances in which the flow of progress is interrupted may arise due to communication issues, difficulty conveying information, or misunderstandings and may depend on structural or technical issues in a DR. When these instances happen, there is “friction” in the communication between participants in the remote DR. Similar instances have been referred to as workflow disruption, flow disruption, and communication friction^[15,16]. In this paper, we introduce the term ‘friction situation’ to refer generally to situations that hinder remote DRs with a focus on moments where the flow of progress is impeded, resulting in delays or disruptions in the workflow. With the growing trend of remote work and the increasing number of product designers that use a combination of CAD with videoconferencing applications, there is a growing need to improve understanding of friction situations in remote DRs using these tools and provide guidance for structuring remote DRs and developing new tools to support remote DRs.

Friction situations are not exclusive to a specific combination of CAD and videoconferencing applications. They can transpire in any form of communication, including face-to-face interactions. In general, within design communication a common point of possible friction is in the presentation format of visual aids such as drawings, 3D models, or physical prototypes to communicate ideas^[17,18]. The effectiveness of design communication is tied to both the type of visual aid and the technology used to present it^[19]. It is essential to recognize that challenges may arise when the visual representation of a design fails to convey information comprehensively to all participants involved in the DR, as well as recognize when the technology used to mediate collaboration fails to do that efficiently^[20,21].

Regardless of the communication medium and the specific visual aids employed, the primary purpose of DRs remains to identify potential issues in design proposals before proceeding to subsequent stages of the PDP^[22]. To achieve this, there are common types of actions typically taken during DRs. These actions include observing the design proposals from different spatial perspectives, discussing different functionalities, taking notes, and engaging in discussions with others. In face-to-face interactions, these actions can be easily executed with tangible representations of the product^[23]. However, when DRs are conducted online, all interactions and visualizations are mediated through software tools and not all users may be using the same set of software tools, even when viewing the same information. Moreover, many of these tools are not specifically developed with remote DRs in mind, increasing the risk of friction situations during DRs. In this paper we identify the recurring friction situations that arise when conducting remote DRs using a combination of CAD and videoconferencing applications.

2. Methods

Fifteen remote DRs within production design at a Swedish automotive company were attended by the first author. The first author, a researcher with a background in mechanical engineering, production, and human centred PDP, was invited to sit in and observe the DRs as a part of an ongoing research project aimed at developing new multi-user design tools for collaborative design processes. A qualitative research approach was applied, in which 15 DRs were studied by collecting data through observations, where findings were concluded in a validating workshop.

2.1 The design review case

The product that was the subject of the DRs was a fixture component that would be part of the assembly workstations in one of the company's future factories. The engineering objective of the DRs was to assess and refine a design proposal for the design of this fixture component. It is important to note that in this case there were not several design proposals being compared with each other, but rather one design proposal that was iteratively refined in detail over the course of the 15 DRs. The DRs were highly structured with three clearly defined roles: the meeting manager (1 person), the product expert (1 person), and an audience of 13 to 16 participants. The meeting manager, the product expert remained consistent throughout the whole duration of study. The meeting manager was responsible for initiating and leading the meeting, serving as a mediator between individuals as needed, and ensuring that the meeting's activities progressed smoothly. The product expert oversaw the design proposal and presented relevant functional components, referred to as units, to the audience. The audience involved 13 to 16 participants, and it was made up of experts from diverse areas, such as maintenance and factory layout, who assessed the design proposal based on their competence and responsibility. The audience remained consistent throughout the study, with minimal variations due to occasional absences. The participants were predominantly experienced engineers responsible for various aspects of the fixture, including maintenance and ergonomics.

Invitations to participate in a DR were sent out by the meeting manager to relevant participants a few days before the DR was to take place. The meeting invitation included the relevant documentation and a link to the virtual meeting. Microsoft Teams (Microsoft Corporation, Redmond, United States) was used for videoconferencing and screen sharing. The CAD tool used was CATIA (Dassault Systèmes SE, Vélizy-Villacoublay, France), which was displayed to meeting participants via screensharing functionalities in Microsoft Teams. Notes were taken in Microsoft Excel (Microsoft Corporation, Redmond, United States). Occasionally, two to three participants gathered physically at the company's offices, although most of them always attended online. The meeting started with an introduction from the meeting manager outlining relevant details about the fixture component, objectives, and remarks specific to each DR. The product expert then proceeded to present the design proposal unit by unit. The product expert was the only person controlling the CAD view. No edits in the CAD model were made during the DR. Throughout each unit's presentation, the audience had the opportunity to provide comments or raise concerns. Both comments and concerns were typically addressed toward the presentation's conclusion. In some instances, urgent or specific issues were addressed during the presentation.

Every comment was evaluated for its impact on the fixture component and, if necessary, formulated as an actionable item. Specifying these actionable items involved identifying required changes, assigning responsibility for each task related to the change, and documenting the details in notes taken by the meeting manager. Figure 1 provides a basic representation of the flow within the DR process.

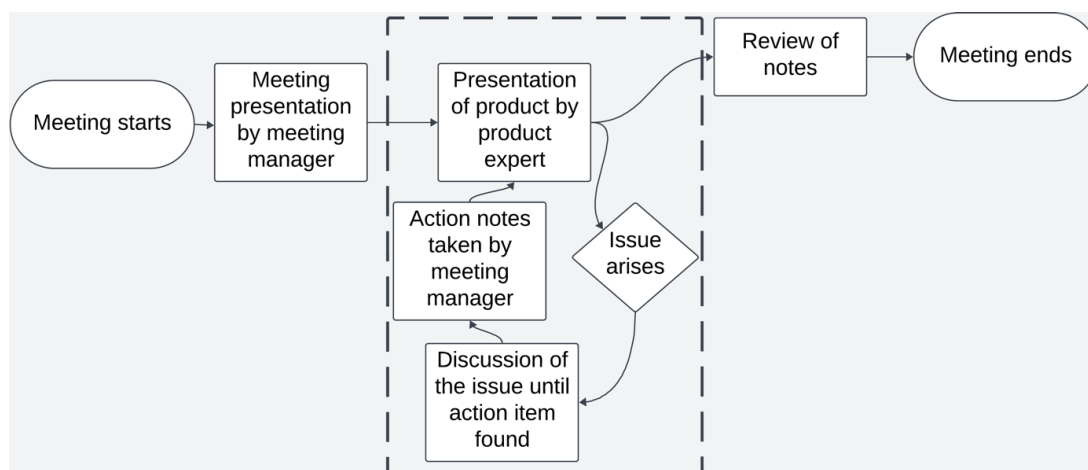


Figure 1. Observed DR flow. DR: design reviews.

2.2 Data collection

The first author passively attended the 15 DRs over a period of three months. The researcher did not engage in any conversation or discussion during the DRs. The participants were informed of the researcher's presence in the meetings through their manager. Moreover, a prior agreement with the automotive company specifying data confidentiality and privacy obligations for all parties was followed throughout the project. The data collection process primarily focused on identifying friction situations during the remote DR process. All the communication with the participant groups was mediated through a contact person at the company. Data was collected in the form of the researcher's notes taken during the DR using the note-taking template illustrated in Table 1. During the DR, any friction situations were recorded as separate items in the template.

Table 1. Template used for notetaking.

Date	Time	Number of Attendees		
Friction situation description	Impact of design review	Cause of friction situation	Attendees' roles involved in the friction	

All recorded data was securely stored on a designated and protected computer system, with access restricted to authorized personnel. Confidential data pertaining specifically to the company was not disclosed to external parties. No audio or video data was collected in the meetings and meeting participant identities were not recorded. The decision not to capture audio or video data during the DR sessions was primarily influenced by confidentiality policies set by the research project that this study is part of, as well as compliance with the company's policies. Without video or audio recordings, data collection relied on notetaking. To increase consistency and decrease any potential loss of data, a systematic note-taking approach was implemented using the predefined template shown in Table 1. A validating workshop was also conducted with participants, providing an opportunity to corroborate the findings and ensure that the observed friction situations accurately reflected the challenges experienced during the DRs.

2.3 Final workshop

After observing 15 DRs, a summary of initial results was produced and presented by the first author at a physical three-hour workshop held with the participants involved in the DRs, at the company's building. All participants in the workshop were located physically in the same room. The workshop aimed to provide an opportunity for knowledge sharing, discussion, and corroboration of the findings. The workshop's main aim was to collect feedback on the observed friction situations from the perspective of the DR participants. The preliminary findings were presented to the participants with the aim of finding out if the findings were aligned with their experiences. After the presentation of the different friction situation categories, the participants were asked to express their ideas, whether they agreed with the findings, and if according to their judgement something was missing. This conversation was carried out in an unstructured setting to allow for more freedom to the participants to express their ideas. Notes were taken about possible areas of improvement and current challenges expressed by the participants. The notes were taken by the contact person at the company. The participants engaged actively in the workshop, offering their perspectives, experiences, and insights related to the identified friction situations presented to them. Furthermore, participants expressed their agreement with the identified friction situations after the presentation. Participants shared their experiences with their current setting on the remote DRs, and a long discussion on how the software used failed to deliver some key functionality was held.

2.4 Data analysis

The notes from the DRs were analysed using qualitative thematic analysis^[24] to identify and derive recurring instances of friction from the collected data. After each DR, the notes were evaluated by the first author, and recurring friction situations were identified and grouped by comparing noted friction situations with the aim of identifying distinct categories of friction situations. After each meeting, the categorized notes were assimilated with the previous notes. An example of this method is illustrated in Table 2 and Table 3. Table 2 illustrates a friction situation as annotated during the DR meeting, and Table 3 illustrates the progressive refinement of notes to convey to categories.

Table 2. Friction situation note taken during the DR meeting.

Friction situation description	Impact of design review	Cause of friction situation	Attendees' roles involved in the friction
Two people from the audience start discussing the design change idea. This discussion does not involve the product expert, and it requires continuous instructions to the product expert to move the camera around so they point at the desired units.	It is slowing down their discussion.	Not have the possibility to control the camera perspective independently.	Two members from audience and product expert.

DR: design reviews.

Table 3. Refinement of the note after the DR meeting.

Friction situation description	Impact of design review	Cause of friction situation	Attendees' roles involved in the friction
Two people from the audience start discussing about design change idea.	It is slowing down their discussion.	The people discussing the design change idea do not have the possibility to independently control the camera perspective.	Two members from audience and product expert.

Friction situation description (Refined)	Cause of friction situation (Refined)
Discussions between members of the audience not involving the product expert which require constantly moving the camera view.	Inability for members of the audience to control the perspective that everybody sees.

DR: design reviews.

After 10 DRs, no novel categories emerged from the data, as all friction situations could be appropriately classified within the pre-established categories presented in Table 4. To validate the suitability of these categories in classifying recurrent friction scenarios, the researcher participated in five additional DRs. After these DRs, no new categories emerged.

Table 4. Four categories of recurring friction situations.

Friction situation	Cause
Requesting specific viewpoints	Inability to freely navigate the 3D space, leading to delays in fulfilling requests. Lack of clear naming and visibility of components. Limited visibility and accessibility of component names, causing confusion.
Indicating specific elements	Verbal communication required to indicate the desired component, instead of enabling direct remote interaction.
Expressing design change ideas	Lack of a more efficient means to express design ideas graphically.
Evaluating ergonomics	Difficulty in understanding how humans will interact with the product.

3. Results

After observing the DRs and processing the notes taken during these sessions, four categories of friction situations were identified (Table 4). For each of these categories, a definition and a detailed description were established. Additionally, within a category, features of specific friction situations may moderate the impact of the friction situation on the meeting. These moderating factors are identified for each category and may be continuous or discrete, but typically account for variation in the impact of friction situations within the same category. Finally, for each category an example annotation of a specific friction situation is presented.

3.1 Requesting specific viewpoints

3.1.1 Definition

This category includes friction situations in which participants need to request specific viewpoints in the 3D model. In these situations, the product expert needs to interpret the requests and change the viewpoint accordingly, which may be relatively easy or may require several complicated procedures.

3.1.2 Detailed description

Participants in remote DRs often want to examine and discuss specific elements of the 3D models. A shared perspective on the relevant element(s) and an understanding of the spatial layout of the model can facilitate clear communication. As a result, participants frequently request specific viewpoints within the 3D virtual space that they believe would best facilitate communication of their ideas and insights. This process is often time-consuming and can lead to minor frustrations as participants have to guide the expert to the desired viewpoint. The necessity for specific viewpoints often arises from the need to visualize and understand complex design concepts. In the observed DRs, viewpoint was controlled at any given moment by a single product expert, thus requiring participants to communicate their preferred viewpoint to that individual and wait for the adjustment to be made. A raw data example of this friction situation is shown in Table 5.

Table 5. Examples of raw data.

2023-04-24	8AM	11	
Friction situation description	Impact of design review	Cause of friction situation	Attendees' roles involved in the friction

Someone from the audience asks the product expert to move to specific perspectives of the 3D model because the person doesn't see what they want.	Unnecessary delays 30 s per request plus the loss of focus by the audience.	Lack of possibility to freely navigate the 3D space.	Product expert and member of the audience.
---	---	--	--

In some cases, two or more participants discussing an element of the 3D model would desire different viewpoints. In these situations, each participant may redirect the product expert to their desired viewpoint, increasing the amount of time required to discuss the element and potentially introducing additional areas of miscommunication.

3.1.3 Moderating factors

This friction situation could be affected by three main factors. The complexity of the requested viewpoint, the frequency of the requests, and the number of participants requesting viewpoints. Some viewpoints were not easy to get right since they could require close-ups in sections where there were many components, making the instruction, normally from a member to the audience to the product expert, quite difficult. The extent to which participants request specific viewpoints may vary, with some DRs experiencing frequent requests while others have fewer. Lastly the number of participants simultaneously requesting viewpoints greatly affected the level of this friction situation. When there were two or more participants requesting viewpoints simultaneously, the discussions could get quite inefficient due to the necessity of constantly directing the product expert to a specific viewpoint.

3.2 Indicating specific elements

3.2.1 Definition

This category includes situations in which a participant attempts to indicate or reference a specific element of a 3D model. With complicated 3D models, when the indicated element is obscured in the current view, and/or when multiple elements are indicated, it can be difficult to direct the attention of all participants to the element(s), slowing or halting the flow of the DR.

3.2.2 Detailed description

Within the context of remote DRs, participants often need to discuss and potentially redesign specific components within complex 3D models. When design changes involve multiple components, participants often suggest new ideas to improve compatibility between them. However, this can lead to friction situations as one participant’s proposed change may require alterations in a different component, causing confusion. In complex products or areas with numerous components, participants may struggle to indicate and discuss specific elements. Additionally, there were instances where participants thought they were talking about the same component, only to realize later that they were referring to different ones. Indicating an element may be done to seek more information or clarification, adding to the complexity of discussions. The complexity and spatial arrangement of components within the 3D model and their visual similarities often contribute to this friction situation. Participants may struggle to distinguish between components with similar appearances or designations in a confined space, leading to difficulty indicating the intended objects. This friction situation is often related to the friction situation “Requesting specific viewpoints”, since there were instances where participants requested specific viewpoints in order to indicate specific elements. A raw data example of this friction situation is shown in Table 6.

Table 6. Examples of raw data.

2023-03-03	8AM	14		
Friction situation description		Impact of design review	Cause of friction situation	Attendees’ roles involved in the friction
2 members want to ask about a specific component. There is a difficulty on pointing that specific object.		Unnecessarily long conversation to just refer to a specific component.	Having to verbally communicate what component they want to highlight.	Product expert and 2 members of the audience.
Issue of knowing what object audience wants the product expert to point.				

3.2.3 Moderating factors

Indicating specific elements was highly affected by the number of additional components surrounding the indicated component. Moreover, if the nearby components were similar to the indicated component, indicating the right component could be difficult and impact the meeting flow. Familiarity with the product also contributed to the impact of this friction situation. When some participants are very familiar with the product, they refer to the desired component by its designation. However, participants who are less familiar with the component might struggle to know what that designation refers to in the product, making following

discussions difficult for some people.

3.3 Expressing design change ideas

3.3.1 Definition

This category includes situations where a design change is proposed by a participant, but where at least one other participant does not understand the proposal or require additional clarifications. In these friction situations, the flow of the DR is disrupted as the participants attempt to clarify and understand the proposed design change in relation to the current design.

3.3.2 Detailed description

Participants in DRs may, at times, disagree with the current design choices and propose design changes. These changes may be motivated by a variety of factors, including the need for higher structural integrity, compatibility with other equipment in the factory, ergonomics considerations, or improved ease of manufacturing. Proposed design changes could range from a simple change in measurements to an entire re-design or complicated reconfiguration. Specifically for complicated changes, verbally communicating the proposed changes could be difficult or even impossible for some participants. Moreover, differences in the domain knowledge of participants, including how they evaluate requirements, can further complicate communication because other participants may not immediately see the relevance or importance of the proposal. This category of friction situation is closely related to the “Indicating specific elements” category, as participants often find it necessary to indicate which component they wish to redesign before articulating their design change idea.

During this type of friction situation, participants may introduce additional tools, such as drawing tools in an attempt to communicate their proposed design change. A raw data example of this friction situation is shown in Table 7. For example, a participant may take screenshots of specific design views and draw on them to visually represent their design change ideas. These supplementary tools are employed to bridge the gap between verbal communication and the conveyance of spatial design concepts. However, this often introduces other friction in the DR process. For example, the screenshot may require them to request that the CAD view be modified by the product expert or that they open the 3D model on their own computer to achieve a specific perspective, thus taking their attention off of ongoing discussions in the meeting.

Table 7. Examples of raw data.

2023-04-17	8AM	14		
Friction situation description		Impact of design review	Cause of friction situation	Attendees' roles involved in the friction
Someone has a disagreement with the structural integrity of one of the pillars. He expresses a design idea but the product expert is not understanding him.		Delayed the design review with an unnecessarily long conversation. Screen shot and drawing over it. Even the drawing has not made it clear. The note that was taken might not reflect what the participant was trying to express.	Lack of possibility to express design ideas more easily.	Product expert and member of the audience.

3.3.3 Moderating factors

The impact of these friction situations may be moderated depending on the complexity of the design change ideas being conveyed. Complicated or intricate design changes typically had a greater impact on the meeting flow. When design modifications were difficult to communicate verbally, visual aids may need to be introduced, introducing additional communication and technology challenges. An additional factor that moderated the impact of expressing design changes on the meeting flow was the individual participant's familiarity with the problem, the component, or the particular unit under discussion. Familiarity often included knowing the names of surrounding components to denote positions, making it easier to specify where the change would happen and what it might affect. When a knowledgeable participant communicated a design change idea to another knowledgeable participant, the communication tended to be smoother compared to when one of the relevant participants was not as familiar with the unit or problem under discussion.

3.4 Evaluating ergonomics

3.4.1 Definition

This category includes situations related to evaluating physical ergonomics with the 3D model. These situations happened when there was a difficulty understanding how end users, e.g. workers at the factory, would interact with the product. As a result,

participants could not accurately assess ergonomic factors including reachability, visibility, and work posture.

3.4.2 Detailed description

Ergonomics evaluations play a crucial role in product design, ensuring that workstations are conducive to user comfort, well-being, safety, and productivity. However, in the context of remote DRs, participants encounter friction situations when attempting to assess aspects related to physical ergonomics, particularly when constrained to 2D screens. This problem partly arises from the limitations in assessing the spatial information needed for ergonomics evaluations. Participants find it challenging to determine if certain spaces are too narrow, require awkward work postures, or accommodate various body types. While there was a possibility to represent a digital human model within the CAD software being used, the functionality of the digital human model was quite basic, and therefore it did not convey all the nuances of ergonomics evaluations. A raw data example of this friction situation is shown in Table 8.

Table 8. Examples of raw data.

2023-04-17	8AM	14		
Friction situation description		Impact of design review	Cause of friction situation	Attendees' roles involved in the friction
Someone is asking about the usability of the product but it is difficult to get a grasp of how people would use it.		Time is spent on subjective assessments when there could be objective data that could allow for a quicker and more accurate assessment.	Not being able to experience the workstation or at least have the possibility to make an ergonomics study.	Member of the audience and product expert.

Furthermore, variations in workstation usage among individuals with different anthropometric dimensions add to the complexity of ergonomic evaluations. Participants often struggle to grasp how considerations related to ergonomics may differ for different users and find it challenging to express these variations effectively.

3.4.3 Moderating factors

This category was related to the complexity of the questions being considered. In some instances of these friction situation, the participants expressed difficulty in assessing whether the space allocated for users to move comfortably is sufficient. Other questions included usability, sequences of manual tasks, and how the design proposal could work for people with different anthropometries. These later questions were more complex, often making the impact of the friction situation more significant.

4. Discussion

In this study, we observed, identified, and classified friction situations as they occurred in a series of DRs within a Swedish automotive company. These friction situations emphasize the complexity of remote collaborative DRs. While several friction situations have been identified, the remote DRs fulfilled their objective of finding issues with the current state of the design proposal. However, as expressed by DR participants and observed in this study, friction situations could still be addressed to improve the remote DR process. One notable observation is that many instances of friction involve more than one source of friction. As a result, reducing one source of friction may reduce friction situations due to other sources of friction. For instance, reducing friction situations related “Requesting specific viewpoints” could also reduce the friction situations related to “Expressing design change ideas”. The relations between friction situations should be considered to address them efficiently, and therefore it is important to understand the root problems that are causing the friction situations. For instance, verbal communication is required to indicate a desired component, which can also affect “Indicating specific elements” and may also influence “Expressing design change ideas”. Recognizing these interdependencies in the causes of friction situations is important for understanding the root issues that impact the primary friction situations. Additionally, friction situations were nested in some instances, meaning that a friction situation could happen within another friction situation. For instance, “Requesting specific viewpoints” was a recurring friction situation that happened as a part of other friction situations. In some cases, participants wanted to “indicate a specific element”, and for that, they needed to request a specific viewpoint, meaning that the fact that a participant wanted to highlight a specific component created the friction situation of “Requesting specific viewpoints”. Similarly, there were instances where participants wanted to request specific viewpoints that would help them express their design change idea. This suggests that addressing the problem of having a fixed viewpoint that is controlled by one person in the meeting could have a positive impact in many of the friction situations, and not only the ones under the category of “Requesting specific viewpoints”. Similarly, as mentioned in the results, there were a few instances where, as a part of a friction situation of “Expressing design change ideas”, there was a friction situation of “Indicating specific components” since participants needed to indicate specific components to express their design change idea. This connection suggests that having an additional way to refer to components other than verbally, could alleviate not only the friction situation of

“Indicating specific components” but also the friction situation of “Expressing design change ideas” or even “Requesting specific viewpoints”. Furthermore, addressing these friction situations could also mitigate the effects of videoconferencing fatigue by making the DRs more streamlined, which has been shown to cause cognitive and physical exhaustion in remote settings^[25].

5. Limitations and Future work

This study focuses narrowly on a set of DRs at a single Swedish automotive manufacturer focused on the design of one component. Data collection in a real-world DR provided a close look at real challenges that emerge in ordinary workflows with professional design teams. However, we acknowledge that the focus on a single company and DR team means that there may be additional friction situations or causes of friction situations in other contexts. Given the challenges of collecting real-world data in an active company, e.g. data collection agreements and time constraints, we decided it was best to focus our resources on a single company in this initial study to ensure timely communication of results and insights in a fast-moving technological landscape. We believe that while these limitations are unfortunate, the insights into challenges in a real-world workflow are incredibly valuable for current and future researchers and technology developers. Future work will aim to collect data over longer periods of time, from more teams/companies, and with more designed products to provide validation and refine understanding of friction situations in remote DRs.

The current study took a user-focused approach to understanding challenges in remote DRs, focusing on challenges that emerged with technology users in existing workflows^[26]. As a result, the friction situations are not defined with the assumption of a specific technology solution. Future work should focus on identifying technologies, hardware, and software that can best address and minimize friction situations in DRs. These solutions may include more advanced solutions, e.g., VR/AR. However, they may also involve simpler software solutions, such as allowing participants to control their own viewpoints or annotate specific components during remote DRs. This could alleviate several interconnected friction situations, such as “Requesting specific viewpoints”, “Indicating specific components”, and “Expressing design change ideas” in a way that is easy for companies to integrate into existing workflows. Evaluating the effectiveness of these features in reducing friction and enhancing collaboration would provide valuable information for designers and technology developers.

Exploring organizational strategies to mitigate friction situations is also important. This could involve establishing best practices for facilitating remote DRs, training programs to improve communication skills in virtual environments, or guidelines for effectively utilizing available technologies. The extent to which existing organizational frameworks for remote collaborative design shape current real-world design practice should be further investigated, and the effect of implementing these frameworks studied^[13,14]. These frameworks emphasize key factors such as shared mental models and workspace awareness, which are critical for effective collaboration. However, recent research suggests that additional factors, such as activity awareness and social presence, are equally important in remote collaborative environments^[27]. Understanding how organizational factors that can alleviate friction may lead to more efficient and productive remote DRs.

Finally, further research will examine the impact of reducing friction situations on overall efficiency, participant satisfaction, and the quality of DRs and design outcomes. By quantifying these effects, organizations can better assess the value of investing in solutions to address friction situations. Moreover, future work should investigate how friction situations are related to cognitive and physical fatigue during remote DRs and how possible connections can be leveraged to improve work environments. This could include exploring alternative communication modalities, optimizing meeting structures, or incorporating breaks to enhance participant well-being and engagement.

6. Conclusion

This study provides insight into friction situations as they occurred in real-world remote DRs using a combination of CAD and videoconferencing applications. In this study, the main friction points in DRs meetings have been identified and analysed. Additionally, friction situations were matched to software functionalities, providing useful insights for developing and integrating critical software features into the remote collaborative design process. Improving remote DRs requires technological innovation, careful controlled research, and regular observation and evaluation of real-world practices in workplace settings. The current study provides critical insights grounded in the latter, and contributes a framework for understanding communication challenges in remote DRs as they emerge in design practice.

Declarations

Acknowledgments

This study was conducted in collaboration with Volvo Cars. This research was funded by the Swedish innovation agency Vinnova as part of the PLENUM project. The support is gratefully acknowledged. To protect the intellectual property of the company, no audio, video, or photographs of the design review sessions were recorded. However, the authors have provided as much raw data as possible while adhering to these constraints.

Authors contribution

Rivera FG: Data collection, data analysis, writing, reviews.

Lamb M, Alenljung B, Högberg D: Supervision and guidance on study framing, manuscript revision.

All authors reviewed the final manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Consent to participate was obtained from all participants. They were fully informed about the study's purpose, procedures, risks, and benefits before consenting to participate.

Consent for publication

Not applicable.

Funding

This project was funded by Swedish innovation agency Vinnova in the PLENUM project (Grant Number: 2022-01704).

Copyright

© The Author(s) 2024.

References

1. Kirby JG, Furry DA, Hicks DK. Improvements in design review management. *J Constr Eng Manag.* 1988;114(1):69-82. [\[DOI\]](#)
2. Ostergaard KJ, Wetmore WR, Divekar A, Vitali H, Summers JD. An experimental methodology for investigating communication in collaborative design review meetings. *CoDesign.* 2005;1(3):169-185. [\[DOI\]](#)
3. Cooper RG. Stage-gate systems: a new tool for managing new products. *Bus Horiz.* 1990;33(3):44-54. [\[DOI\]](#)
4. Gräßler I, Roesmann D, Hillebrand S, Pottebaum J. Information model for hybrid prototyping in design reviews of assembly stations. *Procedia CIRP.* 2022;112:489-494. [\[DOI\]](#)
5. Albers A, Lanza G, Klippert M, Schäfer L, Frey A, Hellweg F, et al. Product-Production-CoDesign: an approach on integrated product and production engineering across generations and life cycles. *Procedia CIRP.* 2022;109:167-172. [\[DOI\]](#)
6. Freeman IJ, Salmon JL, Coburn JQ. CAD integration in virtual reality design reviews for improved engineering model interaction. In: ASME 2016 International Mechanical Engineering Congress and Exposition; 2016 Nov 11-17; Arizona: USA. New York: American Society of Mechanical Engineers Digital Collection. 2016. p. 11-17. [\[DOI\]](#)
7. Tea S, Panuwatwanich K, Ruthankoon R, Kaewmoracharoen M. Multiuser immersive virtual reality application for real-time remote collaboration to enhance design review process in the social distancing era. *J Eng Des Technol.* 2021;20(1):281-298. [\[DOI\]](#)
8. Lapointe JF, Vinson NG, Katsuragawa K, Emond B. A review of distributed VR co-design systems. In: Chen JYC, Fragomeni G, editors. *Virtual, Augmented and Mixed Reality. HCII 2021.* 2021 Jul 24-29; Washington: USA. Cham: Springer; 2021. p. 499-510. [\[DOI\]](#)
9. Germani M, Mengoni M, Peruzzini M. An approach to assessing virtual environments for synchronous and remote collaborative design. *Adv Eng Inform.* 2012;26(4):793-813. [\[DOI\]](#)
10. Horvat N, Kunnen S, Štorga M, Nagarajah A, Škec S. Immersive virtual reality applications for design reviews: systematic literature review and classification scheme for functionalities. *Adv Eng Inform.* 2022;54:101760. [\[DOI\]](#)
11. Ferguson S, Lai K, Chen J, Faidi S, Leonardo K, Olechowski A. "Why couldn't we do this more often?": exploring the feasibility of virtual and distributed work in product design engineering. *Res Eng Des.* 2022;33(4):413-436. [\[DOI\]](#)
12. Wang P, Zhang S, Billingham M, Bai X, He W, Wang S, et al. A comprehensive survey of AR/MR-based co-design in manufacturing. *Eng Comput.* 2020;36(4):1715-1738. [\[DOI\]](#)
13. Carroll J, Rosson MB, Convertino G, Ganoë CH. Awareness and teamwork in computer-supported collaborations. *Interact Comput.* 2005;18(1):21-46. [\[DOI\]](#)
14. Gutwin C, Greenberg S. A descriptive framework of workspace awareness for real-time groupware. *Comput Support Coop Work.* 2002;11(3):411-446. [\[DOI\]](#)
15. Chang HH, Chuang SS, Chao SH. Determinants of cultural adaptation, communication quality, and trust in virtual teams' performance. *Total Qual Manag Bus Excell.* 2011;22(3). [\[DOI\]](#)
16. Joseph A, Neyens D, Taaffe K, Bayramzadeh S, Catchpole K. Understanding "work as done": using a structured video-based observational

- method to understand and model the role of the physical environment in complex clinical work systems. *Health Environ Res Des J*. 2022;15(3):13-27. [DOI]
17. Lauff CA, Knight D, Kotys-Schwartz D, Rentschler ME. The role of prototypes in communication between stakeholders. *Des Stud*. 2020;66:1-34. [DOI]
 18. Noël F, Nguyen A, Ba N, Sadeghi S. Qualitative comparison of 2D and 3D perception for information sharing dedicated to manufactured product design. In: 2012 IEEE 3rd International Conference on Cognitive Infocommunications (CogInfoCom); 2012 Dec 2-5; Kosice, Slovakia. Piscataway: IEEE; 2012. p. 261-265. [DOI]
 19. Shah P, Miyake A. *The cambridge handbook of visuospatial thinking*. Cambridge University Press. 2005. [DOI]
 20. Cho JY, Suh J. Understanding spatial ability in interior design education: 2D-to-3D visualization proficiency as a predictor of design performance. *J Inter Des*. 2019;44(3):141-159. [DOI]
 21. Simon-Liedtke JT, Bong WK, Schulz T, Fuglerud KS. Remote evaluation in universal design using video conferencing systems during the COVID-19 pandemic. In: Antona M, Stephanidis C, editors. *Universal Access in Human-Computer Interaction. Design Methods and User Experience*; 2021 Jul 24-29. Cham: Springer; 2021. p. 116-135. [DOI]
 22. Bordegoni M, Caruso G. Mixed reality distributed platform for collaborative design review of automotive interiors. *Virtual Phys Prototyp*. 2012;7(4):243-259. [DOI]
 23. Huet G, Culley SJ, McMahon CA, Fortin C. Making sense of engineering design review activities. *Artif Intell Eng Des Anal Manuf*. 2007;21(3):243-266. [DOI]
 24. Clarke V, Braun V. Thematic analysis. *J Posit Psychol*. 2017;12(3):297-298. [DOI]
 25. Hove DP, Watson B. The shortcomings of video conferencing technology, methods for revealing them, and emerging XR solutions. *PRESENCE: Virtual Augment Real*. 2022;31:283-305. [DOI]
 26. Morrison-Smith S, Ruiz J. Challenges and barriers in virtual teams: a literature review. *SN Appl Sci*. 2020;2(6):1096. [DOI]
 27. Haines R. Activity awareness, social presence, and motivation in distributed virtual teams. *Inf Manage*. 2021;58(2):103425. [DOI]

Publisher's Note

Science Exploration remains a neutral stance on jurisdictional claims in published maps and institutional affiliations. The views expressed in this article are solely those of the author(s) and do not reflect the opinions of the Editors or the publisher.