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Measuring Remote Collaboration Supported by eXtended Reality: A Multidimensional Evaluation Approach

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ABSTRACT

Remote collaboration supported by eXtended Reality (XR) is a paradigm that transforms how geographically dispersed teams collaborate on shared tasks by leveraging immersive technologies that bridge physical distances. This approach goes beyond traditional communication tools, by creating shared, three-dimensional spaces that enhance the depth and effectiveness of collaboration. Regardless, it also introduces new challenges, like evaluating how collaboration occurs during such contexts, which literature shows is not straightforward. This work delves into evaluation in the realm of remote XR collaboration by proposing that a multidimensional approach is used, considering the level of information understanding, communication effectiveness, or social presence, among others. By analyzing how evaluation could be performed, we intend to offer insights to steer research and development in this dynamic field. These assessments can contribute not only to refining XR-system development but also deepen comprehension of how teams collaborate over time.

Keywords: Remote collaboration, Extended reality, Evaluation, Multidimensional approach

INTRODUCTION

Collaboration is a fundamental aspect of human interaction. In particular, remote collaboration refers to the act of physically distributed team members working together on shared tasks. This happens when on-site individuals cannot handle a given situation, forcing them to request assistance from remote experts. To accomplish this, various technologies and tools can be used to facilitate communication, information sharing, and cooperation. The ability to collaborate remotely is especially crucial in today's globalized world, as it allows efficient cross-border communication, knowledge sharing, and teamwork. These activities have particular relevance in a wide range of scenarios, including industrial, medical, and educational domains, among others (de Belen *et al.*, 2019; Ens *et al.*, 2019; Sereno *et al.*, 2020; Wang *et al.*, 2021).

In recent years, remote eXtended Reality (XR) has witnessed unprecedented growth, with the potential to create a common group and revolutionize the way teams work together across geographical boundaries. This umbrella term encompasses Virtual, Augmented and Mixed Reality

(VR/AR/MR) (Speicher *et al.*, 2019; Ratcliffe *et al.*, 2021; Rauschnabel *et al.*, 2022). All of these can be applied to collaborative scenarios, by creating immersive and interactive environments that bring remotely separated individuals together. For example, after being captured and shared, the on-site environment can be visualized by remote experts through VR. These individuals can enhance their view with virtual content (e.g., drawings, pointers, gaze, gestures, arrows, etc.), explaining what to do and where to act. Later, on-site individuals using AR can visualize superimposed instructions on top of the real-world context, improving situation understanding, awareness and alertness. This paradigm shifts from traditional instant messaging, document editing, or video conferencing alternatives introduce unique challenges and opportunities for the research community (Sereno *et al.*, 2020; Marques *et al.*, 2021; Marques, Silva, Dias, *et al.*, 2022; Marques, Ferreira, *et al.*, 2023).

To elaborate, thus far, remote XR is positioned between the replication and empiricism stages of the BRETAM model, evidencing the need for additional work toward achieving a more advanced stage of maturity (Marques, Teixeira, *et al.*, 2022). An essential step to achieve this is considering evaluation of the collaborative process, where limited research has been conducted, given the number of variables that affect how these multi-user experiences occur. An improved understanding of how collaboration unveils can provide the tools to perform a more contextualized interpretation and define more robust conclusions, not only regarding the performance of the technology but also how XR contributes to an effective/efficient work effort (Dünser *et al.*, 2008; Dey *et al.*, 2018; Merino *et al.*, 2020; Marques, Silva, Teixeira, *et al.*, 2022; Marques, Silva, *et al.*, 2023).

This work explores the significance of considering distinct dimensions of collaboration when conducting user evaluations in the context of remote-XR collaboration. To harness the full potential of XR, it is imperative to better comprehend the collaborative process, which encompasses various dimensions of interest (e.g., level of information understanding, ease of communication, level of social presence, among others). By examining the multifaceted aspects of collaboration in this setting, we aim to provide insights that can guide research and development in this rapidly evolving field. These evaluations not only inform the development of XR-systems but also contribute to a deeper understanding of how remote collaboration can be enhanced. By addressing the distinct dimensions of collaboration, the community can also create more inclusive, and effective XR-remote collaboration experiences that benefit a broad spectrum of users and industries, thus shaping the future of remote collaboration.

A MULTIDIMENSIONAL APPROACH FOR EVALUATING XR-REMOTE COLLABORATION

The literature shows that research on remote collaboration supported by XR (see Figure 1) must evolve from solving technical issues, towards more meaningful studies on collaboration itself (de Belen *et al.*, 2019; Merino *et al.*,

2020; Ratcliffe *et al.*, 2021; Marques, Silva, *et al.*, 2023). Regardless, evaluating these scenarios is a difficult endeavor since many aspects may affect how teams collaborate. Similarly, there is a lack of theories to guide how the collaborative process may be characterized, and beyond that, present evaluation frameworks are also not specifically designed to evaluate the dynamics of XR-remote collaboration, falling short to provide the necessary data to inform a more thorough analysis.

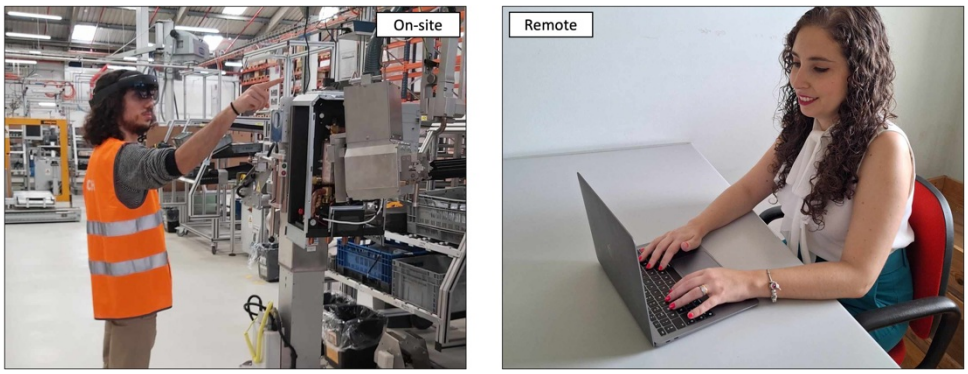

Figure 1: Illustration of a scenario of remote collaboration supported by XR, having an on-site individual located in an industrial scenario being assisted by a remote teammember.

As described in previous work, studies evaluating scenarios of XR-remote collaboration often rely on single-user methodologies, primarily centered on comparing technological aspects or interaction mechanisms, as well as quantify effectiveness in completing tasks, often lacking diversity, difficulty, and ecological validity. However, such approaches may not be the most suitable for multifaceted solutions intended to support collaboration among distributed teams. A significant portion of existing studies concentrates solely on the performance of individual collaborators (on-site or remote). Consequently, the evaluation tends to overlook important aspects of collaboration (Marques, Silva, Dias, *et al.*, 2022; Marques, Silva, Teixeira *et al.*, 2022; Marques, Teixeira, *et al.*, 2022; Marques, Silva, *et al.*, 2023).

Besides, most studies in this field take place in laboratories, collecting objective and subjective data at the tasks' conclusion through standard practices such as scale-based questionnaires (e.g., System Usability Scale (SUS), NASA Task Load Index (TLX), among others) or direct observation. Furthermore, the lack of guidelines hampers researchers from determining which dimensions of collaboration should be collected and how to effectively gather them.

Next, we propose a list of important dimensions of collaboration, that should be considered. These were selected carefully after survey existing literature to create a list of important topics facing the lack of methodologies and frameworks. This list was also displayed to experts in XR/VR/AR/MR, Human-Computer Interaction (HCI), Human-Centered Design (HCD), and Computer-Supported Cooperative Work (CSCW), who had an important role

in selecting, analyzing and filtering said topics of collaboration by voting about the ones they considered more relevant. To elaborate, we took inspiration from works by (Kim *et al.*, 2014, 2018, 2019, 2020; Aschenbrenner *et al.*, 2018; Kim, Billinghurst and Lee, 2018; Huang *et al.*, 2019; Piumsomboon *et al.*, 2019; Teo *et al.*, 2019; Kim, Billinghurst and Kim, 2020; Marques, Silva, Teixeira, *et al.*, 2022; Marques, Ferreira, *et al.*, 2023).

With this proposal, we aim to provide a structured list of relevant artifacts, that can be measured all at once. These characteristics are important since collaboration may occur at many levels and depends on several factors that may directly impact the collaborative outcomes. Nevertheless, other subsets of alternative dimensions can be considered according to the evaluation scope, as long as they are not used in an isolated manner. By only using one of these dimensions, findings reported may be misleading or of limited value in these scenarios.

To elaborate, the proposed list includes the following dimensions of collaboration:

- **level of attentional allocation** - the degree of cognitive focus or mental concentration allocated to a specific task;
- **effectiveness in perceived information understanding** - the extent to which information is comprehended and interpreted by an individual;
- **effectiveness in express ideas properly** - the proficiency in conveying thoughts, concepts, or messages accurately and coherently in a manner that aligns with the communicator's intent;
- **level of satisfaction** - The extent to which an individual experiences fulfillment in the process of engaging with a particular activity or task;
- **level of frustration** - The degree of dissatisfaction experienced by an individual in response to the collaborative process;
- **level of visual complexity** - The degree of intricacy present in the visual elements of the XR tool being used during the collaborative process;
- **effectiveness to communicate** - The ability to convey information clearly, accurately, and comprehensively to other collaborators;
- **level of social presence** - The perceived degree of connection, interaction, or involvement with others in a XR- mediated environment;
- **effectiveness in completing the intended tasks** - The degree to which a team successfully accomplishs the specified goals;
- **level of mental effort** - The amount of cognitive workload experienced by an individual while engaging in a particular task or activity;
- **level of physical demand** - The extent of physical effort required to perform a given task or activity;
- **level of temporal effort** - The amount of time-related investment required to complete a task or achieve a particular objective.

These dimensions may be collected at the end of the collaborative process, using a Likert-type scale (1- Low; 7 - High). Having this list of dimensions may also help researchers create data visualizations to maximize its usefulness during the data analysis process. For example, Figure 2 illustrates a possible visualization, i.e., a radar char representation, in which all dimensions may be

analyzed at the same time, for all team members involved in the collaborative process.

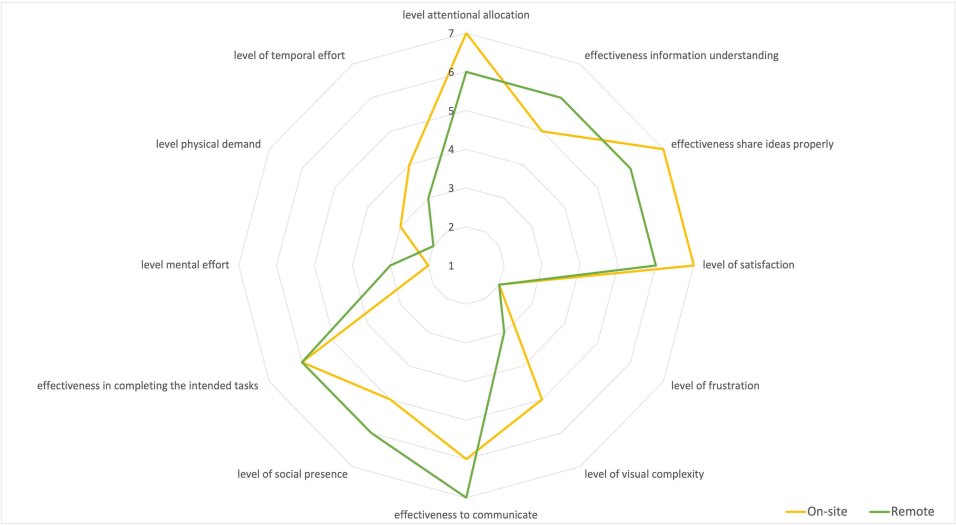

Figure 2: Illustration of a possible visualization for the proposed dimensions that may be considered during an evaluation of a scenario of remote collaboration supported by XR. The radar chart enables to have a better understanding of all dimensions at once.

Enhancing our comprehension of the collaborative process through multiple dimensions equips researchers with the tools for a contextualized interpretation of results, leading to more robust conclusions and efficient work efforts. Therefore, conducting more comprehensive collaborative studies is crucial, enabling the retrieval of the necessary amount of data for a thorough analysis that sheds light on various factors influencing XR-supported collaboration. The proposed dimensions and visualization may also be used over long periods of time, allowing to compare how the same team behaves between collaborative sessions. This information may be extremely relevant if outliers start to emerge, allowing to understand what exactly is affecting the team, e.g., the XR tool, one element in particular, the task being handled, etc. In essence, a profound understanding of these aspects is vital to ensure genuine characterization. By achieving this, the community may be able to better assess a wide range of information, including individual and team personalities, performances, and behaviors, thereby facilitating a more insightful analysis, and establishing conclusions.

Final Remarks and Next Steps

The significance of remote collaboration supported by XR lies in its ability to break down geographical barriers, fostering efficient cross-border communication, knowledge sharing, and teamwork. For instance, using VR, remote experts can visualize and engage with on-site environments in real-time,

providing guidance and insights. On the other hand, AR allows on-site individuals to receive superimposed instructions or information directly within their real-world context.

This collaborative model finds applications across various domains, including industrial, medical, and educational sectors. The immersive and interactive nature of XR not only enhances situational awareness but also facilitates a more natural and engaging form of communication among team members. As XR technologies continue to advance, the potential for creating realistic, shared experiences across distances expands, leading to a paradigm shift in how teams collaborate remotely.

In the rapidly evolving landscape of remote XR collaboration, the importance of developing and implementing new evaluation models cannot be overstated. Traditional methods often fall short in capturing the nuanced dynamics of collaborative processes facilitated by immersive technologies. The unique blend of existing realities introduces novel domains such as spatial awareness, interactive visualization, or social presence, which demand innovative evaluation approaches. Relying on established models may hinder our ability to fully grasp the impact and effectiveness of XR in remote collaboration scenarios. As we navigate the uncharted territories of remote XR collaboration, given its level of maturity, crafting new evaluation approaches becomes paramount. By embracing these new evaluation paradigms, we may be able to truly unlock the transformative potential of remote XR collaboration and foster more meaningful, efficient, and user-centric collaborative interactions across diverse industries.

Moving forward, we intend to prioritize conducting extended and formal user studies, especially within industrial scenarios such as maintenance scenarios. These studies could provide valuable insights into the real-world applicability of the proposed approach, enabling the collection of a comprehensive and robust dataset for in-depth analysis and continual improvement. Industry settings present complex and dynamic environments that could further validate the effectiveness of the approach in practical, high-stakes situations.

Another avenue for future exploration involves extending the proposed approach to multi-user scenarios, involving multiple team members in the collaborative process. This expansion would assess the scalability of the approach and its ability to facilitate seamless interaction among various team members in a shared XR environment. Evaluating how the system performs when supporting collaboration among multiple users is crucial for ensuring its practicality and effectiveness in diverse team-based settings.

Furthermore, it is important to dedicate efforts to developing a visualization tool tailored for remote XR collaboration. This would empower team leaders and decision-makers with the means to make more informed decisions. It could offer features such as real-time data visualization, collaborative data annotation, as well as interactive analysis, having an overview of how collaboration unfollowed.

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