DE GRUYTER i-com 2025; 24(3): 477–489

Research Article

Jan Christoph Gutzmann, Michael Prilla* and Gian Luca Dossena

From troubleshooting to status reporting: insights from long-term use of an HMD remote support system in a craft company

https://doi.org/10.1515/icom-2025-0034
Received September 21, 2025; accepted November 7, 2025;
published online November 24, 2025

Abstract: Many German crafts companies are faced with the situation of increasing orders and a decreasing workforce. In this paper, we report on the use of an AR HMD-based remote support system in a craft company that aimed to reduce travel times and speed up problem-solving. We present findings from a long-term field study examining how the system influenced work organization in a small craft company. Over the course of 10 weeks, we observed how employees in a small craft business integrated the system into their daily work practices. Using qualitative interviews, video recordings, and system logs, we observed the evolution of communication and coordination practices. Instead of primarily supporting spontaneous problem solving, as initially expected, the system was adopted for structured status reporting and video documentation. This shift reduced the need for traditional end-of-day debriefings and changed both the timing and frequency of coordination. While the system complemented rather than replaced existing communication channels, its sustained use subtly reshaped collaboration and introduced new forms of workload due to increased expectations for real-time availability. Our findings provide insights into the appropriation of remote support systems in small, real-world organizations and highlight design considerations for remote collaboration tools.

Keywords: head-mounted-displays; remote support; field deployment; workers

***Corresponding author: Michael Prilla**, Interactive Systems, University of Duisburg-Essen, Duisburg, Germany, E-mail: michael.prilla@uni-due.de
Jan Christoph Gutzmann and Gian Luca Dossena, Interactive Systems, University of Duisburg-Essen, Duisburg, Germany

1 Introduction

Many companies in the German craft sector share the same problem: while there are numerous client orders, the number of apprentices and the availability of skilled workers are declining.[1] In this context, companies face the need to manage several construction sites in parallel with the limited availability of expert time. In practice, this often leads to long waiting times for clients and stressful coordination of daily schedules of the remaining workers. A particular problem in this context is the time- and travel-intensive coordination between construction sites. One way to mitigate this problem is to reduce travel times between construction sites, as they do not provide added value and detract from the time available to provide services to other clients. For this, there is huge potential in remote support for workers. Currently, specialized or senior workers often visit construction sites to solve problems or ensure quality. Providing these workers with a means to remotely support on-site workers would reduce travel, speed up the fulfillment of client orders, and free expert time.

This case reflects a broader trend in human-computer interaction research: the increasing importance of virtual collaboration.[2] It refers to individuals or teams working remotely through digital platforms such as video conferencing that enable real-time communication between locations, improving efficiency and flexibility in work processes.[3] In practice, remote support is a particularly relevant form of virtualization, where an on-site user receives assistance from a remote consultant who provides expert advice and guidance. This approach reduces travel requirements and increases temporal flexibility in everyday work.

The potential of HMDs as a remote support platform has been increasingly recognized e.g. Ref. 4–6. In this type of remote support, on-site users are typically equipped with a head-mounted display. Advantages include being free to move around, supporting information intake while performing tasks, and allowing consultants to provide visual guidance. These benefits are often considered

Figure 1: Our AR HMD-based remote system application in field use. Left: A consultant discusses the maintenance of a heating system remotely. The red circles are the visual cues placed by the remote worker. Right: An on-site employee discusses problems and answers questions regarding which steps have already been taken.

superior to traditional solutions such as handheld mobile devices e.g. Ref. 7–9.

However, while AR HMD-based remote support systems show great promise, there is still limited understanding of their long-term impacts and the challenges they pose when deployed outside controlled laboratory settings.[10] Although there are some long-term field studies e.g. Ref. 4,11, detailed insights into how such systems affect the organization of work and integrate into existing communication processes in small companies are still lacking. This leads to our **research question**: How does an AR HMD-based remote support system influence the organization of work under real field conditions over a longer period of time?

We addressed this question in an empirical study of a smartphone-based head-mounted camera (HolokitX with iPhone) used in the craft sector (see Figure 1). This context provides a unique lens due to its reliance on manual tasks and dynamic work environments, which have been shown to benefit from AR HMD-based technologies in supporting real-time guidance, spatial coordination, and hands-on problem solving. The study provides valuable insights into the adoption and organizational integration of remote AR HMD-based support in real-world workflows.

The contribution of our work lies in empirical findings on the effectiveness of AR for remote support in real-world scenarios over an extended period. Our results show that workers gradually appropriated the system, often for purposes other than those originally planned. Technology influenced established communication practices, complementing rather than replacing existing tools, and affected face-to-face interactions.

2 Related work

2.1 Remote task support with augmented reality

A substantial body of research has examined remote AR-based support in applications such as assembly,[5,9,12] maintenance,[6,13] inspections,[4,14,15] object placement,[16] co-design in manufacturing,[17] and healthcare.[18,19] In these scenarios, less experienced on-site users typically stream live video from an AR device to a remote consultant, who provides real-time guidance without being physically present.[4,20]

Specialized tasks such as inspections, maintenance, or assembly often require consultants to travel to work sites, which is time-consuming and costly.[4,21,22] Remote AR-based support can mitigate these costs by reducing the need for physical presence.[4,21,23] Commercial applications such as Linde Go and Microsoft Dynamics 365 Remote Assist already offer AR-based support through headsets, including hardhat-integrated versions.[4,24,25]

Vocal instructions alone are often insufficient for spatial information in assembly tasks.[26,27] To address this, video streaming and virtual cues are frequently used to maintain situational awareness and establish shared understanding.[23,28–31] Pointing cues, the placement of a single colored point in the user's field of view, have proven to be effective in directing attention and indicating objects of interest.[5,32,33]

To minimize cognitive load, previous work recommends relying on a single reference method rather than multiple overlapping cues, as redundant options can increase mental effort and cause sensory overload.[29,33–35]

Importantly, social presence depends less on the number of cues than on their clarity and integration.[30]

Although AR support has been evaluated using different devices such as mobile AR[36,37] or *in situ* projections,[38,39] AR HMDs offer several advantages over other AR devices when it comes to remote support: They allow users to use both hands to perform a task while receiving instructions through the AR application,[22] improving the speed of task completion. This has also been reported as a key advantage by users of such systems.[4] The ability to work in hands-free mode is particularly beneficial in physical and dynamic tasks, where relying on handheld devices would require frequent interruptions to establish them between steps, ultimately increasing the task duration.[40] In addition, HMDs enable users to move more freely on their job site, which is a necessity when it comes to complex and dynamic job sites, such as construction sites.[4]

In summary, HMD-based remote support systems have proven to be beneficial, particularly when they integrate not only video streaming, but also the ability to utilize visual cues for referencing objects.

2.2 Augmented reality remote support in practice

Research on AR-based remote support in real-world field settings is relatively new, as most previous work has focused on laboratory studies. El Kassis et al.[4] explored factors that influenced the communication between AR users on site and remote consultants on a construction site. Over several months, on-site users utilized a Trimble XR10 with a HoloLens 2 to conduct video calls with off-site users whenever AR was deemed beneficial in those cases. Among other findings, users perceived hands-free operation and the ability to work remotely without traveling to the construction site as beneficial, saving both time and costs. In addition, they noted that the clear camera feed facilitated the detection and correction of errors. However, users also reported challenges, such as working in bright or noisy environments or areas with poor Internet connectivity. Lodetti et al.[11] conducted a study on remote support for electricians working in power distribution utilities. During a four-month period, they observed general positive user feedback regarding the suitability of AR for their tasks, as well as its usability, ability to enhance communication, and general acceptance of the technology. Furthermore, the authors suggest that AR-based remote support could increase monitoring and inspection activities at construction sites while simultaneously minimizing the need to travel. Similarly, Pejoska et al.[41] found that workers on a construction site perceived remote AR support as a viable alternative to phone calls. Another study examined the acceptance of AR HMDs in the craft sector through a qualitative field study involving three craft companies of different sectors.[22] Their findings suggest that AR can improve time efficiency, task learnability, and hands-free operations, but adoption in practice is hindered by issues such as device fragility, bulkiness, cost, and variable working conditions.

However, little is known about how such systems are actually integrated into daily workflows, a perspective that is crucial for generating meaningful design recommendations in the context of HCI.[42] This lack of understanding limits our ability to derive actionable design recommendations, an issue that has long been emphasized in HCI research. As Schmidt and Bannon[42] argue, the success of cooperative systems depends not only on their technical functionality, but crucially on how well these systems support the 'articulation work' required to coordinate complex distributed tasks. In this light, studying AR HMD-based remote system integration over time is essential for uncovering the subtle ways in which technologies reshape communication, coordination, and routines in practice, and for designing systems that meaningfully support rather than disrupt established work practices.

2.3 Research gap

Previous research has mostly examined AR HMD-based remote support systems through short-term studies in laboratory or controlled field environments; detailed insights into the effects of their long-term application in real-world settings remain limited. Understanding how communication structures and work organization evolve over extended periods is essential for designing systems that go beyond optimizing direct usability features and also address crucial organizational factors. These aspects are particularly important for the successful adoption of such technologies, but also depend on their alignment with existing workflows and collaboration practices.

Therefore, we ask the following **research question**: How does an AR HMD-based remote support system influence the organization of work under real field conditions over a longer period of time? For this, we conducted a field study with workers in the craft sector. In the following section, we describe why the craft sector and the case company were seeking a new remote support solution, the designed solution, and what benefits they expected from its use.

3 Background

3.1 Context: challenges in the German craft sector

Many craft companies in Germany are currently under significant operational pressure: while order books are full, both the number of apprentices and the availability of skilled workers continue to decline.[1] As a result, project implementation is often delayed and smaller assignments are sometimes no longer accepted, leading to dissatisfaction among clients. The Minerva Research Project, funded by the German Federal Ministry of Research, Technology and Space, addresses this challenge. Its aim is to enable specific tasks to be performed independently of location and with greater temporal flexibility, reducing the need for multiple craftsmen to be physically present on-site. The project investigates to what extent craft companies in Germany can benefit from digital transformation measures and what requirements must be met to achieve this benefit. Craft enterprises are typically small organizations with fewer than 10 employees, which makes the implementation of such strategies particularly demanding, as resources for these initiatives are often very limited.

3.2 Company and intervention

Our case study examines a 10-week period from October 15, 2024, to January 17, 2025, at a medium-sized craft company in the plumbing, heating, and air conditioning (PHC) sector in a German metropolitan region, which we will refer to as ”the company” in this paper. It is family-run and, aside from the family members, employs 10 workers. They specialize in building high-quality bathrooms for their clients, but also provide services such as maintenance, repairs, and installation of heating systems. During the day, workers are usually present at construction sites or visit clients who have ordered services. This is a typical situation for many companies in the PHC sector and other crafts domains, as their main work is done on the client's site. As a consequence, workers need to be knowledgeable and versatile to deal with a multitude of devices, installations and problems. This often results in the need to ask questions to other workers or the central office to complete tasks. It should be noted that this situation is not specific for the PHC sector only, but that similar problems are present in other crafts sectors as well.[22] The daily work of the company is coordinated from a central office, which takes calls from clients and plans assignments for the workers. Contact between the office and the workers occurs in the morning, when they collect their vans to visit clients and receive their work plan for the day, and in the afternoon, when they return from their shift and report on their day's activities. During the day, phone and video calls are the primary means of staying in contact. During our work with the company prior to the study reported here, we observed that this communication was often insufficient to resolve problems, and that other workers needed to visit the client site to do so.[22] The company deemed this inefficient, as time was lost and clients were unhappy with the resulting delays.

3.3 Challenges of the case

At the beginning of the project, the company and their workers were observed by a researcher in day-to-day work. This was done to analyze the current state of the organization of work: How are inquiries processed? How are orders planned? What difficulties arise during execution? How are problems on the construction solved? Which media are used for communication? These were the guiding questions of the initial assessment. At the beginning of the project, the company under study operating in the plumbing, heating and air conditioning sector was observed by a researcher in its day-to-day work. During this phase, the current state of the organization of work was analyzed: How are inquiries processed? How are orders planned? What difficulties arise during execution? These were the guiding questions of the initial assessment. Additionally, workshops were conducted to identify pressing problems in daily operations and explore how specific technologies could provide support. A recurring issue was the need for spontaneous on-site assistance by highly qualified staff. In many craft enterprises, only a few individuals possess the authority, expertise, and experience necessary to resolve complex issues on-site. This created a demand for a remote support system that would be low-cost, require minimal training, and be adapted to the specific needs of the craft sector. In addition to environmental conditions such as dust, dirt, and the risk of theft on construction sites, the solution also had to be portable and robust.[22] Given that workers in the craft sector typically require both hands for their tasks and operate in dynamic environments, they are particularly well-suited for HMDs as a platform for remote support.

3.4 AR HMD-based remote support system as a tool for flexibilization

For this purpose, we used a HolokitX as an AR smartphone-based HMD (Figure 2).[43] The HoloKitX, shown in 2, is a lightweight HMD that uses an inserted smartphone to display AR content. Since previous research indicated that bulky AR HMDs can be impractical on construction sites,[22]

Figure 2: The Holokit mount with an inserted smartphone (iPhone 15).

we chose a lightweight and portable alternative. The advantage of our smartphone-based HMD application is that almost everyone has a smartphone with them, and therefore only the head device needs to be brought along to use the application. HolokitX has built-in support for hand tracking and gesture recognition through its Unity software development kit.[43,44] Since we needed a LiDAR scanner to display our AR content in a 3D space, we used an Apple iPhone 15 Pro for our study.[45] However, our application is compatible with all iPhone Pro models from model numbers 12 to 16. The application was developed in Unity and enables the streaming of real-time video from a mobile device to a desktop client used by a remote consultant. The video stream is captured using the iPhone's wide-angle camera, providing the remote consultant with a first-person perspective of the on-site user's environment. The desktop client displays the received video feed, allowing the remote consultant to observe the AR experience, seen in Table 1. Additionally, a two-way audio connection was established between the AR headset and the desktop client, enabling communication between both users. Furthermore, the remote consultant could indicate specific cues within the video stream by clicking with the mouse. This action projected red circular pointing cues in the on-site user's field of view, highlighting the selected spots. The cues are illustrated in Figure 1. Lastly, the remote consultant was able to record the incoming video feed and the audio to document the performed work and made arrangements. We planned to include the resulting video recordings in our analysis. The application results from a long-term collaboration with the company, which aimed to provide a permanent solution to the challenges outlined above. The company and its workers were closely integrated into the development process from the outset and remained so throughout. At the beginning of the project, we ran workshops to identify and understand their main pain points, which turned out to be travel times and remote support options. After developing the initial prototypes, the company tested them in its workshop.[22] This was done to ensure the development of a solution that provides added value and would be accepted by the workers. The next step we agreed on with the company was to introduce the final version of the application into the company's practice and to analyze the first 10 weeks of its usage regarding its impact on work and work organization. The resulting study is described below.

Table 1: Overview of key information of the participants.

ID	Age group	Job experience (years)	Job role
ID 1	56–65	42	Project manager
ID 2	26–35	10	Planner in the office
ID 3	18–25	7	On-site worker
ID 4	26–35	10	On-site worker
ID 5	26–35	11	On-site worker

4 Method and data collection

The system was systematically observed over a 10-week period in daily work to investigate its adoption and the potential effects of work and organization of work. A qualitative field study was conducted to analyze the integration process, identify emerging challenges, and assess the early effects on work practices.

4.1 Participants

In total, the study comprises five participants, who used the system for a period of 10 weeks. All participants were male and worked for a craft company described above (see Table 1). The participants held various roles within the organization. One served as a remote consultant with a German "master craftsman" title in his professional field. This means he has extensive knowledge and specialized training in the specified field, as well as the authorization to operate as a training establishment for trainee craft workers. Another participant was a remote consultant and planner responsible for scheduling, customer service, and design of bathrooms and other plumbing installations. The master craftsman had over 40 years of professional experience, while the planner had over 10 years of experience. The employees who used the system on-site were responsible for executing the job on-site and were trained as craftsmen in the specified field. Their professional experience amounted to 7, 10, and 11 years. The master craftsman in the office and two employees (7 and 10 years of professional experience) had previously gained little AR experience through a previous study, but had no experience with the hardware used in this study.

4.2 Procedure

As mentioned above, the study described here is part of a long-term collaboration with the company, which was intended to lead to the permanent use of the system within the company. Therefore, the introduction of the application was planned in advance, and it was ensured that the workers selected for the study would be available during the intended study period. The workers were also informed ahead of the study that they would be provided with the opportunity to use the system for 10 weeks. The procedure of the study can be found in Table 2 and is explained below. When we started the study, we met all participants in the company's office. They were briefed about the study objectives, and consent was obtained for data collection. All participants underwent a brief training to familiarize themselves with the technology. This included the connection process and the use of the system to perform a short task common to their craft sector. The short task involved locating a specific sink model in a showroom with multiple options and inspecting its sealing. Consultants were assigned to the desktop application during the task to familiarize themselves with it, while on-site workers practiced on the HMD device of the system. After the introduction, it was used as a substitute for all conventional communication methods, such as phone calls, in-person discussions, and video calls, allowing employees to become familiar with its operation and explore potential use cases for the first two weeks. Following this initial phase, the system was integrated into daily work practices for an additional eight weeks. During this period, usage was voluntary and situational, and employees were encouraged to use the application whenever they considered it helpful. It should be noted that, due to the timing of the study between October 2024 and January 2025, the study was interrupted for two weeks, as the company went into a holiday break. After the break, system usage continued as before.

Each participant was interviewed weekly during the first two weeks and twice a week thereafter. These interviews lasted between 15 and 30 min each. During the study, video recordings of selected sessions were taken from the consultant's desktop for further analysis. These analyses were initiated during the study to enable reference to specific facts from the events recorded in the interviews. After a total of 10 weeks of use, the study was concluded with final interviews.

Table 2: The procedure of the study.

Time	Activity
Day 1	Introduction to the system and training for all participants at partner's office
After week 1	Interviews with workers and experts
After week 2	Interviews with workers and experts
After week 4	Interviews with workers and experts
After week 6	Interviews with workers and experts
Holidays	Study break
After week 8	Interviews with workers and experts
After week 10	Final interviews

4.3 Data collection

To address the research question, we focused on collecting qualitative data. The core of this approach consisted of in-depth one-on-one interviews with participants about their experiences using technology in daily work. Two researchers conducted the interviews alternately to ensure the variation in perspective.[46] Semi-structured interviews were organized around three themes: **usage, communication, and work processes**. Early interviews began with broad, open-ended questions (for example, Tell me how you experienced the technology), while later sessions were based on video-recorded material. Depending on the participants' responses, the interviews explored one of the three themes while also allowing new aspects to emerge. For **usage**, questions explored how technology supported work, the tasks it was applied to, and the experiences and difficulties of the participants, including potential improvements. The **communication** theme focused on the effectiveness of the instructions and explanations communicated, with participants asked to describe challenging and particularly effective situations. The third theme, **work processes**, addressed how technology was integrated into routines and whether it altered workflows. Participants were also asked about reasons for long-term use. Remote consultants were interviewed separately to assess their satisfaction and provide feedback on practices. In addition to interviews, remote sessions were recorded on video to capture contextual use during the eight-week deployment. Since the system was used spontaneously, video analysis provided otherwise inaccessible insights. The recordings were reviewed using a structured guideline to capture environmental context, tool use, and clarity of communication. Uncertain situations were documented and revisited in interviews for clarification. In addition to these data sources, a logging system was implemented to document the date and duration of each session.

4.4 Analysis

The data collected was analyzed using the affinity diagram method.[47] This method was chosen to systematically organize the findings from the interviews and video recordings, enabling a deeper understanding of the participants' experiences. The Miro board tool was used to facilitate collaborative data analysis between researchers.[48] Three collaborating researchers, with the two researchers who conducted the interviews, performed the analysis. Initially, all researchers agreed on five main categories that served as an initial framework for organizing the data. The categories were defined, including clear criteria for when they should be applied, with an example from the collected data. These categories were derived based on preliminary impressions of the collected material and were informed by the existing literature on HMD-based remote support systems (see Table 3). The data were then classified individually by each researcher. During this phase, interview notes and relevant video excerpts were grouped into clusters of related observations to ensure that each category captured meaningful themes rather than isolated statements. If necessary, the respective researchers defined subcategories during this phase, and the data were clustered accordingly. After the initial categorization was completed, all researchers gathered to compare, refine, and merge their respective groups and subcategories. This phase included discussions to identify inconsistencies, add missing aspects, and adjust the categorization as needed.

Table 3: Summary of categories from the affinity diagram.

Category	Subcategory
Intended and adopted use cases (Section 5.1)	
	Status report and controlling
	Video documentation
	Clarifying unexpected problems
	Approval of completed tasks or projects
	Repairs
Organizational use in daily work (Section 5.2)	
	Organization of application usage
	Integration within existing communication practices
	Inclusion of additional tools
	Inclusion of other employees
Perceived efficiency (Section 5.3)	
	Replacement for on-site coordination
	Increased density of information exchange
	Advantages over other technologies
New demands (Section 5.3)	No subcategories identified
Limits and challenges in usage (Section 5.3)	
	Technological obstacles
	Environmental and infrastructural obstacles
	Content limits

This process was iterative: categories were expanded, merged, or restructured based on emerging insights. Some themes that initially appeared in separate clusters were later linked under broader patterns, reflecting overarching aspects of work adoption, communication efficiency, and usability challenges. Additionally, particular attention was given to the interaction between the various data sources. The interview responses were cross-referenced with the behaviors observed in the video recordings, allowing the validation of self-reported experiences against actual interactions with the system. To account for the frequency of the mentioned aspects, counterbalancing was applied, considering both the absolute number of occurrences and the contextual significance of less frequently mentioned but potentially critical insights. Particular attention was paid to whether the collected data unit was collected during the first two weeks (intensive use as a substitute for all usual communication channels) or in the following eight weeks of free independent use. The data from the eight weeks was weighted substantially higher, especially when it comes to aspects of the change in the organization. This was carried out during the phase where researchers came together to compare and refine their categorizations. This ensured that recurring patterns were recognized without overshadowing nuanced observations that emerged less frequently but carried analytical weight.

Through this methodical structure, a hierarchical representation of the insights was developed, progressing from individual observations to broader thematic clusters. This helped identify key patterns in how participants integrated technology into their daily workflows, the kinds of challenges they encountered, and the communication dynamics that evolved during remote support. The final Affinity Diagram provided a visual representation of relationships between themes, supporting the derivation of key findings that informed the subsequent discussion. The following section will present the key findings derived from this analysis.

5 Results: changing work processes

In total, six interview sessions were conducted with each participant, and almost all attended regularly. Exceptions included an office planner who used the application only occasionally and a field service employee who was interviewed three times due to illness. Five video recordings, with a combined duration of approximately 60 min, were analyzed. An overview of the key aspects is presented in Table 3.

5.1 Evolution of intended and adopted use cases

Table 4 shows which use cases were planned at the beginning of field deployment ('intended') and which spontaneously emerged during the company's own use ('adopted'), as well as their frequency in the first two weeks of the trial phase and in the following eight weeks of everyday use. In total, 17 sessions with the remote support system were logged: seven during the first two weeks of intensive testing and 10 during the free use phase. Due to the two-week company break, this corresponds to an average of two sessions per week. The sessions were evenly divided between the mornings (before 12 p.m.) and the afternoons (after 12 p.m.), with durations ranging from 2 to 16 min and an average of 8 min.

One of the most frequent uses was **status reporting and controlling** (see Table 4). This interactive exchange allowed real-time updates and ensured shared understanding between on-site workers and remote consultants. It was always initiated by the craft master, and although unplanned, it became the most common use case, with a total of six sessions. These typically involved site walkthroughs, such as "So, I am here in the hallway, in front of the bathroom. We have already covered everything here" (ID 3), and clarifying consultants' questions, such as "Is that partition wall also going to be removed?" (ID 1). In some cases, issues emerged that would not have been noticed until much later, such as insufficient spacing between a shower and a sloping wall. The conversations covered a wide range of topics, from bathroom renovations to heating systems, lighting, tiling, and drainage. Status reporting was also used to check materials or revisit issues from the previous day. Before the study, such questions were only briefly addressed during infrequent site visits or evening office meetings, often without resolution due to the absence of a visual reference.

Table 4: Usage frequencies of use cases, categorized as 'intended' and 'adopted'.

Use cases	Intended or adopted	First two weeks	After two weeks testphase
Status reporting and controlling	Adopted	1	5
Video documentation for knowledge management	Adopted	2	5 (embedded in use cases)
Remote support – clarifying unexpected problems	Intended	3	1
Approval of completed tasks or projects	Intended	1	2
Remote support – repairs	Intended	0	2

Another frequently adopted use case was **video documentation for knowledge transfer**. First tested during the test phase, it was later integrated into status reporting and repair sessions. 'Previously, there was no structured documentation of knowledge' (ID 1). With the remote support system, specialized maintenance tasks previously handled by a single expert could be documented from an egocentric perspective. This allowed the manager to observe tasks remotely and created training material for future employees: 'System documentation is used to prepare employees for future tasks' (ID 2). The egocentric perspective was considered a key advantage compared to conventional video recordings. However, the long-term use of these recordings for training could not yet be evaluated during the study.

The intended use case of **clarifying unexpected problems** was observed only rarely. Many potential issues were already resolved during status reporting, and the office planner's experience allowed him to anticipate problem areas early. As a result, this use case decreased while status reporting increased. Examples included ventilation of a heating system and the placement of pipes for an installation.

We also observed the **approval of completed tasks or projects** infrequently. Facilitated discussions on milestones and smaller tasks, and recordings served as documentation and potential proof for warranty claims. Over time, this use case was largely absorbed by status reporting.

Finally, the use case of **repairs** occurred only twice. In one case, minor repairs of luxury washroom fixtures were conducted remotely after an initial on-site inspection. Normally, a second joint visit would have been required, but HolokitX enabled the consultant to guide the employee virtually. The general rarity of repair tasks limited this use case.

5.2 Evolution of organizational practices and system usage over time in daily work

Several observations were made regarding the **organization of application usage** in daily work (see Table 3). In most of the use cases, remote support sessions were planned in the morning before leaving the construction site. After six weeks, including the test phase, the system was considered part of the standard toolkit: "In the morning while packing, HolokitX [the remote support system device] is already in mind: Did you pack it?" (ID 4).

Status reports were typically conducted on arrival at the site after unloading materials and tools. The manager had a dedicated slot for these conversations between 9:30 and 11:00 a.m.: "As soon as you arrive in the morning, there is usually a briefing via HolokitX" (ID 3). Project approvals were scheduled later in the afternoon, while unexpected problems had no fixed scheduling. Status reports were primarily initiated from the office, but employees also called independently when they could not proceed: "Employees call on their own when they need something and really cannot proceed" (ID 1).

Another aspect was the **integration of the application into existing communication practices** (see Table 3). Before the study, phone calls and in-person meetings were the primary methods, supplemented by photos and, rarely, video calls. HolokitX did not replace these practices but was integrated into them: "A new way of communication, not a replacement, but a shift" (ID 1). It was regarded as a supplement that added visual elements: "It [the remote support system] is seen more as a substitute for being on site" (ID 2). After the test phase, phone calls were primarily used for brief inquiries, while HolokitX was employed when a visual reference offered an advantage: "HolokitX is an escalation level when a phone call does not lead to a solution" (ID 3).

The study also showed the integration of **additional tools and employees** (see Table 3). The high audio quality of the smartphone allowed other employees to participate spontaneously or on request: "I explained something on-site even though I wasn't wearing the headset" (ID 5). External employees often took measurements when required, while the HolokitX user continued discussions or tasks in parallel. This division of labor enabled more efficient workflows.

For **video documentation and knowledge transfer**, an alternative approach emerged after the test phase. Instead of the HolokitX user explaining tasks, a more experienced colleague provided verbal instructions while a less experienced worker wore the headset and executed the tasks: "I recorded while my colleague explained to the manager" (ID 4).

5.3 Other side effects: perceived efficiency, added workload, and challenges

Throughout the study, participants emphasized **efficiency** gains. The travel time for site visits was reduced and remote sessions were judged to provide information equivalent to in-person exchanges. The frequency and density of communication increased, leading to more thorough discussions of project details. Compared to phone calls, the participants valued the egocentric perspective, pointing cues, and the ability to keep their hands free while working.

At the same time, employees experienced **new forms of workload**. The higher frequency of communication sometimes disrupted tasks and added stress during busy periods: "When there is a lot of stress on the construction site, the more frequent exchanges with the manager can be exhausting" (ID 4). Although management saw this as beneficial, technicians had to adapt their workflows to accommodate the increased interaction.

Finally, **technical and contextual challenges** limited usage. The optical see-through headset was less effective in dark environments and connectivity issues frequently interrupted sessions in basements where heating systems were installed. Participants also noted clear boundaries: the system was not suitable for direct customer interactions or for coordinating with other trades, such as electricians, where in-person presence remained indispensable.

6 Implications for evolving work practices in small craft businesses

The research question of this study was: How does an AR HMD-based remote support system influence the organization of work under real field conditions over a longer period of time? Overall, the findings show that the introduction of the AR HMD-based remote support system influenced how work was coordinated and how communication routines evolved and shifted over time. Rather than replacing existing structures, the system became embedded in daily practices by adopting new use cases. In this way, the research question is addressed through the adoption of new use cases, the integration into existing communication practices, and the emergence of new forms of work-related strain. This argument is supported by the following three result-based conclusions, each addressing these dimensions of the evolving impact of the system on the organization of work.

The first aspect observed was the adoption of new use cases, such as status reports and video documentation, for structured knowledge transfer. This phenomenon can be classified and discussed under the concept of appropriation.[49] This phenomenon is not new; however, many studies focus primarily on traditional collaborative software platforms.[50–52] In the context of our study with an AR HMD-based remote support system, the appropriation can be described in terms of adopting use cases. Based on the literature in Section 2 and the background in Section 3, we assumed that the primary use case for remote support would be resolving problems on-site spontaneously. This was also confirmed in the first two weeks of our study. However, the primary application of the system was to provide the office planner with a continuous status overview of the construction site. This use case also covered emerging or anticipated issues that were then resolved through remote guidance. The popularity of the status reporting use case can also be understood in terms of organizational structure. The planner's need for control and oversight shaped the way the system was used, with status reports serving as a tool to maintain a constant overview. This mode of use may have limited the natural emergence of problems in the field, as the experienced planner was often able to anticipate and address problems before they fully materialized. While this proactive coordination contributed to efficiency, it also raises questions about how such practices influence autonomy, initiative, and problem ownership in manual work environments. Future studies could investigate this phenomenon and provide design recommendations. With regard to the system used here, the simplicity of use seems to be the main reason why it was possible to focus on the use and potential for further applications. This observed use case can be aligned with collaborative problem-solving, known as "Management by Walking Around" (MBWA),[53] where managers identify issues by actively observing workplace activities. Participants adopted this approach to remote consultation via the application over time. Future research could explore the optimization of remote support systems with features such as persistent annotations, similar to the mechanisms discussed in[54,55] A potential feature is persistent annotations that remain visible in status reports, allowing users to mark areas for later review, as explored in contexts such as[54,55] This type of interaction not only supported individual task appropriation but also naturally involved nearby employees during the virtual MBWA process. Beyond enabling this through sufficient audio quality, the system points to an important design consideration for future MBWA-oriented systems: supporting multiple HMDs to enhance remote collaboration. However, this requires further exploration of multi-user design, especially from the perspective of the remote consultant, as current research on one-to-many remote support systems remains limited e.g., Ref. 56.

The second aspect concerns how the application fits into the existing spectrum of communication channels, ranging from phone calls to site visits. The study suggests that our application was not perceived as a replacement, but as a complementary tool that filled the gap between them. Compared to phone calls, the system offered advantages through visual reference and reduced misunderstandings. However, phone calls remained useful for quick, low-effort inquiries, while physical presence was still required for direct customer interactions, complex coordination with other trades, or highly detailed discussions.

These findings align with previous research, which shows that new communication tools are generally integrated into established workflows rather than replacing existing practices e.g. Ref. 41,57,58. Future research could explore the long-term impact of remote support systems on communication hierarchies in other domains.

This integration was also reflected in changes to daily communication routines. End-of-day visits to the planner's office to discuss on-site issues became less frequent or shorter, likely due to more frequent virtual communication during the day. Since the status report use case enabled real-time problem solving, many issues were resolved earlier. This suggests that remote support systems can improve problem-solving and alter communication timing, reducing the need for traditional end-of-day debriefings.

Real-time discussion of problems can also provide better learning effects and reduce cognitive load compared to memorizing problems until the next day. However, this change may also affect team satisfaction, as informal evening discussions are often important for team cohesion.[59] Both aspects should be examined in future field studies.

The third aspect is that advantages such as the adoption of the application for status reporting, which led to a more frequent and intensive exchange of information, **also introduced a notable drawback** repeatedly mentioned by on-site employees: the perceived increase in workload and stress due to the increased need for coordination with office planners. Employees reported feeling pressured and, to some extent, "observed" during their work. Similar effects have been observed in previous studies on remote monitoring and support technologies in the workplace.[60] The introduction of continuous monitoring in the form of status reporting, while improving efficiency, can also affect workers' sense of autonomy and create additional cognitive demands.[61–63] Future research should further investigate the balance between increased supervision and worker well-being, particularly in contexts where manual work requires a degree of independent problem-solving and self-guided execution.

It is interesting to know that the system is **currently still in use at the company**. After the ten-week analysis period, they continued to use the system for documentation and other purposes mentioned above. After discussing the analysis results with the company, they purchased additional HoloKitX and iPhone devices, and we assisted them in installing and introducing an improved version of the system. Currently, they are using the system on five devices to support their daily work.

7 Limitations

Although this study provides valuable information on the long-term use of an AR HMD-based remote support system in real-world conditions, several limitations must be acknowledged.

First, the study was conducted as a case study within a single small craft business. Although this setting allowed for a rich and contextualized understanding of evolving work practices, it also limits the generalizability of the findings to other domains or organizational structures. Future studies should include multiple companies and sectors to capture a broader spectrum of practices and adoption processes. Second, the number of observed sessions was relatively small, with only 17 documented instances of system use. Although these sessions provided detailed information on how the system was integrated into daily routines, they may not fully represent the complete range of variability in work practices over time. Future research with a larger dataset is needed to validate and expand on these findings.

8 Conclusions

In our study, we investigated how an AR HMD-based remote support system affected the organization of work in a medium-sized craft company in the plumbing, heating, and air conditioning (PHC) sector over a ten-week period of usage. The system enabled them to remotely connect between construction sites and the company office and to share a live view of construction site. While previous research has focused largely on short-term lab studies or technology evaluations of similar systems, only a long-term field deployment offers insights into how such systems are adopted in practice. We have implemented a remote application based on a smartphone-based HMD system with the HolokitX. HolokitX is a head-mounted device that carries a smartphone, serving as an optical see-through AR device. Over the 10 weeks, we observed five workers using the system, which resulted in a shift from spontaneous troubleshooting to structured status reporting and documentation. These new use cases changed how communication and coordination were managed, enabling more continuous exchange but also increasing the perceived need for availability and contributing to the workload. While the system complemented existing communication channels, its long-term use reshaped routines and introduced new demands. These findings underscore the need to investigate the integration of the system over time to inform the design of remote support tools that are effective without creating unintended workload.

Acknowledgments: We would like to thank the German Federal Ministry of Research, Technology and Space for funding the “Minerva” project in the “Handwerk 4.0 digital und innovativ” funding line, funding code 02K20D111, in the context of which this study could be carried out.
Research ethics: The local Institutional Review Board deemed the study exempt from review.
Informed consent: Informed consent was obtained from all individuals included in this study, or their legal guardians or wards.
Author contributions: The author has accepted responsibility for the entire content of this manuscript and approved its submission.
Use of Large Language Models, AI and Machine Learning Tools: None declared.
Conflict of interest: The authors state no conflict of interest.
Research funding: German Federal Ministry of Research, Technology and Space, funding code 02K20D111.
Data availability: The raw data can be obtained on request from the corresponding author.

References

1. Schirner, S.; Hickmann, H.; Malin, L.; Werner, D. *Fachkräfteengpässe in Unternehmen — Fachkräftemangel und Nachwuchsqualifizierung im Handwerk , Studie im Rahmen des Projektes Kompetenzzentrum Fachkräftesicherung (KOFA) in Zusammenarbeit mit dem Bundesministerium für Wirtschaft und Energie (BMWi) und in Zusammenarbeit mit dem Zentralverband des Deutschen Handwerks e.V. (ZDH)*; Kompetenzzentrum Fachkräftesicherung (KOFA) im Auftrag des Bundesministeriums für Wirtschaft und Klimaschutz (BMWK): Köln, 2021.
2. Druta, R.; Druta, C.; Paul, N.; Silea, I. A Review on Methods and Systems for Remote Collaboration. *Appl. Sci.* **2021**, *11* (21), 10035.
3. Olson, G. M.; Olson, J. S. Distance Matters. *Hum. Comput. Interact.* **2000**, *15* (2—3), 139—178.

4. El Kassis, R.; Ayer, S. K.; El Asmar, M.; Tang, P. Discovering Factors that Influence the Use of Augmented Reality for Communication on Active Highway Construction Sites. *Transp. Res. Rec.* **2023**, *2677* (5), 376−389.
5. Kim, S.; Billinghurst, M.; Lee, G. The Effect of Collaboration Styles and View Independence on Video-Mediated Remote Collaboration. *Comput. Support. Coop. Work* **2018**, *27*, 569−607.
6. Palmarini, R.; Erkoyuncu, J. A.; Roy, R.; Torabmostaedi, H. A Systematic Review of Augmented Reality Applications in Maintenance. *Robot. Comput. Integr. Manuf.* **2018**, *49*, 215−228.
7. Leon, E.; Lambrecht, J. Evaluating Digital Work Instructions with Augmented Reality Versus Paper-based Documents for Manual, Object-Specific Repair Tasks in a Case Study with Experienced Workers. *Int. J. Adv. Des. Manuf. Technol.* **2023**, *127* (3), 1859−1871.
8. Hou, L.; Wang, X.; Bernold, L.; Peter, E. D. L. Using Animated Augmented Reality to Cognitively Guide Assembly. *J. Comput. Civ. Eng.* **2013**, *27* (5), 439−451.
9. Ojer, M.; Alvarez, H.; Serrano, I.; Saiz, F. A.; Barandiaran, I.; Aguinaga, D.; Querejeta, L.; Alejandro, D. Projection-Based Augmented Reality Assistance for Manual Electronic Component Assembly Processes. *Appl. Sci.* **2020**, *10* (3), 796.
10. de Moura Costa, G.; Petry, M. R.; Moreira, A. P. Augmented Reality for Human−Robot Collaboration and Cooperation in Industrial Applications: A Systematic Literature Review. *Sensors* **2022**, *22* (7), 2725.
11. Zenni Lodetti, P.; Dos Santos, A. B.; Hattori, L. T.; Carvalho, E. G.; Martins, M. A. I. Mobile Remote Assistance with Augmented Reality Applied in a Power Distribution Utility: A Qualitative Study. In *2022 Intermountain Engineering, Technology and Computing (IETC)*; IEEE, 2022; pp. 1−6.
12. Blattgerste, J.; Renner, P.; Pfeiffer, T. Advantages of Eye-Gaze Over Head-Gaze-Based Selection in Virtual and Augmented Reality Under Varying Field of Views. In *Proceedings of the Workshop on Communication by Gaze Interaction*, 2018; pp. 1−9.
13. del Amo, I. F.; Erkoyuncu, J. A.; Roy, R.; Wilding, S. Augmented Reality in Maintenance: An Information-Centred Design Framework. *Procedia Manuf.* **2018**, *19*, 148−155.
14. Buń, P.; Grajewski, D.; Górski, F. Using Augmented Reality Devices for Remote Support in Manufacturing: A Case Study and Analysis. *Adv. Produc. Eng. Manag.* **2021**, *16*, 4.
15. Ramakrishna, P.; Hassan, E.; Hebbalaguppe, R.; Sharma, M.; Gupta, G.; Vig, L.; Sharma, G.; Shroff, G. An Ar Inspection Framework: Feasibility Study with Multiple Ar Devices. In *2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*; IEEE, 2016; pp. 221−226.
16. Teo, T.; Lee, G. A.; Billinghurst, M.; Adcock, M. Investigating the Use of Different Visual Cues to Improve Social Presence Within a 360 Mixed Reality Remote Collaboration. In *Proceedings of the 17th International Conference on Virtual-Reality Continuum and Its Applications in Industry*, 2019; pp. 1−9.
17. Wang, P.; Bai, X.; Billinghurst, M.; Zhang, S.; Wei, S.; Xu, G.; He, W.; Zhang, X.; Zhang, J. 3DGAM: Using 3D Gesture and CAD Models for Training on Mixed Reality Remote Collaboration. *Multimed. Tool. Appl.* **2021**, *80*, 31059−31084.
18. Carey, M.; Barnett, T.; Broucek, V.; Saunders, A.; Grattidge, D.; Huang, W. Helping Hands: Using Augmented Reality to Provide Remote Guidance to Health Professionals. In *Context Sensitive Health Informatics: Redesigning Healthcare Work*; IOS Press: Amsterdam, 2017; pp 57−62.
19. Wang, S.; Parsons, M.; Stone-McLean, J.; Rogers, P.; Boyd, S.; Hoover, K.; Meruvia-Pastor, O.; Gong, M.; Smith, A. Augmented Reality as a Telemedicine Platform for Remote Procedural Training. *Sensors* **2017**, *17* (10), 2294.
20. Zhang, X.; Bai, X.; Zhang, S.; He, W.; Wang, S.; Yan, Y.; Yu, Q.; Liu, L. A Novel MR Remote Collaboration System Using 3D Spatial Area Cue and Visual Notification. *J. Manuf. Syst.* **2023**, *67*, 389−409.
21. El Kassis, R.; Ayer, S. K.; Asmar, M. E. L. Augmented Reality Applications for Synchronized Communication in Construction: A Review of Challenges and Opportunities. *Appl. Sci.* **2023**, *13* (13), 7614.
22. Gutzmann, J. C.; Dossena, G. L.; Prilla, M. Augmented Reality Glasses for the Crafts Sector-Acceptance Factors for Tasks with Highly Variable Workspaces. In *Proceedings of Mensch und Computer 2024*, 2024; pp. 381−385.
23. Obermair, F.; Althaler, J.; Seiler, U.; Zeilinger, P.; Lechner, A.; Pfaffeneder, L.; Richter, M.; Wolfartsberger, J. Maintenance with Augmented Reality Remote Support in Comparison to Paper-based Instructions: Experiment and Analysis. In *2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA)*; IEEE, 2020; pp. 942−947.
24. Ciprian Firu, A.; Ion Tapîrdea, A.; Feier, A. I.; Drăghici, G. Virtual Reality in the Automotive Field in Industry 4.0. *Mater. Today: Proc.* **2021**, *45*, 4177−4182.
25. Silva, J.; Nogueira, P.; Martins, P.; Vaz, P.; Abrantes, J. Exploring the Potential of Mixed Reality as a Support Tool for Industrial Training and Production Processes: A Case Study Utilizing Microsoft Hololens. In *International Conference on Disruptive Technologies, Tech Ethics and Artificial Intelligence*; Springer, 2023; pp. 187−196.
26. Heiser, J.; Tversky, B.; Silverman, M. Sketches for and from Collaboration. *Visual Spatial Reas. Design III* **2004**, *3*, 69−78.
27. Leonard, T. *Toward a Cognitive Semantics: Concept Structuring Systems*; MIT Press: Cambridge, Vol. 1, 2000.
28. Kraut, R. E.; Fussell, S. R.; Siegel, J. Visual Information as a Conversational Resource in Collaborative Physical Tasks. *Hum. Comput. Interact.* **2003**, *18* (1-2), 13−49.
29. Oda, O.; Elvezio, C.; Sukan, M.; Feiner, S.; Tversky, B. Virtual Replicas for Remote Assistance in Virtual and Augmented Reality. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, 2015; pp. 405−415.
30. Osmers, N.; Prilla, M.; Blunk, O.; Brown, G. G.; Janßen, M.; Kahrl, N. The Role of Social Presence for Cooperation in Augmented Reality on Head Mounted Devices: A Literature Review. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021; pp. 1−17.
31. Piumsomboon, T.; Lee, G. A.; Hart, J. D.; Ens, B.; Lindeman, R. W.; Thomas, B. H.; Billinghurst, M. Mini-Me: An Adaptive Avatar for Mixed Reality Remote Collaboration. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 2018; pp. 1−13.
32. Kim, S.; Lee, G.; Billinghurst, M.; Huang, W. The Combination of Visual Communication Cues in Mixed Reality Remote Collaboration. *J. Multimodal User Interfaces* **2020**, *14*, 321−335.
33. Kim, S.; Lee, G.; Huang, W.; Kim, H.; Woo, W.; Billinghurst, M. Evaluating the Combination of Visual Communication Cues for HMD-based Mixed Reality Remote Collaboration. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 2019; pp. 1−13.

34. Zbigniew, J. L. Sensory and Information Inputs Overload: Behavioral Effects. *Compr. Psychiatry* **1975**, *16*, 199−221.
35. Wang, Z.; Bai, X.; Zhang, S.; He, W.; Wang, Y.; Han, D.; Wei, S.; Wei, B.; Chen, C. M-AR: A Visual Representation of Manual Operation Precision in AR Assembly. *Int. J. Hum. Comput. Interact.* **2021**, *37* (19), 1799−1814.
36. de Souza Cardoso, L. F.; Mariano, F. C. M. Q.; Zorzal, E. R. Mobile Augmented Reality to Support Fuselage Assembly. *Comput. Ind. Eng.* **2020**, *148*, 106712.
37. Kim, M.; Lee, J. Y. Touch and Hand Gesture-Based Interactions for Directly Manipulating 3D Virtual Objects in Mobile Augmented Reality. *Multimed. Tool. Appl.* **2016**, *75*, 16529−16550.
38. Büttner, S.; Prilla, M.; Röcker, C. Augmented Reality Training for Industrial Assembly work-are Projection-based Ar Assistive Systems an Appropriate Tool for Assembly Training? In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 2020; pp. 1−12.
39. Büttner, S.; Sand, O.; Röcker, C. Exploring Design Opportunities for Intelligent Worker Assistance: A New Approach Using Projetion-Based AR and a Novel Hand-Tracking Algorithm. In *Ambient Intelligence: 13th European Conference, AmI 2017, Malaga, Spain, April 26−28, 2017, Proceedings 13*; Springer, 2017; pp. 33−45.
40. Johnson, S.; Gibson, M.; Mutlu, B. Handheld or Handsfree? Remote Collaboration Via Lightweight Head-Mounted Displays and Handheld Devices. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 2015; pp. 1825−1836.
41. Pejoska-Laajola, J.; Reponen, S.; Virnes, M.; Leinonen, T. Mobile Augmented Communication for Remote Collaboration in a Physical Work Context. *Australas. J. Educ. Technol.* **2017**, *33*, 6.
42. Schmidt, K.; Bannon, L. Taking CSCW Seriously: Supporting Articulation Work. *Comput. Support. Coop. Work* **1992**, *1*, 7−40.
43. Holo Interactive, Inc. Holokit X — Stereoscopic Augmented Reality Headset for Iphone, 2024. https://holokit.io/products/holokit- (accessed 2024-07-11).
44. Hu, B. A.; Zhang, Y.; Elan Tao, Y.; Yu, T. Holokit: Demonstrating an Open-Source Smartphone-based Mixed Reality Headset for Mixed Reality Design Education. In *Companion of the 2024 on ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 2024; pp. 205−209.
45. Apple Inc. Apple iPhone 15 Pro Tech Specs, 2023. https://support.apple.com/en-us/111829 (accessed 2025-03-10).
46. Matteson, S. M.; Lincoln, Y. S. Using Multiple Interviewers in Qualitative Research Studies: the Influence of Ethic of Care Behaviors in Research Interview Settings. *Qual. Inq.* **2009**, *15* (4), 659−674.
47. Rogers, Y.; Preece, J.; Sharp, H. *Interaction Design: Beyond Human-Computer Interaction*, 3rd ed.; John Wiley & Sons: Hoboken, New Jersey, 2019.
48. 2023. Miro Board. Online Collaboration Software Tool. https://miro.com/ (accessed 2025-03-7).
49. Pipek, V. *From Tailoring to Appropriation Support: Negotiating Groupware Usage Faculty of Science*. Ph.D. Dissertation; Department of Information Processing Science (ACTA UNIVERSITATIS OULUENSIS A 430), University of Oulu: Oulu, Finland, 2005.
50. Draxler, S.; Stevens, G. Supporting the Collaborative Appropriation of an Open Software Ecosystem. *Comput. Support. Coop. Work* **2011**, *20*, 403−448.
51. Hwang, A. S.; Jackson, P.; Sixsmith, A.; Nygård, L.; Astell, A.; Truong, K. N.; Mihailidis, A. Exploring How Persons with Dementia and Care Partners Collaboratively Appropriate Information and Communication Technologies. *ACM Trans. Comput. Hum. Interact.* **2020**, *27* (6), 1−38.
52. Pablo-Alejandro, Q. Cultivating Practice & Shepherding Technology Use: Supporting Appropriation Among Unanticipated Users. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 2014; pp. 305−318.
53. Peters, T. J.; Waterman, R. H. In Search of Excellence. *Nurs. Adm. Q.* **1984**, *8* (3), 85−86.
54. Marques, B.; Silva, S.; Rocha, A.; Dias, P.; Sousa Santos, B. Remote Asynchronous Collaboration in Maintenance Scenarios Using Augmented Reality and Annotations. In *2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*; IEEE, 2021; pp. 567−568.
55. Irlitti, A.; Smith, R. T.; Von Itzstein, S.; Billinghurst, M.; Thomas, B. H. Challenges for Asynchronous Collaboration in Augmented Reality. In *2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*; IEEE, 2016; pp. 31−35.
56. Lee, G.; Kang, H. Y.; Lee, J. M.; Han, J. H. A User Study on View-Sharing Techniques for one-to-many Mixed Reality Collaborations. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*; IEEE: Atlanta, GA, USA, 2020; pp. 343−352.
57. Bresnahan, T. F.; Brynjolfsson, E.; Hitt, L. M. Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence. *Q. J. Econ.* **2002**, *117* (1), 339−376.
58. Schiavone, F.; MacVaugh, J. A User-based Perspective on Limits to the Adoption of New Technology. *Int. J. Technoentrepreneursh.* **2009**, *2* (2), 99−114.
59. Kraut, R. E.; Fish, R. S.; Root, R. W.; Chalfonte, B. L. Informal Communication in Organizations: Form, Function, and Technology. In *Human Reactions to Technology: Claremont Symposium on Applied Social Psychology*, Vol. *145*, 1990; p 199.
60. Janßen, M.; Prilla, M. Investigating the Use of Head Mounted Devices for Remote Cooperation and Guidance During the Treatment of Wounds. In *Proceedings of the ACM on Human-Computer Interaction*; GROUP, Vol. *6*, 2022; pp. 1−27.
61. Fleischer, J.; Wanckel, C. Job Satisfaction and the Digital Transformation of the Public Sector: The Mediating Role of Job Autonomy. *Rev. Publ. Person. Adm.* **2024**, *44* (3), 431−452.
62. Gerten, E.; Beckmann, M.; Bellmann, L. Controlling Working Crowds: The Impact of Digitalization on Worker Autonomy and Monitoring Across Hierarchical Levels. *Jahrb. Natl. Stat.* **2019**, *239* (3), 441−481.
63. Karimikia, H.; Singh, H.; Joseph, D. Negative Outcomes of ICT Use at Work: Meta-Analytic Evidence and the Role of Job Autonomy. *Internet Res.* **2021**, *31* (1), 159−190.

Supplementary Material: This article contains supplementary material (https://doi.org/10.1515/icom-2025-0034).