

Equipment Teleoperation and Its Impacts on Future Worker and Workforce in Construction: Semi-Structured Interviews

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ABSTRACT

Heavy equipment is crucial for construction work and depends on skilled operators to ensure productivity and safety. The inclusion of robotics and its applications, particularly teleoperation, have the potential to revolutionize the construction industry. Via semi-structured interviews, this research explores the current practice of equipment automation technology adoption, potential needs, and benefits on equipment teleoperation, as well as its impacts on workforce diversity. The study highlights the significance of equipment teleoperation on increasing work safety and worker comfort, as well as its importance in improving workforce diversity and reducing labor shortage. With technology limitations being identified as a main barrier to practical adoption, the research also emphasizes the need for user-inspired and worker-centered teleoperation and automation technologies to facilitate implementation in practice. The study contributes to the development of future teleoperation technology by identifying the needs of construction professionals and the potential impacts on both construction work and workers.

INTRODUCTION

The construction industry is a critical sector of the global economy, playing a vital role in buildings and infrastructure that support various industries. However, the construction industry faces several challenges that impact its performance, including labor shortages, aging workforce, low productivity levels, and workplace safety concerns, etc. (Bock 2015). Construction automation and robotics have emerged as a potential solution to address these challenges. (Everett and Saito 1994) suggested that incorporating construction automation and robotics will undoubtedly enhance the efficiency of construction projects. Akinradewo et al. (2018) further stated that utilizing robotics in construction has proven to be advantageous in terms of improving productivity, reducing costs, resolving labor-related problems, and timely project delivery. Similarly, (Bogue 2018) highlighted several benefits of adopting robotics in construction, including improved safety and productivity, enhanced quality, greater reliability, and faster and more consistent performance compared to human labor.

Although robotics and automation have the potential to revolutionize the construction industry, construction is still widely recognized as one of the least digitized sectors globally (Young et al. 2021). Many construction companies are still reluctant to its adoption in their operations due to multiple factors, including high initial cost (Mahbub 2008, Bogue 2018), incompatibility of the technologies (Mahbub 2008), the nature of the construction industry (Mahbub 2008, Bogue 2018, Yahya et al. 2019), technological usability (Balaguer 2004, Mahbub 2008, Yahya et al. 2019), technologies adoption by workers (Mahbub 2008, Bogue 2018), resources (Mahbub 2008, Yahya et al. 2019) and retraining of workers (Yahya et al. 2019). Daniel and Holt (2020) classified the obstacles to the implementation of automation and robotics technologies into three main categories: cultural barriers, technical barriers, and team-related barriers. Amaifeobu et al. (2023) further classified the obstacles to the implementation of robotic technologies in the construction industry into seven distinct categories and classified barriers are human, site/environment, finance, technical, material/market, government/ethics, and cultural-related barriers.

Teleoperation systems, as one of the robotic applications, was expected to be widely accepted and implemented in the construction industry due to its ability of seamless operation of the machine from a remote location. For instance, companies, such as Husqvarna and Brokk, have successfully implemented teleoperated demolition machines in unstructured and hazardous workspaces (Osumi 2014). However, controlling machines through teleoperation is still rudimentary in the construction industry, with operators using levers to control each joint of the machine directly. Since construction machines possess multiple degrees of freedom to expand their reachability, operators require months of training to gain familiarity with the control system. Even after the extensive training, work performance cannot always be guaranteed and manual labor continues to be the preferred option on construction sites (Motzko et al. 2016). Lee et al. (2022) conducted a systematic review to identify challenges, tasks, and opportunities of excavator teleoperation and discuss the future directions in terms of technology development to enable human-in-the-loop automation technologies.

Despite the extensive studies on technology adoption in construction practice, most existing research is related to general technologies on construction automation and robotics, with an emphasis on identifying barriers for practical implementation. Significantly less efforts have been devoted to equipment teleoperation, which might largely change the way workers interact and collaborate with each other and bring new opportunities and challenges via remote operation. Furthermore, there is a lack of knowledge on how technology, especially equipment teleoperation, could benefit construction work and workforce from practical perspectives. Such knowledge is critical as it drives the motivation of practical implementation and points the future direction for user-inspired technology development.

More importantly, as a male-dominated industry, women workers have been traditionally underrepresented due to various reasons, such as physically challenging work environment (Perrenoud et al. 2020), male-oriented training program (Dainty and Lingard 2006), hostile work environment and discrimination (Sunindijo and Kamardeen 2017, Mariam et al. 2021, Pamidimukkala and Kermanshachi 2023). On the other hand, women workers are recognized with multiple advantages and merits, including innovation, teamwork, flexibility/adaptability, quick learning, motivating others, etc. (Arditi and Balci 2009), which are significant to the construction industry, especially in the context of industry-wide labor shortage and labor aging. However, there remains a lack of knowledge on how future technology could help attract more diverse talents into the industry and enhance workforce diversity, thus ensuring the sustainable growth of the industry.

To this end, this research aims to explore the current practice of equipment automation technology adoption, potential needs and benefits on equipment teleoperation, as well as its impacts on workforce diversity, via semi-structure interviews.

RESEARCH METHODOLOGY

Semi-structured interviews were conducted with construction professionals to collect their insights and perspectives. In semi-structured interviews, questions are somewhat structured but still allow participants the freedom to introduce new ideas during the interview. This approach involves designing open-ended questions or topics before data collection, which introduces some flexibility to the study (Trinh 1992). Because of this flexibility, semi-structured interviews are considered one of the most effective and convenient ways to collect qualitative scientific data (Kvale 1994). Based on the objective of this research, the interview questions are designed to cover three topics: 1) The current practice of equipment automation technology in construction industry, where the types of technology adopted by companies, the impact of technology on work performance, practice for workforce training, and the feedback from workers on the use of technology were asked. 2) Impacts of equipment teleoperation on future construction work, where application scenarios, potential benefits, as well as practical needs and requirements for teleoperation technology were asked. Furthermore, the current barriers and strategies to promote future adoption were also discussed. 3) Impacts of teleoperation technology on workforce diversity in construction, with discussion on current states of women in construction and the potential role of technology in improving diversity on construction sites.

Seven participants were selected with different roles and work experience in different types of companies (see Table 1). The interviews were conducted in person or virtually, depending on the participants' availability and preferences. The interviews were recorded and transcribed to facilitate data analysis. The data were analyzed using thematic analysis, a qualitative method for identifying patterns and themes in data. The transcripts were reviewed multiple times and verified by two researchers to identify key themes and patterns related to the research questions. The data was then coded and grouped into different categories based on these themes.

Table 1: Details of interviewees

ID	Gender	Role	Years of experience	Company type	Number of employees
1	Male	Director of construction technology	30+	General contractor (GC) – Heavy civil projects	2000
2	Female	Project manager	7.5	Trade contractor - manufacturing, pre-fabrication	250-300
3	Female	Quality manager	8	GC - commercial building	250-300
4	Male	Division manager/vice president	25	GC - commercial building	5500
5	Male	Vice president of strategy and innovation	15	GC - commercial building	500
6	Male	Manager of virtual design & construction	5	GC	3000
7	Female	Owner and president	9	Construction service	15

RESULTS AND DISCUSSIONS

Current Practice of Equipment Automation Technology in Construction Industry

Adopted Technologies and Their Benefits to Construction Work. The construction industry is progressively incorporating various technologies to enhance construction operations. It was found that the adopted technologies largely depend on the type of construction company as well as the type of projects each company specializes in. The direct adoption of equipment automation technology is still limited to intelligent equipment assistance systems instead of more advanced equipment teleoperation and semi-automated machines. With more heavy civil projects, Interviewee 1 mentioned that their company has adopted intelligent machine control system on earthwork as well as segment erector to help erect pre-cast segments in roadway construction. It was highlighted that the use of such technologies improved productivity, resulting in a large amount of early completion bonus for the project. Furthermore, Interviewee 1 also mentioned that the introduction of equipment automation technology effectively reduced the requirements of skilled operators. In addition, Interviewee 2 mentioned that they have systems with digital drawings and designs embedded within the machine, which could assist operation in steel fabrication. It has been found to improve productivity and accuracy, and reduce waste and costs.

The other five companies, on the other hand, have not directly adopted equipment automation-related technologies. One reason, as highlighted by one interviewee, is that most general contractors in building sectors rely on subcontractors for site work, and do not invest much in heavy equipment. However, all general contractors in buildings (ID 3-6) mentioned that they have implemented drones on jobsite for a variety of applications, including site survey and inspection, reality capture, progress tracking, and quality control. All of them agreed that it is beneficial for project coordination and management with great visualization capabilities and can be used for rapid measurement and quantity survey with less human efforts required. Other technologies mentioned in the interviews focus on software for data and project management, which is out of scope of this study and is not further discussed herein.

Typical Procedure for Technology Adoption. Through the interviews, the participants highlighted the importance of having a clear process for adopting and implementing new technology. The overall adoption process could be classified into two categories, i.e., the bottom-up approach and top-down approach. Two companies adopted the bottom-up approach, where pain points are first identified for the current work processes, then appropriate technologies are selected as potential solutions. The technologies are usually tested in pilot projects before full implementation throughout the company. Another four companies adopted the top-down approach, where the administration and/or a dedicated department for innovation identifies potential technologies to use and advocate to other departments for test and implementation. Standardization was also emphasized as a crucial aspect of technology adoption. One interviewee revealed that they use standardized processes for each tool they use, with a designated person responsible for standardizing the process. For instance, they have a drone operation manager to standardize drone usage. This approach ensures that everyone follows the same protocols, leading to enhanced efficiency and safety.

Overall, the interviewees emphasized the importance of identifying pain points, having a department to lead adoption, standardizing processes, and testing and piloting technology before implementing it throughout in the company. These insights provide a valuable perspective on the

adoption of automation technology in the construction industry and can serve as a guide for companies looking to implement new automation technology in their operations.

Required Skills and Workforce Training. Depending on the types of technologies adopted, the required skills and training may vary. For instance, with the intelligent equipment assistant system adopted in Company 1, limited training with no specialized skills is needed as the process is designed to be highly automated to assist worker operation. However, another interviewee indicated that training is needed to access and operate the machine in their company. For those companies that adopt drones, training and pilot license are required for workers to operate drones. In terms of training strategies, companies tend to provide training for project managers first, and then extend it to employees who will be involved in technology adoption. For instance, one interviewee mentioned that their company focuses on providing necessary training to individuals involved in the technology selection process, starting with the managers. After selecting the technology, two or three project managers are trained, who then develop the standards for the specific project. After that, workers would receive training at the job site. Another interviewee also mentioned that they have subject matter experts to provide guidance on the use of the technology and assist in obtaining licenses. It was also mentioned that most previous technologies introduced to the industry require specialized skills and trainings, while only until recently, technology becomes more intuitive and easier to use. These findings suggest that companies recognize the importance of investing in training to ensure successful adoption of new technologies in the construction industry.

Feedback from Workers. In terms of workers' feedback on the adopted technologies, both positive and negative responses were brought up. For the first two companies that directly adopt equipment-related technologies, the feedback is quite positive. Workers prefer to have the technology and appreciate the improved efficiency introduced by the technology. The feedback of drones is also overall positive, and users found it can save much time for site survey and inspection, and it is very helpful for visualization and coordination. On the other hand, other interviewees raised some concerns during the adoption process. For instance, one interviewee mentioned less positive feedback on other robotic technologies they have tested out but did not adopt eventually, as it required extensive preparatory work. Another two interviewees also mentioned the reluctance to change and skepticism about new technology, especially in the beginning phase and for senior workers, and safety is another concern for workers. However, they also mentioned that workers finally accepted the technology and emphasized the importance of clear communication regarding the purpose and functions of the new technology. The interviews also revealed that workers are overall open to new technologies, if they are proved to be helpful, efficient, and can save their time and effort, with safety concerns addressed. The question posed to several professionals in the construction industry was their feedback on adopting a new technology from workers. The answers varied, with some expressing those senior workers had a generation gap in accepting new technology due to issues with site connectivity, remote locations, and the lack of internet access.

Impacts of Equipment Teleoperation on Future Construction Work

Application Scenarios of Equipment Teleoperation. When discussing the vision of future equipment teleoperation, all interviewees strongly agreed that teleoperation technology has the potential to enhance a variety of construction tasks and scenarios. Earthwork (e.g., mass excavation, grading) and roadwork (e.g., compaction) were mentioned by most of the interviewees,

as the extensive manual work and high precision required in the current practice. Crane operation including heavy lift tasks was another application that receives broad interest considering the potential safety hazards and difficulty for workers to perform. Other applications, such as masonry work and drywall framing were also mentioned that could benefit from teleoperation. In addition to the above general applications, detailed scenarios were also discussed, which could be valuable for future technology development. For instance, in earthwork task, future teleoperation could be more beneficial by allowing one operator to control multiple machines (e.g., trucks) to transport materials between site and borrow pit, which could further release the challenge of operator shortage. Moreover, it was acknowledged that although many ongoing efforts have been dedicated to developing fully automated equipment, teleoperation could benefit as a transition to full automation, and provide additional safety and flexibility in human control for the complex and dynamic construction work.

Potential Benefits to Workers. Improved safety has been identified as a primary benefit of teleoperation by most interviewees, as equipment teleoperation is expected to reduce the exposure of workers to hazardous environments. The interviewees also emphasized the importance of enhancing workers' comfort to increase productivity and job satisfaction. They explained that the work conditions of equipment operators are usually challenging, including extreme hot and/or cold, windy, and physically demanding conditions. Moreover, most roads on construction projects are rough with heavy vibration. Such conditions increase workers' experiences of discomfort and fatigue, which can impact workers' performance and well-being. Teleoperation is more flexible and allows operators to control the equipment in more comfortable and controlled environments (e.g., office, home).

Many interviewees highlighted the great potential for teleoperation to create more opportunities for people who could not do construction work before, such as physically challenged individuals. Furthermore, with better work environment and less physical requirements attributed to the use of new technologies, teleoperation could attract more people who might not tend to choose construction as their careers, such as younger generations and women, thus relieving labor shortage. However, one of the interviewees also raised concerns regarding mental stress associated with operating equipment remotely, as well as the need for coordination and effective communication. This also points out some practical needs and future direction of technology development, which will be discussed in later sections.

Practical Needs and Requirements for Teleoperation Technology. Numerous studies (Dimitropoulos et al. 2020, Liu et al. 2021), have explored diverse teleoperation technologies for construction equipment. Practitioners emphasize that vital teleoperation systems must include real-time feedback for situational awareness, intuitive control interface, safe and trustworthy mechanisms. In current practice of equipment operation, situational awareness is one of the main challenges, as equipment operators usually have a limited view of surroundings. Despite integrating sensors and cameras, spotters are often needed for safety. Thus, prioritizing real-time visual feedback with comprehensive environmental coverage is the key.

It is also suggested that visual cameras should be embedded with advanced AI models, such as automatic object recognition and proximity detection, to further assist smooth teleoperation and reduce worker's mental load. Additionally, the control interface should be intuitive and user-friendly to allow non-experts to use it without extensive training. Safety was also a primary

concern among the interviewees, who called for the implementation of safety protocols, including the automatic shutdown of machines in the case of unsafe conditions or abnormal situations.

Current Barriers for Adoption of Teleoperation Technology. The interviewees identified two main categories of barriers to the adoption of teleoperation in construction: human factors and technical limitations. From a human perspective, the interviewees emphasized the importance of willingness to accept new technology among both workers and leaders. The conservative nature of construction industry was highlighted during the interviews which is generally resistant to change and often skeptical about the reliability of new technologies, leading to a slow adoption process. Furthermore, the slow learning curve associated with teleoperation, particularly for older workers, was also highlighted. One of the interviewees highlighted the potential challenges to introduce new technologies and launch their training with the existing unions. On the technical side, interviewees highlighted the lack of real-time feedback and real-time communication between different systems as a major barrier to perform constructions tasks with a new technology. In addition, it was pointed out that the current technology is not mature enough to complete complex tasks without the need for extensive human involvement, which hinders the motivation of adoption of a new technology. Other barriers include the initial capital investment required for teleoperation, ensuring the technology's safety for use, and the need for education and raising awareness among workers and administrators. Addressing these barriers will be crucial for the successful adoption and integration of teleoperation in the construction industry.

Strategies to Promote Future Adoption. The interviewees provided some suggestions for minimizing the technical and human-related barriers to teleoperation adoption in construction. The interviewees suggested that technical barriers could be minimized by the adoption of 5G technology, which can be seen as a potential solution to improve communication and connection on construction sites. Furthermore, developing more secure technology and having backup plans in case of technological failure were also suggested. To minimize the human-related barriers, the interviewees suggested establishing open communication channels and seeking feedback to understand the leadership and workers' perspectives. To convince leaders, it can be beneficial to organize meetings with them and allow them to experience the tools or the new technology by themselves. To convince workers, conducting career fairs and training can encourage them to learn new skills and become more interested in using technology. One of the interviewees suggested that the human-related barriers can be minimized by demonstrating the safety benefits of new technology as safety is always the primary concern for both workers and leaders in construction. It was also interesting that the interviewees expect large companies to adopt innovations at an early stage, and establish some benchmark and best practices for the entire industry.

Impacts of Teleoperation Technology on Workforce Diversity in Construction

Current Status of Women in Construction. The interviewees highlighted the meager representation of women in construction industry, with certain interviewees indicating the absence of female operators, while others reported less than 5% female trade workers. The overarching pattern deduced from the responses suggests that women remain underrepresented in the construction sector. The main reason for this underrepresentation, as highlighted during the interviews, is the nature of construction work, which tends to be physically demanding and often in harsh work conditions. This has led to a perception that construction is a male-dominated industry. Women are more likely to apply for administrative or office-related positions rather than construction jobs that require heavy lifting or manual labor. Other reasons include limited

awareness about opportunities for women, insufficient outreach activities, and woman's lack of exposure to the industry.

Impacts of Teleoperation on Workforce Diversity. The interviewees agreed that teleoperation can help the construction industry achieve a more diverse workforce. As labor shortages increase, hiring more women in the construction industry becomes inevitable. Teleoperation technology can make physically demanding tasks less strenuous, which can help break down gender barriers and create more opportunities for women to enter the construction industry. The flexibility in terms of workplaces would be another reason that can attract more women workers. In addition to gender diversity, teleoperation can provide more flexibility for older workers to continue working, allowing them to pass on knowledge to younger generations.

CONCLUSION

This study conducted semi-structured interviews with seven practitioners in the construction industry and identified 1) the current practice of equipment automation technology in construction industry, 2) the impacts of equipment teleoperation on future construction work, and 3) the impacts of teleoperation technology on workforce diversity in construction. Through the interviews, it was found that the construction industry is progressively incorporating various technologies to enhance construction operations. However, the current adopted technologies are mainly constraints to intelligent assistance systems that are integrated with conventional equipment and drones for general project monitoring and management. Considering equipment teleoperation as a future technology that could potentially revolutionize construction sites, all interviewees strongly agree that it could be beneficial to various applications, especially in earthwork, roadwork, and crane operation. By allowing remote equipment control, it could improve safety and worker comforts. Furthermore, with new technology, teleoperation could improve work environment and mitigate physical requirements, and consequently attract more people who might not tend to choose construction as their careers, such as physically challenged people, younger generations, and women. Specifically, in the interviews, the current lack of representation of women in equipment teleoperation and trade work was a prominent topic of discussion, and the importance of teleoperation technology in increasing workforce diversity and reducing labor shortage was highlighted.

Regarding the barriers of teleoperation adoption, in addition to the human factors (e.g., conservative nature of the industry) that are common to all technology adoption in construction, the limitations of technology have been identified as another main reason. Real-time feedback for better situational awareness, intuitive and user-friendly control interface, safe and trustworthy mechanisms, and more reliable performance in complex tasks, have been emphasized as essential needs and requirements for future adoption. To promote the adoption of teleoperation and improve productivity and safety in construction, several strategies were suggested. The study recommends establishing open communication channels with workers, emphasizing the safety and cost-efficiency benefits of new technology, developing more secure technology with backup plans, and providing training and education for workers.

To address the underrepresentation of women in construction, companies should promote leadership roles for women, increase woman's exposure to the industry through internships and outreach activities, and create a comfortable and inclusive work environment for construction workers regardless of their gender and race. Teleoperation and other technologies have the

potential to improve diversity on job sites, particularly for machine operators, and can create more entry-level opportunities for women while reducing the physical requirements of certain tasks. Overall, the adoption of teleoperation technology in construction requires a significant investment of time and resources, proper education and awareness, and a change in mindset towards technology. By addressing the barriers identified and implementing the suggested strategies, the construction industry can improve productivity, safety, and workforce diversity.

As an ongoing study, a limited number of interviews, with most interviewees being managers, were conducted. The findings could provide some valuable insights on the potential impacts of equipment teleoperation on future construction work and workforce from practical perspectives. Based on these preliminary findings, the research team is currently conducting large-scale survey studies to collect feedback from more diverse population (including frontline workers) and will obtain quantitative data based on the findings and insights generated from the interviews. It is expected with more responses from construction professionals with diverse backgrounds, more representative and quantitative findings will be derived in future study, which could contribute to the future technology development and promotion of practical implementation.

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