Workers' Perception and Acceptance of Collaborative Robots in Construction Using the Technology Acceptance Model

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ABSTRACT

The adoption of collaborative robots in construction is one major step toward achieving intelligent and automated construction to improve productivity and safety. Many construction tasks require physical human-robot collaboration (HRC), where workers and robots collaborate side-by-side in a common workspace. Such close-distance interactions may cause worker resistance, hindering successful HRC implementation. This study aims to understand workers' acceptance of HRC via experimental study. Experiments on human-robot collaborative wood assembly were performed, where participants were tasked to connect wood pieces, and a robot was programmed to place pieces according to design. Two designs with different complexity levels were given. Surveys adapted from Technology Acceptance Model were collected before and after the experiments to investigate individual perceptions and acceptance of robots. The results show that gender and complexity of tasks have a great impact on the acceptance of robots. Finally, the implications for the future development of HRC in construction were discussed.

INTRODUCTION

The construction industry accounts for a large portion of the economy in the U.S. – ranking 5th in U.S. GDP contribution among 22 industry groups in 2020 (*U.S. Bureau of Economic Analysis (BEA)*, 2020). Despite the significant economic impact of the construction industry, construction has been suffering from safety issues over the years (Lingard, 2013). The construction industry ranked 1st in fatal occupational injuries, with around 20% of the total worker fatalities (*National Census of Fatal Occupational Injuries*, 2019). To address these issues, robotics, and automation have been applied to improve safety and productivity in the construction industry (Bock, 2015). Various task-oriented robots have been applied to different construction tasks, such as brick-laying robots, material-delivering robots, and painting robots (Liang et al., 2021). In addition, to balance automation and flexibility for the dynamic working environment, collaborative robots are emerging for human-robot collaboration (HRC) in construction tasks (Liang et al., 2021).

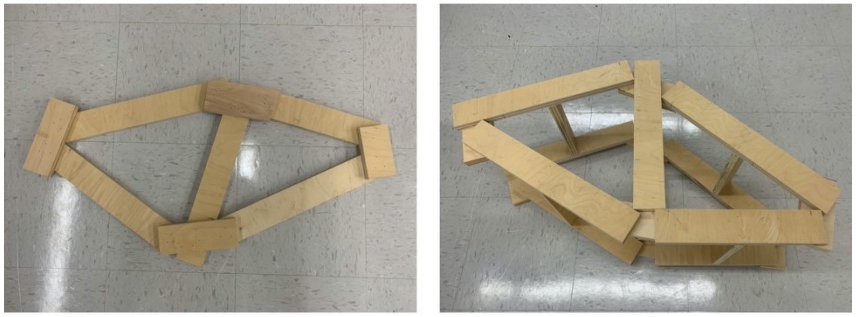
Despite the considerable attention on HRC, its implementation from research to real-world application is encountering numerous limitations (Bröhl et al., 2016). To facilitate the successful implementation of HRC, previous studies focused on exploring factors that prevent the adoption of collaborative robots in companies and organization (Davila Delgado et al., 2019). Law et al. (2022) identified potential barrier (e.g., high investment) of adopting construction robots from multiple stakeholders' perspective, including managers, owners, and directors in construction companies. However, to ensure successful HRC implementation in construction tasks, it is crucial to gather the perspectives and apprehensions of construction workers, who are the primary individuals directly interacting with collaborative robots.

The technology acceptance model (TAM) has been used as a reliable framework for anticipating and explaining the degree of acceptance towards information technology. The TAM proposes that perceived ease of use (i.e., perception of the easiness level that a technology requires) and perceived usefulness (i.e., the expectation of a technology that can improve task performance) would be two determinants of the intention to use a technology (Davis, 1989). To help understand and explain the acceptance of technology beyond the potential usage, Venkatesh (2000) extended the TAM by adding four personnel anchoring factors and two adjustment factors to perceived ease of use. This model was further accommodated with social and other interventions for predicting perceived ease of use and perceived usefulness (Venkatesh & Bala, 2008). Marangunić & Granić (2015) investigated 85 scientific publications on the TAM. This literature review concludes that TAM has broad applicability to numerous technologies and that additional variables like cultural difference and gender difference should be considered in TAM. Although Lotz et al. (2019) quantitively examined the anxieties from the employees' point of view, considering gender and work experience as factors, it was delivered through online surveys with a majority of participants having no experience with HRC.

Therefore, leveraging TAM, this study aims to evaluate the perceptions and acceptance of workers on HRC in construction tasks through an experimental study. This study contributes to successful HRC implementation in two aspects. First, this paper analyzes workers' perceptions and acceptance of collaborative robots regarding workers' characteristics. Second, qualitative analysis is conducted to identify the considerable need for effective HRC adoption in the construction field. Furthermore, the implication of the findings to facilitate HRC development in the construction industry is discussed.

EXPERIMENT DESIGN AND PROCEDURE

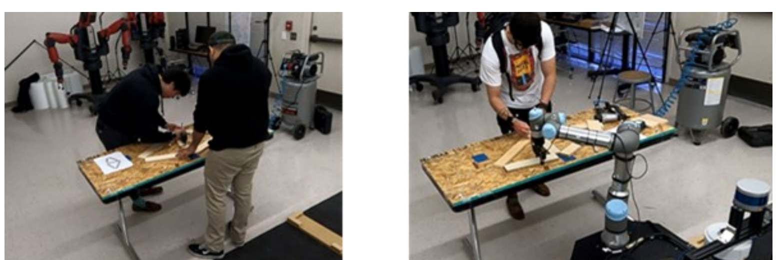
Two wood assembly tasks in a controlled lab environment were designed with two difficulty levels to test the potential influence of task complexity on workers' perception of HRC (Park et al., 2023) (see Figure 1). Both designs are simplified roof trusses in real construction tasks for practical implication. The design of the simple task (Figure 1 (a)) is a 2D structure, while the design of the complex task (Figure 1 (b)) is a 3D structure. Each group of two participants performed two types of collaboration on the same task to establish the comparison, including human-human collaboration (HHC) and HRC. For each group, a primary person worked with a helper to assemble the wood structure according to a given design drawing in HHC setting. In HRC setting, the primary person collaborated with a collaborative robot arm with a 2-finger gripper to perform the assembly task. Figure 2 illustrates the setup for both HHC and HRC environments. In HHC (Figure 2 (a)), the primary person stands on one side of the working bench, and the helper is on the other side. During the experiment, the helper and the primary person work together to measure and place the wood pieces according to the design drawing, while only the primary person completes the connection using a nail gun. In HRC experiment (Figure 2 (b)), the robot assists the primary person with lumber pickup and placement.



(a) (b)

Figure 1. a) The simple task structure; b) The complex task structure

In total, 13 college students with basic carpentry skills (e.g., cutting) participated in the study. Most of them have already worked in or will pursue a career in the construction and architecture industry after graduation. In addition, 90% of participants had no experience with any kind of collaborative robot. Gender was almost balanced: 42% were female, and 58% were male. Age ranged from 21 to 30 years old, and half of the participants were under 24. A training session was given on nail gun usage before the experiment. Participants were grouped by pairs: one primary person and one helper. All primary persons had limited work experience and had never worked with a collaborative robot. All participants were asked to complete a pre-experiment TAM questionnaire before the experiment and a post-experiment TAM survey after HRC experiments. Furthermore, the primary person in each group also participated in a post-experiment interview to solicit their feedback on HRC.



(a) (b)

Figure 2. a) The primary person collaborates with the helper in an HHC experiment. b) The primary person collaborates with a robot in an HRC experiment.

SURVEY DESIGN

To evaluate acceptance towards HRC before and after collaborating with a robot, TAM-based questionnaires were administered. The questionnaire measures workers' perception toward HRC in construction wood assembly tasks. It is adapted from the questionnaires of TAMs, including Davis (1989), Venkatesh (2000), Venkatesh & Bala (2008). All the questions in the survey utilized a seven-Likert scale ranging from "strongly disagree" to "strongly agree" with a middle neutral point. The survey identifies and evaluates participants' perceptions from the following aspects.

Perceived usefulness of collaborative robot (PU). Perceived usefulness is the degree of usefulness that a person feels about a collaborative robot. There are four questions developed and validated to measure PU with an Internal Consistency Reliability (ICR) of 0.92, where ICR measures the consistency of questions with the corresponding variable (Venkatesh & Bala, 2008).

Perceived ease of use of the collaborative robot (PEU). Perceived ease of use means the level of easiness that a person believes when working with a collaborative robot. It is measured with the four-questions scale, validated by Venkatesh & Bala (2008), with an ICR of 0.93.

The intention of use (IU). The intention to use collaborative robots in construction tasks points to the willingness to use a collaborative robot in future construction tasks. It is measured with one question adapted from TAM validated by Davis (1989).

Perception of self-efficacy to work with a collaborative robot (SE). Self-efficacy to work with a collaborative robot means the perception that the person holds regarding the degree of ability to work with a collaborative robot. SE comprises four questions validated in the study of (Venkatesh & Bala, 2008) with an ICR of 0.8.

Job Relevance of HRC (JR). Job relevance refers to the degree of relevance to his/her task that a person believes when using a collaborative robot, with an ICR of 0.83 (Venkatesh & Bala, 2008). Three questions are measured in this scale.

Safety anxiety toward collaborative robot (SA). Safety anxiety toward collaborative robots is described as the degree of anxiety or fear that a person feels when working with a collaborative robot (Venkatesh, 2000). This scale is composed of four questions and an ICR of 0.83 (Venkatesh & Bala, 2008).

Intrinsic motivation to work with a collaborative robot (IMU). It is measured by four questions and has a mean internal consistency of 0.85 (Venkatesh, 2000).

Semi-structured interviews were also conducted after HRC experiments to further explore participants' interaction experience with the robot and their perceptions towards HRC. Sample questions include "How do you think about this collaboration?", "What changes do you like to see on the robot for better performance in HRC?", etc.

RESULTS

Changes in Worker Perception and Attitude Toward HRC

The results show that scores for all variables are above the neutral score (4 in a seven-Likert-scale questionnaire), indicating that workers hold an overall positive attitude toward HRC. As shown in Table 1., the change in mean scores of each variable before and after the experiment was calculated. It is noted that in the original questionnaire, a higher score of SA means a higher level of unacceptance that a participant holds, so those scores were converted in data processing for attitude consistency among all variables. As a result, the higher score suggests that the worker feels comfortable and is likely to work with a robot. PEU, IU, SE and SA slightly increased after HRC experiment, indicating workers' intention to use a collaborative robot has gently increased. JR has dropped by 0.49 after HRC, indicating that workers feel HRC is less relevant to their jobs than initially thought. This could be because the HRC in this experiment is less intuitive compared to the way the workers collaborate with their colleagues.

The percentages of workers' choices regarding different variables are analyzed using diverging stacked bar charts, as shown in Figure 3 and Figure 4. Figure 3 presents the survey results based on gender differences. In the pre-survey, males have a more positive perspective toward collaborative robot – the percentage of "agree" on PEU, PU, and IU separately are higher than that of females, but females have higher scores in SA than males. After HRC experiment, the percentage of “agree” on PEU, IU and SA increased in males by 16% and 18%, and 6%, respectively. Besides, post-survey results for males exhibit lighter color in the percentage of “disagree” compared to the results in the pre-survey. It indicates that the positive perspective is enhanced in males – males feel collaborative robot is really helpful in construction tasks. However, the results of females show that their perspective of collaborative robot has not changed much, with only a slight increase in PEU. The main difference in perceptions among genders is that SA dropped significantly among females while it increased in males, suggesting that females are more nervous about using a collaborative robot. The results indicate the difference in initial cognition and anxiety among genders. Females care more about safety and show more concern about collaborative robots than males do. It may be because there is a difference in the cognition of technology among males and females.

Table 1. Summary of TAM construct scores: mean (standard deviation).

Variables	Pre	Post	Difference (Post - Pre)
PU	4.94 (1.77)	4.9 (1.34)	-0.04
PEU	4.38 (1.93)	5.07 (1.37)	0.69
IU	4.75 (1.61)	5.13 (1.73)	0.38
SE	4.94 (1.53)	5 (0.64)	0.06
SA	4.94 (2.05)	5.25 (1.18)	0.31
JR	5.25 (1.57)	4.76 (1.42)	-0.49
IMU	4.56 (0.86)	4.55 (0.96)	-0.01

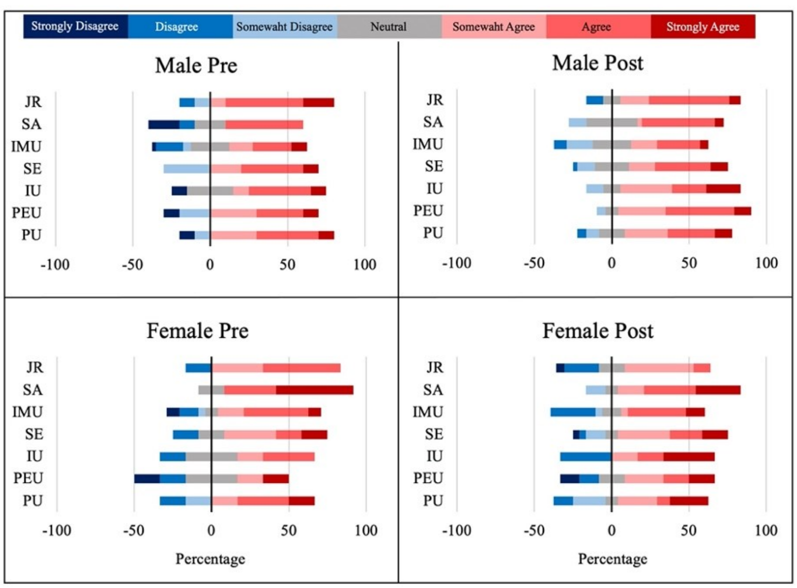


Figure 3. Survey results based on gender difference.

In Figure 4, the survey results are presented based on two difficulty-level tasks – simple tasks and complex tasks. The overall perspective in the pre-survey of complex tasks shows a higher percentage of “disagree” than simple tasks. Since all participants performed HHC experiments before they took HRC pre-survey, they had a general understanding of the task complexity. Thus, the results proved that the difficulty of tasks did affect workers' perception of HRC. After the HRC experiment, workers had an overall positive attitude toward HRC in both simple and complex tasks. Specifically, SA, IU, and PEU increased greatly in both tasks, suggesting that workers believe collaborative robot is helpful no matter the difficulty level of a task and that they are willing to use HRC in different tasks. On the other hand, SE decreased dramatically in simple tasks, but it increased in complex tasks, indicating that workers feel more confident when collaborating with a robot in complex tasks. This could be because the robot stopped and held the connector for the primary person to nail, while in simple tasks, the robot continuously moved and placed wood pieces while the primary person was nailing.

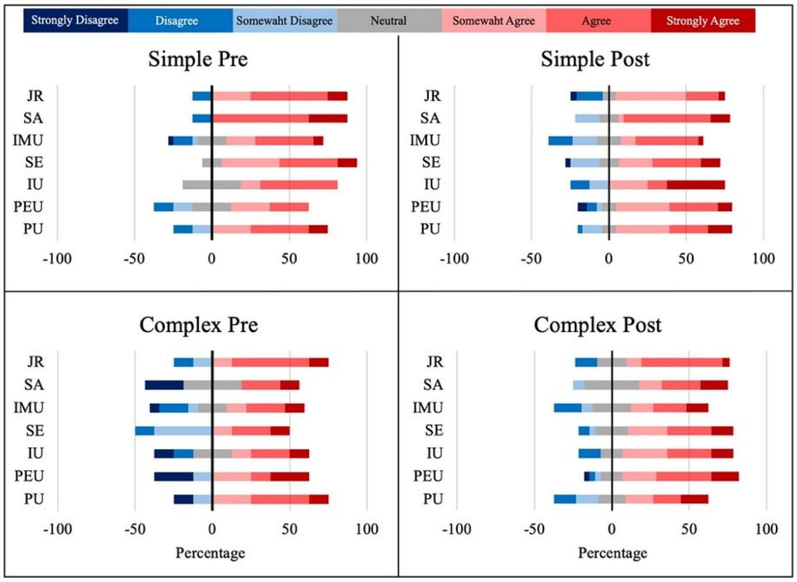


Figure 4. Survey results based on task difficulty level.

Insights from Interviews Toward Future HRC

A short interview was conducted after the HRC experiment. The questions covered workers' feedback and expectations of HRC in their work, e.g., "What changes do you like to see on the robot for better performance in HRC?". The answers are summarized in Table 2. Overall, most participants increased their interest in using HRC in their future jobs. However, there are a few people who prefer to work with a human because they think the robot is not intuitive enough compared to a human helper. In addition, more than half of the participants mentioned the low speed of robot arm movement. They would like to increase the speed to improve work efficiency. This also aligns with the intuition of a robot because the robot used in this experiment is preprogrammed, which is not flexible for adapting to human movement. Therefore, it kept a relatively low speed for a safety guarantee. Besides, some participants mentioned the "uncertainty of robot operation", indicating the lack of communication in terms of robot's intention and operation. For the improvement of HRC, the participants suggested that workers should be trained in the robot's operation so that they can interpret robot's intention and movement. Some of them prefer to have HRC in a larger open space, which relates to safety concerns.

Table 2. Summary of participant responses to open-ended questions about future HRC.

Question	Responses (n=8)		
How do you think about this collaboration?	Increased interest in HRC (6)	Had fun, but prefer to work with human (2)	NA
What changes do you like to see on the robot for better performance in HRC?	Increase the speed of the arm movement (5)	More intuitive robot navigation (2)	Express the robot's intention (1)
What can be done in the preparation for better HRC?	Educate workers about the robot's operation (4)	Increase working space for HRC (2)	It's alright but better navigation of the robot (2)

CONCLUSION

This study conducted an HHC and HRC experiment in wood assembly tasks to analyze workers' perceptions and attitudes toward collaborative robots in construction tasks. Survey data was collected using TAM-based questionnaires. The surveys were analyzed in terms of gender difference and task difficulty levels to have valuable insights into worker attitudes toward HRC in construction tasks. The results lie in two parts. First, there is a significant difference in perception of HRC among males and females: females hold higher safety anxiety toward collaborative robots than males, and males show a more open mind in HRC implementation in construction tasks. Second, this study provides valuable insights into expected HRC in future construction from workers – intuitive and seamless collaboration is expected. It includes two aspects. One is the need for an intuitive and intelligent collaborative robot, and another is the training of workers who are about to work with the robot in their future jobs.

The findings of this study provide potential research directions for successful HRC implementation, as well as quantitative and empirical survey data on workers' perceptions and attitudes toward collaborative robots. Despite the contributions, there are limitations to this study. The small size of sample limited the possibility of taking various populations into account (i.e., age range, work experience). The experiment settings are different from what happens on real construction sites, which could limit the experience of participants with HRC in the construction field. The tasks are simplified wood assembly tasks instead of using real-scale construction tasks. To understand the perception toward real-world HRC in construction, larger-scale tasks with real workers should be investigated in future research.

ACKNOLWEDGMENTS
This research was funded by the U.S. National Science Foundation (NSF) via Grants 2138514 and 2222670. The authors gratefully acknowledge NSF's supports. Any opinions, findings, recommendations, and conclusions in this paper are those of the authors, and do not necessarily reflect the views of NSF and The University of Texas at San Antonio.

REFERENCE

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113–121. https://doi.org/10.1016/j.autcon.2015.07.022

Bröhl, C., Nelles, J., Brandl, C., Mertens, A., & Schlick, C. M. (2016). TAM Reloaded: A Technology Acceptance Model for Human-Robot Cooperation in Production Systems. In C. Stephanidis (Ed.), *HCI International 2016 – Posters' Extended Abstracts* (pp. 97–103). Springer International Publishing. https://doi.org/10.1007/978-3-319-40548-3_16

Davila Delgado, J. M., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M., & Owolabi, H. (2019). Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *Journal of Building Engineering*, *26*, 100868. https://doi.org/10.1016/j.jobe.2019.100868

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340. https://doi.org/10.2307/249008

Gross Domestic Product, (Third Estimate), GDP by Industry, and Corporate Profits, Fourth Quarter and Year 2020 | U.S. Bureau of Economic Analysis (BEA). (2021). Retrieved March 8, 2023, from https://www.bea.gov/news/2021/gross-domestic-product-third-estimate-gdp-industry-and-corporate-profits-4th-quarter-and

Law, K. K., Chang, S., & Siu, M.-F. F. (2022). Factors Influencing Adoption of Construction Robotics in Hong Kong's Industry: A Multistakeholder Perspective. *Journal of Management in Engineering*, *38*(2), 04021096. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001011

Liang, C.-J., Wang, X., Kamat, V. R., & Menassa, C. C. (2021). Human–Robot Collaboration in Construction: Classification and Research Trends. *Journal of Construction Engineering and Management*, *147*(10), 03121006. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002154

Lingard, H. (2013). Occupational health and safety in the construction industry. *Construction Management and Economics*, *31*(6), 505–514. https://doi.org/10.1080/01446193.2013.816435

Lotz, V., Himmel, S., & Ziefle, M. (2019). *You're My Mate – Acceptance Factors for Human-Robot Collaboration in Industry*. https://www.semanticscholar.org/paper/You%E2%80%99re-My-Mate-%E2%80%93-Acceptance-Factors-for-Human-Robot-Lotz-Himmel/d50f7fb24d25bbebd7c44050446037868327c338

Marangunić, N., & Granić, A. (2015). Technology acceptance model: A literature review from 1986 to 2013. *Universal Access in the Information Society*, *14*(1), 81–95. https://doi.org/10.1007/s10209-014-0348-1

BLS (Bureau of Labor Statistics). (2020) *National Census of Fatal Occupational Injuries in 2019,* USDL-20-2265. BLS, Washington, DC.

Park, S., Yu, H., Menassa, C. C., & Kamat, V. R. (2023). A Comprehensive Evaluation of Factors Influencing Acceptance of Robotic Assistants in Field Construction Work. *Journal of Management in Engineering*, *39*(3), 04023010. https://doi.org/10.1061/JMENEA.MEENG-5227

Venkatesh, V. (2000). Determinants of Perceived Ease of Use: Integrating Control, Intrinsic Motivation, and Emotion into the Technology Acceptance Model. *Information Systems Research*, *11*(4), 342–365. https://doi.org/10.1287/isre.11.4.342.11872

Venkatesh, V., & Bala, H. (2008). Technology Acceptance Model 3 and a Research Agenda on Interventions. *Decision Sciences*, *39*(2), 273–315. https://doi.org/10.1111/j.1540-5915.2008.00192.x