Evaluating the Perception of Human-Robot Collaboration among Construction Project Managers

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ABSTRACT

In construction applications, a robot is commonly seen a semi-automated tool or a piece of equipment that assists with specialized work tasks. However, as robots become more technically capable and widely available, they may be seen more as a teammate or co-worker that collaborates with human crews. Using a survey questionnaire, 63 project managers from two national construction management firms in the US were shown videos of three different applications of robotic systems, each exhibiting different characteristics, and were asked to share their perceptions of the robot. Through a between and across group comparison of their responses, we found that a robot was more likely to be seen as a teammate when its movement was less unpredictable, it was seen as more productive than human workers, it was considered durable, it remained constantly active, it took its surroundings into account before moving, it worked well alongside human workers, it was not unreliable, and it made the task more predictable. These findings identify clear challenges for human-robot teaming and the design of robotic systems for construction applications.

INTRODUCTION

The application of robotic technologies in the construction industry has the potential to improve productivity, reduce serious injuries, and increase the cost and schedule reliability in project delivery (de Soto et al. 2018). To date, most applications have been focused on the prefabrication and modularization of building components offsite in a controlled warehouse or manufacturing facility. The adoption of robotic systems in onsite applications has been slower due to the high variability in design project-to-project and uncertainty in site conditions, including exposure to weather and dust (Delgado 2019), and as a result, onsite work remains predominantly manual. However, some robotic manufacturers are starting to develop systems for onsite construction applications. The semi-automated mason (SAM), for example, is a bricklaying robot that can be purchased or leased from the manufacturer to support masonry crews in the field. Robotic total stations (RTSs), which are sold by multiple manufacturers, are becoming more common in practice and allow a single surveyor to perform their layout without a partner. As these systems and others become more widely available and technically capable, human workers will eventually find themselves working alongside robots on the jobsite. Collaborative robots can cause replace or enhance existing methods and make them more efficient and accurate (Hadidi et al.

2018). When sharing a task and workplace, how human workers perceive their robot co-workers can be a significant factor in effective collaboration (Furlough et al. 2019). For some workers, robots may be a welcome assistant, capable of performing physically demanding or dangerous tasks. Others may be distrustful of robots and their capabilities.

Human-robot collaboration represents a new operating model for the construction industry that can affect the design of work tasks and the role of human workers. The aim of this research is to explore how industry professionals perceive robotics in construction applications, with a specific emphasis on their acceptance of robots as a potential teammate. These professionals include project managers as the ones that making decision whether employed the robotic system as part of the work, and craft workers who are involved in the work every day. To address this aim, a survey questionnaire was distributed to a group of project managers in two national construction management firms in the U.S. The participants were asked to review one of three videos showing robots in different construction applications and then respond to a series of statements about what they viewed. The survey data was analyzed to identify between and across group differences.

LITERATURE REVIEW

The question, "What is a robot?" is fundamental in the field of robotics. The Robot Institute of America (1980) defined industrial robots as "reprogrammable multifunctional manipulators designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks". As robotic technology improved, the definition has been expanded. Bekey (2005) mentions that "robot must have sensors, processing ability that emulates some aspects of cognition and actuators". Kumar (2014) defined robot as "a device that performs functions ordinarily ascribed to human beings or operates with what appears to be almost human intelligence". However, these definitions are technical in nature. When human workers engage with technology, the worker's perception of what is and is not a robot may differ. In the context of human-robot collaboration, there are three types of broad factors affecting human workers' perception of robots: (1) factors inherent to the human workers, (2) factors related to the robotic system itself, and (3) factors related to the work environment.

Human Worker Characteristics. Personal characteristics, such as the age of human workers, can change how they react to robots (Crowelly et al. 2009). The emotional, cognitive, and behavioral features of an individual can also influence their perception of robots (Taherdoost 2018). One of the most cited of these features in literature is trust. Trust in the robot influences a person's enthusiasm and willingness to accept robot-produced information, suggestions, and work (Honcock et al. 2011). If a person has little trust in the robot, they will doubt its capabilities and intervene sooner in its work. Whether or not a person trusts a robot is influenced by their familiarity with the robot. Specifically, increased familiarity with the robot is associated with higher estimations of the robot's intelligence and whether they consider the robot as colleague or co-worker (Bröhl et al. 2019). Faith, dependability, predictability, competence, reliability, and responsibility are other factors that influence trust (Muir and Moray 1996). The level of perceived safety when interacting with robots is another antecedent to trust. Doubting if the robot would stop in unexpected situations or injure human co-worker has a negative effect on trust (Ljungblad et al. 2012). Educational background can also affect how robots are perceived in the workplace. Workers without an engineering education and little exposure to robotics are unsure of how to engage with robots when given the opportunity. On the other hand, engineers can be more critical of robots than users without technical training and experience (Szczepanowski et al. 2020). People with of certain cultural backgrounds accept and adapt to robotic systems differently (Bartneck et al. 2007).

For instance, robots are more accepted in Japan than in America and European countries, as the level of robotic research and development is high in Japan (Kaplan 2004).

Robotic System Characteristics. The structure or form of a robot are important in how people perceive its function, as the form creates an expectation in the mind of the human-worker (Fong et al. 2003). Robot morphology is commonly divided into three types: anthropomorphic (human-like), zoomorphic (animal-like), and functional (neither humanlike nor animal-like, but is shaped in a way relevant to the robot's function) (Bartneck et al. 2009). According to Ishiguro et al. (2001), people believed that a human-like robot was less responsible than a real human, but more responsible than a vending machine. Indeed, individuals interact more easily and naturally with human-like robots in contrast with machine-like robots (Hinds 2004). The performance of human participants was affected by the presence and speed of a human-like robot in a shared workplace. Based on Vasalaya's (2018) research, individuals become slower with a slower robot co-worker and faster with faster one.

Autonomy in the context of the robotic system is defined as a scale that a robot can feel the environment, make decisions and plan based on that environment, and behave in that environment to reach some purposes without outer control (Beer 2014). Robots need comprehensive knowledge about their workplace to perform efficiently. Robotic sensors are applied to evaluate the robot's position and workplace (Morecki 1999). Robotic sensors affect its level of autonomy (LOA) which helps robots to make decisions and changes in their performance and goals. Levels of robot autonomy vary from teleoperation to completely autonomous systems. Some authors suggest that higher robot autonomy needs lower levels or less frequent human-robot collaboration (Huang et al. 2004). Other authors argue that higher robot autonomy needs higher levels or more complicated forms of human-robot collaboration (Thrun 2004).

Work Environment. The ability of human workers to collaborate with robots is also dependent on factors in the work environment, such the type of interaction, type of task, distance between the robot and workers, and time spent in proximity. Whether the worker and robot are using computing systems in the same place (e.g., co-located) or in different places, and while at the same time (e.g., synchronous) or at different times (asynchronous) can influence the performance of the human worker (Fong et al. 2003). Muller et al. (2017), categorized five different methods in which humans and robots can collaborate: (1) a traditional system, where humans and robots work separately with barriers and protective cages, (2) coexistence, where a human operator and robot are in the same workplace, but generally do not have any interaction together, (3) synchronized, where a human operator and robot work in the same workplace, but not at the same times, (4) cooperation, where a human operator and robot work in the same workplace at the same time, but each of them focuses on their own task, and (5) collaboration, where a human operator and robot must complete a task together and each action of one has important outcomes on the other. In a situation where humans and robots are co-located, there are five forms of physical closeness between them, ordered from less to more physical interaction: none, avoiding, passing, following, approaching, and touching (Huttenrauch and Eklundh 2004).

RESEARCH METHODS

To address the research questions, a survey questionnaire was developed as a data collection instrument in Qualtrics. The survey was divided into two parts. First, the participants were shown a video, showing one of three potential examples, selected at random, of a robotic system in a construction application. The factors affecting human worker acceptance of robots, as previously identified in literature, were used to select these examples of robotic systems (see Table 1). The videos were provided by the manufacturers of each robotic system and were edited to reduce their duration, while still maintaining an accurate representation of the robotic system in use alongside human workers. After watching the video, participants were asked to indicate their level of agreement with 15 statements on a 7-point Likert scale (1=Strongly disagree, 7=Strongly agree) about the robot and the task being performed. A complete listing of these statements is provided in Figure 1. Lastly, participants were asked to provide demographic information about themselves, such as age, education, gender, and role in their organization.

Table 1. Summary of videos included in survey questionnaire

Robotic system	Description of video	Characteristics
Semi-automated mason (SAM)	This video shows the bricklaying robot, "SAM," designed and built by Construction Robotics. The robot is highly machine-like, having a large rectangular cabinet mounted on wheels that houses an extendable robotic arm, a mortar hopper, a feeder for brick, and the computer controller. In the video, SAM is shown laying four bricks in 30 seconds, with human workers shown following behind to perform finish work on the mortar joints and load additional bricks into the feeder.	Machine-like Medium-sized Slow and steady Repetitive motion Cooperation Following
Robotic arm timber assembly	This video shows an overhead gantry-mounted robotic arm system, supplied by ABB Robotics and used by ETH Zurich to assemble dimensional timber. In the video, the arm quickly and precisely moves a pre-cut length of timber into position, holding it in place while a human worker applies fasteners to fix the timbers together. The process takes 45 seconds to complete. The robotic arm moves in six axes with a reach of 2-meters and moves quickly, but smoothly during operation.	Machine-like Large-sized Fast and smooth Variable motion Collaboration Approaching
Robotic total station (RTS)	This video shows a GPS-enabled robotic total station supplied by Trimble. From the outside, this robot is nearly identical in appearance to a manual total station. The system has a large rotating optical lens, mounted within a rotating frame with an LCD screen interface. In the video, a human worker is seen entering commands through this interface before walking away with a prism pole. The RTS then rotates to follow and track the position of the prism with the human worker over a period of 30 seconds.	Machine-like Small-sized Slow and smooth Repetitive motion Collaboration Touching

Prior to distribution, we engaged in two survey pilots with practitioners. During the first pilot, we had two project managers and one superintendent join a video conferencing call with the research team and conduct a think-aloud. This process allowed us to improve the clarity and sequencing of questions, as well as confirming the effectiveness of the videos at demonstrating each robotic system. During the second pilot, we distributed the survey to a small sample of 15 project managers within a single construction management firm to gauge the length of time needed to complete each part of the survey. Based on feedback from this pilot, several questions were removed as being too similar and adding to the length of the survey with little added value.

At the completion of both pilots, the finalized survey was distributed within two large construction management firms. Contacts within these firms emailed a flyer and survey link to their project management teams on behalf of the research team. Project managers were specifically targeted for this research, as they are more likely to be the initiators of robotic adoption on the jobsite, when compared to trade workers. Two reminder emails were sent over a period of two weeks, after which the data was exported from Qualtrics, cleaned, and coded for analysis. A between and across group comparison was then performed to analyze the responses. The between group comparison used an independent samples Kruskal-Wallis (K-W) test to determine whether the distribution of responses between robotic systems were significantly different. For K-W tests that indicate a significant difference, post-hoc tests were then performed with a Bonferroni correction to determine between which systems the difference was found. The across group comparison was conducted through a Spearman Rho correlational analysis of the aggregated perception questions from all three robotic systems and selected demographic variables.

RESULTS

The results are separated into three sections. First, the respondent demographics are summarized to contextualize the perceptual data. Then, the between group comparison results are presented, which describe similarities and differences in respondents' views on each robotic system. Lastly, the across comparison results provide correlational evidence of both robotic and task characteristics associated with respondents seeing a robot as a good teammate.

Respondent Demographics. A total of 63 responses to the survey were received: 23 that reviewed the SAM, 18 for the robotic arm timber assembly, and 22 for the RTS. Estimating that the survey reached approximately 400 employees across both firms, the response rate was calculated at 15.8%. Across this sample, most respondents were male (81%), college educated (88%), working in the commercial construction sector (77%), and employed in the role of a project manager (50%). The average age of respondents was 35.3 years old (*s.d.*=9.5 years) and the average years of construction experience held by respondents was 12.6 years (*s.d.*=9.5 years). There were no significant differences in respondent age or experience by robotic system reviewed.

Between Group Comparison. A summary of survey responses for each application of robotic systems is provided in Figure 1. For visual clarity, the 7-point Likert scale has been reduced to three categories. Statements indicating disagreement (e.g., strongly disagree, disagree, and somewhat disagree) were combined into a single category named "Disagree" and those indicating agreement (e.g., strongly agree, agree, somewhat agree) were combining into a single category named "Agree." Neutral responses (e.g., neither agree, nor disagree or do not know) were placed into their own category. Of the three systems, the SAM experienced the highest percentage of neutral responses across all statements, indicating comparatively more uncertainty about the robot. For example, 57% of respondents seeing the SAM video demonstration could not determine whether the robot used an understanding of its surroundings before making a movement, when compared to 27.8% for the robotic arm timber assembly and 28.6% for the RTS. Similarly, 38.1% of respondents were unsure of whether the SAM would be good teammate—over double the uncertainty of the robotic arm (16.7%) and the RTS (14.3%).

Kruskall-Wallis test results show a significant difference in response distributions for the following statements: "The robot looks dependent on human worker to function" (H=14.7, p=0.001), "This robot looks more productive than human workers" (H=6.3, p=0.042), "This robot looks like it can work well with or among human workers" (H=6.8, p=0.034), "This robot doesn't look reliable" (H=6.9, p=0.031), and "By using this robot, the task is being performed with increased precision" (H=7.9, p=0.019). There was no significant difference in response distributions between the three robotic systems with respect to their perceived: unpredictability of movement, durability, ability to stop when encountering an unexpected site condition, fitness as a teammate, ability to maintain constant activity, ability to take surroundings into account before moving, ability to perform a variety of tasks, ability to make the tasks more predictable, reduction in the quality of installed work, or ability to make the task safer.

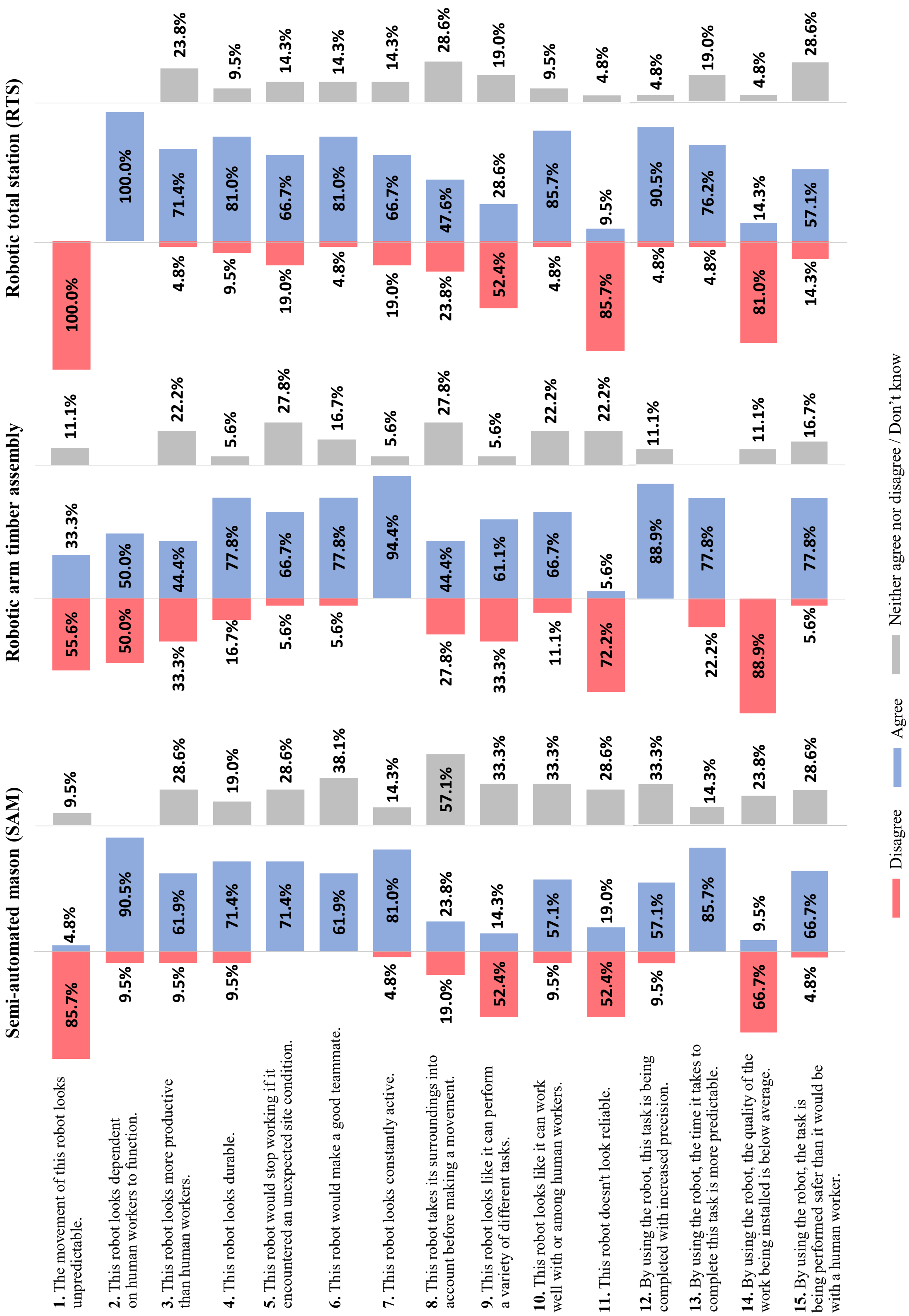

Figure 1. Respondent perceptions of robotic systems

When evaluating the robotic system's dependence on humans to function, the SAM and RTS had statistically different response distributions than the robotic arm timber assembly. Specifically, the SAM and RTS were more often seen to need human intervention (p=0.026 and p=0.000, respectively), when compared to the robotic arm. However, when evaluating whether the robot looks more productive than human workers, the robotic arm timber assembly was the only application where respondents frequently disagreed with the statement. This distribution of responses was different from the responses for the RTS (p=0.039). When evaluating whether the robotic system works well with human workers, the response distribution for the RTS also was different from the robotic arm timber assembly (p=0.029), where respondents were more likely to express agreement when viewing the RTS. In terms of perceived reliability and precision of the robotic systems, the RTS was seen as both more reliable and increasing task precision when compared to the SAM, with a significant difference in response distributions (p=0.027 and p=0.015, respectively).

Across Group Comparison. Spearman Rho correlations for the aggregate responses across all robotic systems is provided in Table 2. Three demographic variables were included to determine whether perception varied by gender, years of experience in the construction industry, or whether the respondent was working onsite as opposed to the office. Male respondents generally had more years of experience (r=0.03, p<0.05). The only statement related to these demographic variables was "By using this robot, the task is being completed with increased precision," which had a significant negative relationship with years of experience (r=-0.45, p<0.01). In other words, the more years that respondents had worked in the industry, the more skeptical they were that robots were precise enough in their work. There was no difference in perception whether the respondent was male or female, or located onsite or in the office.

Of particular interest in this research is the perception of a robotic system as a teammate (highlighted in Table 2), rather than a tool or piece of equipment. There were multiple statements related to the characteristics of the robot and task that had a significant association to this perception. Specifically, the robot was more likely to be seen as a teammate when: its movement was less unpredictable (r=-0.30, p<0.05), it was seen as more productive than human workers (r=0.42, p<0.01), it was considered durable (r=0.32, p<0.05), it remained constantly active (r=0.42, p<0.01), it took its surroundings into account before moving (r=0.31, p<0.05), it worked well alongside human workers (r=0.30, p<0.05), it was not unreliable (r=-0.27, p<0.05), and it made the task more predictable (r=0.34, p<0.05).

Beyond consideration of the robot as a teammate, there were other significant correlations between the remaining statements. These correlations suggest multicollinearity and perhaps the presence of one or more underlying or latent factors influencing multiple responses. For example, seeing the robot as improving the precision of the task was negatively associated with believing the robot was installing below average quality work (r=-0.61, p<0.01). Thus, although quality of work is determined by more than simply precision, respondents saw precision and quality as highly interrelated when evaluating robots on the jobsite. Perceived reliability was also related to quality, where robots seen as less reliable were also believed to install below average quality work (r=0.49, p<0.01). The perceived dependence of robots on human workers was moderately correlated with seeing the robot as working well alongside human workers (r=0.43, p<0.01). This relationship suggests that full automation or independence of the robot's operation from human workers may make them less desirable to work alongside in the field. In addition, robots with unpredictable movement were negatively associated with working well alongside human workers (r=-0.36, p<0.01).

Table 2. Spearman rho correlations for respondent demographics and robot characteristics

	Gender	Exp.	Onsite	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Exp.	0.30*	1															
Onsite	-0.03	0.02	1														
1.	0.05	-0.20	-0.20	1													
2.	0.10	0.10	0.02	-0.17	1												
3.	0.04	-0.19	-0.02	-0.13	0.25*	1											
4.	-0.13	0.05	0.16	-0.17	-0.10	0.36**	1										
5.	0.14	0.12	-0.08	-0.10	0.20	0.07	0.16	1									
6.	0.20	0.03	0.00	-0.30*	0.15	0.42**	0.32*	0.24	1								
7.	0.04	0.06	0.10	-0.22	0.01	0.20	0.20	-0.09	0.42**	1							
8.	-0.06	0.15	0.24	-0.03	0.08	0.11	0.13	0.04	0.31*	0.15	1						
9.	-0.05	-0.11	0.21	0.29*	-0.18	-0.11	-0.14	-0.13	-0.11	0.03	0.26*	1					
10.	0.17	0.02	0.18	-0.36**	0.43**	0.17	0.01	0.17	0.30*	0.24	0.06	0.06	1				
11.	0.22	0.04	0.03	0.30*	0.02	-0.10	-0.31*	-0.08	-0.27*	-0.02	0.04	0.06	-0.19	1			
12.	-0.23	-0.45**	0.07	-0.29*	0.06	0.41**	0.19	0.13	0.34**	0.09	0.04	-0.05	0.23	-0.32*	1		
13.	0.00	-0.04	0.12	-0.24	-0.10	0.20	0.06	-0.06	0.17	0.35**	0.05	0.08	0.10	0.11	0.34*	1	
14.	0.20	0.06	-0.02	0.24	-0.08	-0.18	-0.26*	-0.04	-0.19	-0.04	0.13	0.12	-0.29*	0.49**	-0.61**	-0.08	1
15.	-0.12	0.02	0.09	-0.01	-0.07	0.05	0.01	-0.07	0.08	0.19	0.06	0.33*	0.08	-0.02	0.18	0.39**	-0.10

CONCLUSIONS

By exploring how construction professionals perceive robotic systems in onsite applications, this research identified several characteristics that may contribute to greater acceptance of robots as a teammate, as opposed to a tool or piece of equipment. Respondents were more likely to see robots as teammates when the robot moved in a predictable way that improved the productivity of the task, looked durable and reliable, and worked well alongside human workers. These findings identify clear challenges for human-robot teaming, related to pre-existing opinions and perceptions about robots in the construction industry. Future work could be done to compare project manager perceptions to craft worker perceptions. These findings have implications for the manufacturers of robotic systems, such as the creators of SAM, to assist with the design and implementation of robots that will be more readily accepted by construction professionals. We acknowledge that the limited diversity of the sample is a limitation of this research. Balancing the largely college-educated, male project manager opinions presented here with an additional sample of construction trade workers would both allow greater generalization of these findings and reveal whether these is a difference in perception between office and field operations.

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