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Understanding Workers' Acceptance of Robotics in Construction

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Abstract

Robotics is expected to enhance productivity and safety in the construction industry, but the real-world application remains limited. Introducing robotics in construction may require humans and robots to work together for the same tasks or in close proximity. While significant attention has been paid to organizational-level robot adoption, little exploration has been done from the perspective of construction workers. This paper aims to provide a comprehensive understanding of the many factors that may influence workers' attitudinal acceptance of robotics in construction. A case study including observations and interviews with 40 construction workers of a project in the Guangdong-Hong Kong-Macao Greater Bay Area was conducted, coupled with semi-structured interviews with 13 site managers. Various factors influencing workers' acceptance were identified, including individual differences of workers, technological performance, and output quality of robots. Additionally, external factors including organizational support and social influences can affect workers' attitudes toward robots. The findings reveal that most workers will passively accept construction robots when their organization mandates their utilization, although changes in income remain a major concern. Strategies are recommended for future research and practice of robots for various stakeholders, such as guaranteeing workers' income, strategizing practice-based technology, improving multi-level robot interface management, and enhancing government support. This study should encourage different stakeholders to design and adopt construction robots guided by human-centered design principles.

Keywords - Construction Robotics, Worker Acceptance, Human-centered Robotics, Technology Acceptance Model, Robot Adoption.

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1 Introduction

Construction represents a significant component of the global economy. In 2023, the gross annual output of global construction projects accounts for about 7% of the world's gross output (McKinsey, 2024). Despite its significance, the construction industry faces severe challenges such as labor shortages and tight workforce markets. Construction projects heavily depend on the manual tasks provided by skilled construction workers (Durdyev et al., 2017). However, retirement, shorter job cycles, and talent competition have led to a notable decline in the skill and experience levels of construction labor (World Economic Forum, 2023). For example, in Hong Kong, the Construction Industry Council (2023) states that there is a significant manpower shortage of skilled construction workers, with a supply-demand mismatch of 5-15% in 2023 expected to increase to 15-20% by 2027. Moreover, the gradual decline in the number of young individuals entering the industry has resulted in the trend of an aging workforce, exacerbating the talent shortage (Pan et al., 2020b). Therefore, there is an urgent need to consider and introduce new methods to alleviate labor shortage and boost productivity across the construction sector.

Robotics has been widely recognized as an important technological innovation in construction (Pan & Pan, 2020). However, robot adoption is still limited. One major challenge facing the use of robots, not only in construction, is related to humans and robots working together for same tasks or in close proximity. There is also increasing concern that robots may displace human workers, leading to negative attitudes of humans toward working with robots in many industries (Nomura et al., 2006; Takayama et al., 2008). Given the great potential of robotics in future construction, a comprehensive understanding of workers' acceptance of robotics in construction is needed (You & Robert, 2017). Scholars have also explored the determinants of construction robot adoption from an organizational perspective (Pan et al., 2020a; Vora et al., 2024). However, little is known from the workers' perspective in terms of which factors could influence workers' attitudinal acceptance of robotics, especially for those working closely with robots.

To address the gap, this paper aims to provide a comprehensive understanding of potential factors that may influence workers' attitudinal acceptance of robotics in construction. Guided by the technology acceptance model (TAM), the research was carried out in the combination of a critical literature review, a case study of a residential project involving interviews with construction workers, and supplementary semi-structured interviews with site managers, which provide a comprehensive understanding of influencing factors on workers' attitudinal acceptance of construction robots. The findings should provide practical implications and policy recommendations to facilitate the development and adoption of robotics in the construction industry.

2 Related Work

2.1 Innovation Adoption Theory

The technology acceptance model (TAM) is a generic innovation theory for predicting individual adoption, which is widely used for studying behavior intention toward technological innovations and examining factors affecting user acceptance (Zhang et al., 2008; Charness & Boot, 2016). Specifically, TAM explores why users accept or reject an innovation and which factors influence their willingness to accept it (Davis 1986). As shown in Figure 1, TAM focuses on exploring the prospective overall attitude of corresponding users toward using a given system. The effect of external variables on attitudinal acceptance is mediated by two fundamental determinants, perceived usefulness (refers to the degree to which a person believes that using a particular system would enhance his or her job performance) and perceived ease of use (refers to the degree to which a person believes that using a particular system would be free of effort). Davis's work (1986) laid the foundation for many innovation studies on individual acceptance, and has been extended to considering additional external variables, such as social influence and cognitive instrumental processes (Venkatesh & Davis, 2000), and the application to understand innovation in different fields, such as the acceptance of information technologies (Venkatesh & Bala, 2008). TAM has also been effectively used in construction research, in combination with other innovation theories, to understand the acceptance of different technologies (Katebi et al., 2022; Park et al., 2023). Previous studies have demonstrated the feasibility of applying and extending TAM by adding further variables to understand user acceptance of innovative technologies on different applications. This study employed TAM as the theoretical basis considering it solid theoretical foundation and applicability in exploring potential external variables influencing workers' attitudinal acceptance of robotics in construction.

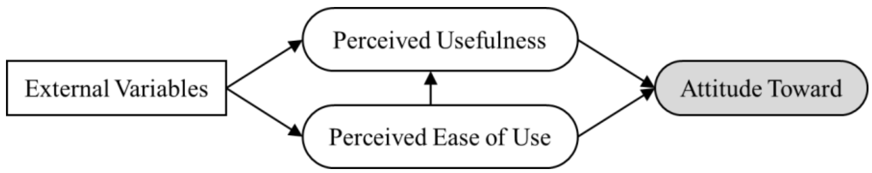

Figure 1: Technology acceptance model (Davis 1986)

2.2 Construction Robot Adoption

Research has been carried out to examine determinants for the adoption of construction robots. Pan & Pan (2020) investigated the determinants of construction robot adoption from the perspectives of building contractors based on the technology organization environment (TOE) framework and identifiedtop management support as the predominant factor in robot adoption. Kim et al. (2022) collected the perceptions from trade workers and managers and illustrated that job complexity and safety risks had the most significant influence on construction personnel's desired capabilities and perceived usefulness of robots. Park et al. (2023) investigated construction personnel's behavioral intention to accept human-robot collaboration, including craftsmen, supervisors, managers, engineers, and directors in the US construction industry, and indicated that perceived usefulness and perceived ease of use had a positive and significant impact on the intention. Vora et al. (2024) found that saving time by reducing rework and facilitating quality control are the top driving factors of various stakeholders to adopt construction robots. The interest in bringing robots onto construction sites will force robots and human workers into closer proximity. However, little has been done to explore factors influencing construction worker acceptance of robotics from the individual and practical perspective. Although robot adoption decisions are typically made at management or organizational level, the actual adoption performance would be affected by workers' attitudinal acceptance.

3 Research Method

The study was conducted by combining a critical literature review, a case study including observations and semi-structured interviews with 40 construction workers of a residential building project in the Guangdong-Hong Kong-Macao Greater Bay Area, and supplementary semi-structured interviews with 13 site managers. This mixed-method research design enables a comprehensive and in-depth understanding of attitudes and perceptions of workers toward the adoption of construction robots.

3.1 Case Study with a Residential Building Project

The case study method was employed to enable an empirical investigation (Taylor et al., 2006), using multiple sources of evidence: (1) document analysis based on factual data; (2) observations including participant observations by one researcher engaged as a project engineer from project inception to closeout, with a particular focus on challenges and pain points encountered by workers; (3) semi-structured interviews with 40 workers from eight major subcontractors.

The case study was based on a residential project with a floor area of approximately 200,000 square meters. The project duration is approximately 2 years, including 1,017 residential units, 136 commercial units, 3 level basement, and a kindergarten. Many construction robots have been deployed on a trial basis in this project, including a construction measuring robot, a building cleaning robot, an indoor concrete wall grinding robot, a concrete floor smoothing/screeding robot, and an intelligent follow-up distribution machine.

Semi-structured interviews were conducted with 40 workers selected through purposive sampling, a method used to select respondents most likely to provide appropriate and useful information (Campbel et al., 2020). Selection criteria include employment on the site with first-hand experience, holding certain degree of knowledge and awareness of construction robots, and trades related to applicable fields of robots, including electrician, steeplejack, handyman, bricklayer, plaster, painter, concretor, and tiler (Table 1). The majority of interviewees (52.5%, n=21) were over 40 years old, reflecting the aging trend in the construction industry. Each interview lasted approximately 20-30 minutes and was audio-recorded with permission. This includes an introductory explanation of existing construction robots with the aid of photos and videos, which allow workers to better understand the functions and current usages of construction robots, followed by in-depth discussions on robot acceptance. The transcripts and notes taken were translated, and analyzed through seven steps formulated by Easterby et al. (2002) and NVivo version 15 software.

Trade	n	Percentage	**Work experience**	n	Percentage	**Age**	n	Percentage
Plaster	3	7.5%	0-9 years	16	40.0%	20-29 years	7	17.5%
Electrician	3	15%						
Steeplejack	6	12.5%	10-19 years	11	27.5%	30-39 years	12	30.0%
Handyman	5	7.5%						
Bricklayer	3	7.5%	20-29 years	7	17.5%	40-49 years	7	17.5%
Painter	10	25%						
Concretor	4	10%	> 30 years	6	15.0%	50-59 years	14	35.0%
Tiler	6	15%						

Table 1: Details of semi-structured interviewees with construction workers (n=40)

3.2 Semi-structured Interviews with Site Managers

Supplementary semi-structured interviews were conducted with 13 site managers, which provided insights from the management on the workers' acceptance of construction robots, as well as suggestions for future human-centered construction robot development. The purposive sampling method was used for interviewee selection. Participants held key positions from key stakeholder groups in the construction industry, including clients, contractors, subcontractors, and supervisors (Table 2). Notes taken during site manager interviews were analyzed similarly to those taken during case study interviews.

Company	Position	n	Company	Position	n
Client	Engineering manager	1	Contractor	Project manager	2
	Electrical engineer	1		Quality manager	1
	Civil engineer	1		Technical manager	1
Supervisor	Supervising engineer	1	Subcontractor	Decoration manager	2
	Chief supervisory engineer	1		Landscape project manager	2

Table 2: Details of semi-structured interviewees with site managers (n=13)

4 Results and Analyses

The data obtained from the case study and semi-structured interviews was carefully analyzed to tease out pertinent themes and categories. As a result, five dimensions and their associated factors that could influence workers' acceptance of construction robots were identified (Table 3). The study also revealed considerable variation in workers' attitudes toward robots. Specifically, 43% (n=17) of workers expressed a positive attitude toward robots, while 30% (n=12) and 28% (n=11) of workers exhibited neutral and negative attitudes, respectively.

Dimension	Influencing factor	Description
Individual differences	Years of work experience	Duration of workers' work experience
	Trade	Type of work for which the worker is responsible
	Age	Age of workers
Technological performance	Adaptability	The robot's capacity to adapt to complex working environments and its user-friendly interface
	Technology maturity	Technology readiness level of robots
Output quality	Auxiliary capability	Performance of construction robots assisting workers in completing a task
	Construction quality	Robot's performance in construction results
Organizational support	Work interface management	Division of tasks and responsibilities between construction robots and workers
	Income assurance	Remuneration of workers for their labor
Social influence	Social processes	Developments and changes in society and industry
	Job competition	Employment pressure on workers from construction robots

Table 3: Influencing factors of workers' acceptance on construction robots

4.1 Individual Differences

Individual differences refer to personality and/or demographics that can influence an individual's perception of the usefulness and ease of use of a particular product or service (Venkatesh & Bala, 2008). The findings indicate that years of work experience and trades significantly impact workers' attitudinal acceptance of robotics, while the age of workers has a relatively minor effect.

Years of work experience: The length of work experience has a clear impact on workers' acceptance of robotics. Specifically, 62.5% (n=25) of workers with 0-9 years of experience have a positive attitude toward robots, while only 16.7% of workers with more than 30 years of experience hold a similar view (Figure 2). Some workers indicated that they were reluctant to embrace changes in their roles and were uncertain about their ability to adapt to new challenges posed by the introduction of robots. As workers accumulate experience, they become more familiar with their tasks and responsibilities, leading to greater resistance to change and new challenges.

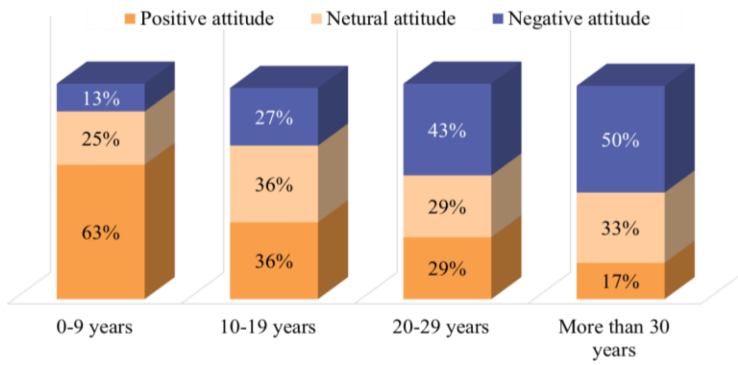

Figure 2: Relationship between workers' attitudes and years of work experience

Trade: There is a notable discrepancy in the acceptance of robots among workers with different trades (Figure 3). Researcher's observations and interviews with site managers identified the following reasons for different workers.

- Electricians (100% positive attitude) have high acceptance of robots because the skills required for electrical services are highly specialized and require a high level of knowledge and expertise, making them more open to new technologies.
- Handymen and bricklayers (80% and 67% positive attitude, respectively) have a high acceptance of robots due to the relatively simple nature of their tasks, which often involve cleaning and lifting. Robots can help them save physical strength to a large extent and are technically easier to implement.
- Steeplejacks (67% positive attitude) believe that robotics can assist in dangerous tasks, resulting in a more favorable outlook towards robots.
- Plasterers, painters, and concretors (33%, 20%, and 25% positive attitude, respectively) are less receptive to robots as their jobs usually require more manual experience to ensure good output quality.
- Tilers (17% positive attitude) have the lowest level of acceptance. Tiling requires flexible adjustments based on site conditions, and workers believe that robots lack the necessary intelligence for the task.

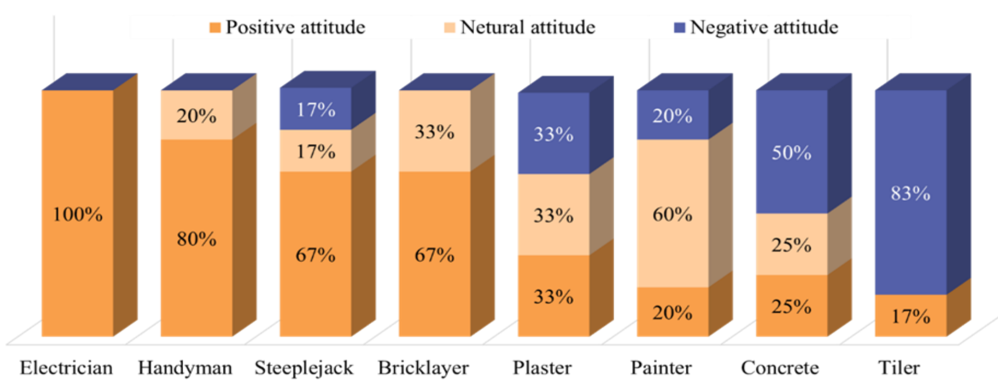

Figure 3: Relationship between workers' attitudes and trades

Age of workers: In terms of age, both the 20-29 and 50-59 age groups expressed positive attitudes toward robots, with 71.4% and 50% acceptance, respectively (Figure 4). The former (younger) group is more willing to accept new things, while the latter (older) is usually curious or indifferent to new things as they approach retirement. For others, results from the case study and site manager interviews indicated that workers aged 30-49 generally face greater financial pressure, view robots as competitors, and are concerned that robots may replace them, leading to reluctance to accept robots.

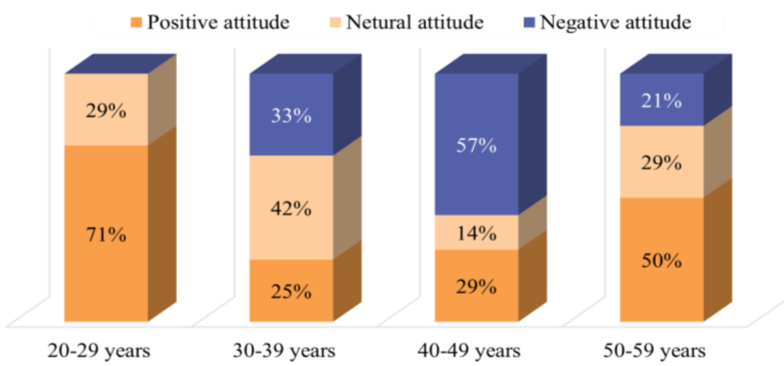

Figure 4: Relationship between workers' attitudes and their age

4.2 Technological Performance

Technological performance considers the performance of construction robotics at the technological level, which was identified as an important factor influencing workers' acceptance, particularly in terms of adaptability and maturity. Key viewpoints obtained during the case study and interviews are summarized as follows.

Adaptability: Nearly half of the workers (48%, n=19) believed that the adaptability of robots significantly affects their acceptance. Generally, robots are not as flexible as workers in dealing with problems encountered in the construction process and are largely confined to work according to established procedures and standards, limiting their adaptability to dynamic construction environments. Particularly, the complex environment of construction sites was perceived by 30% (n=12) of the workers as a significant challenge for the application of construction robots. Primary challenges include: 1) presence of obstacles or restricted walking paths within the designated working environment would prevent the robot from reaching the work area and carrying out its intended work; 2) substandard construction quality of preceding process would adversely affect the normal operation of the robot, and it is challenging for the robot to adaptively address issues such as 'uneven ground' and 'misaligned walls'; and 3) a wide range of disparate tasks, processes, and cross-works make it difficult to provide a conducive environment for robots to operate independently. Consequently, the performance of robots operating in complex construction environments is often suboptimal. Furthermore, the complex operation and commissioning of robots present challenges for workers, providing additional workload for workers and affecting workers' efficiency and willingness to collaborate with robots.

Technology maturity: During the interviews, most of the workers who were neutral about robots stated that they would accept robotic technology if it reached a high maturity level. Conversely, workers are reluctant to collaborate with robots if the technology maturity is low. Some workers even expressed their willingness to purchase highly useful robots themselves if existed, indicating that technology maturity is a key factor affecting workers' attitudes toward robots. Construction site managers also believed that a high readiness level of robots would encourage companies to promote the application vigorously.

4.3 Output Quality

Output quality in the context of robot acceptance could be interpreted as the extent to which an individual perceives the robot to be effective in fulfilling the requirements of their job tasks (Venkatesh & Davis, 2000). The identified factors influencing workers' acceptance and the primary perspectives collected from the case study and interviews are summarized below.

Auxiliary capability was identified as the uppermost factor influencing workers' acceptance of robotics in construction, raised by 35 out of the 40 workers (88%) and 10 of the 13 site managers (77%). The strenuous physical nature of construction works means that if robots can assist workers in their tasks with greater ease, this would positively influence worker perception and acceptance. In addition, robots that enable time saving and productivity enhancement could help workers generate more income within a certain period, fostering a positive perception from workers on robots. Moreover, robots can help workers complete hazardous tasks (such as working at heights) and enter harsh environment, reducing workers' physical harm and improving their acceptance of robots.

Construction quality: More than half of workers (53%, n=21) identified the quality of the robot's work as a significant factor. This is because when robots do not complete tasks to the required standard, responsibility for rectifying construction defects falls on the workers. The case study also revealed that the majority of workers preferred to complete work in one go and were reluctant to assist robots with rework tasks. However, as noted by some workers, if the robot's work quality surpassed that of humans, they would be more open to accepting the robot and learning to operate it.

Furthermore, many workers (62.5%, n=25) and site managers (over half) perceived limited coverage as a technological disadvantage of construction robots. However, it was found to have little impact on the workers' acceptance of robots, since complete coverage by robots would challenge workers' employment opportunities. The limited coverage is reflected in two main aspects: 1) the robot's size, movement ability, and other factors limit its capability to complete tasks in corners and narrow areas, which restricts its work coverage; 2) immature technology makes it difficult for robots to complete tasks for certain construction processes and special positions that heavily reliant on human experience.

4.4 Organizational Support

Organizational support refers to the influence from the organization on workers' acceptance of robots, mainly in the areas of work interface management and income assurance, as elaborated below.

Work interface management: As highlighted by many workers (40%), the division of work between robots and workers is a significant issue that requires attention at the organizational level. The main purpose of work interface management is to clarify tasks and define the responsibilities between robots and workers, thereby preventing mutual interference during construction. Proper work interface management is crucial during the early stages of robot technology to avoid disrupting workers' normal activities, which could adversely affect the acceptance of robots by workers.

Income assurance: Almost half of the employees (48%, n=19) believe that the company must guarantee their income regardless of robot performance. This can be interpreted in two ways: (1) when the introduction of robots affects the efficiency of workers, they are happy to accept them if guaranteed a reasonable income (e.g. time-based pay); (2) even though robots somehow save workers' time and effort, workers are unwilling to reduce their income as a result. It is evident that income is the primary concern for workers and significantly affects their acceptance of robots.

4.5 Social Influence

Social influence refers to various social processes and mechanisms that influence workers' perceptions of construction robotics (Venkatesh & Bala, 2008), which was also found to influence the acceptance of robots by workers, grouped into social processes and job competition, as mentioned below.

Social processes: The development of society and advances in technology across various industries have shown workers the benefits new technology has brought, encouraging a positive attitude toward construction robotics. Furthermore, the increasingly aging population suggests that robots are likely to be widely used in the future to supplement the workforce. It was perceived that accepting and learning robotics could enhance workers' competitiveness. However, the development trend of the construction industry may influence workers' perceptions of construction robotics. For example, the current downturn of the construction industry in China negated interviewed workers' acceptance of this new technology, as they believed the advancement of construction robotics was contingent upon industry growth.

Job competition: During the case study interviews, a majority of workers (58%, n=23) perceived robots as competitors and potential threats to their employment. There is a growing concern that robots are taking job opportunities away from human workers. The introduction of robotics will reduce labor demand, potentially leading to job losses or income decline for construction workers. This trend may engender negative attitudes toward accepting construction robotic in their work sites.

5 Discussion

5.1 Factors Influencing Workers' Acceptance of Robotics

The study examined the attitudinal acceptance of construction robots from the perspective of workers, who are the key group that works most closely with robots in practice. The study identified five major dimensions that influence workers' acceptance of construction robots, which are related to workers, robots, and external influences. Specifically, a new framework of workers' acceptance of construction robots (WACR) was derived, as shown in Figure 5. Key findings are elaborated below.

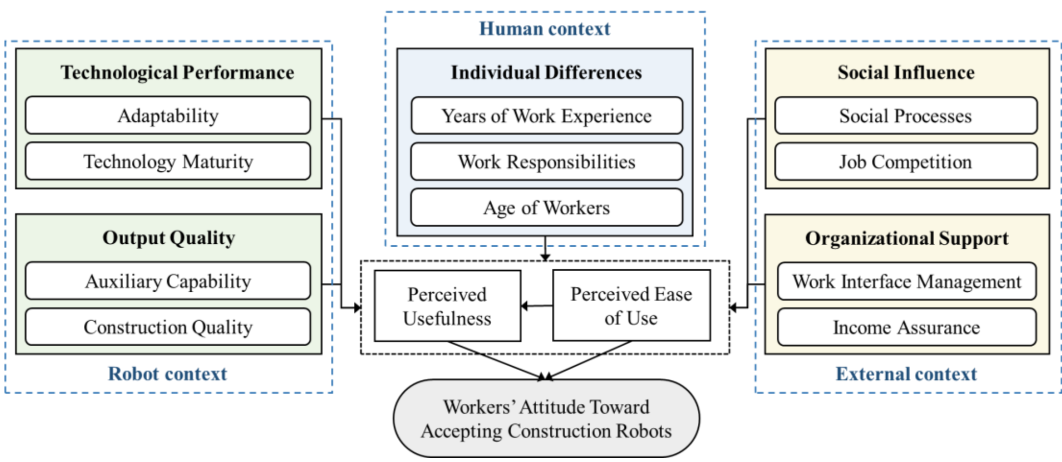

Figure 5: Framework of workers' acceptance of construction robots (WACR)

Firstly, the findings of the case study and semi-structured interviews indicated that differences in workers' age, years of work experience, and trades affect their acceptance of construction robots. The findings echo with those reported by Esterwood, et al. (2022), who highlighted that factors such as personality traits, age, gender diversity, and tasks impact the acceptance of general robots. Besides, younger workers with less experience were more likely to accept the use of construction robots. Additionally, workers engaged in different types of work exhibited varying levels of acceptance.

Secondly, previous studies revealed that both technological performance and output quality are key determinants of the acceptance of new technological innovations (Marangoni & Andrina., 2015; Silberer et al., 2023), which are consistent with the results of this study. The ability of construction robots to perform complex tasks in site environments is crucial for workers' acceptance of robots, particularly for workers with a neutral attitude toward robots. Besides, if robots can assist workers to achieve better construction results while saving time and labor, it encourages workers to form a more positive attitude.

Thirdly, external influences from the organizational and societal levels primarily impact workers' employment opportunities and income, which indirectly influence their acceptance of construction robots, echoing earlier research (e.g. Meissner et al., 2020).

In summary, the extent to which robots can assist workers in achieving high returns with minimal effort was considered to significantly influence workers' acceptance of construction robots. However, this finding differs from Park et al. (2023)'s study, which identified that the perceived effect of life—considering that robots could bring better working conditions, increase productivity, and reduce occupational risks—has no significant impact on construction personnel acceptance of robotic assistants in construction works. This might be due to several possible reasons: 1) the different focused regions, considering China and US; 2) the different surveyed personnel, as this study focused on frontline workers while Park et al. (2023) considered five groups and targeted not just worker level; and 3) the different survey distribution mode considering whether the survey is allocated as a top-down task. This distinction further reveals that the impact of construction robotics on the quality of life could be a significant concern for frontline workers, whereas other construction personnel who engage in non-heavy labor and do not directly participate in construction activities tend to exhibit different attitudes.

5.2 Strategies for Future Development of Construction Robotics

Based on the research findings, the paper proposed several strategies to facilitate the workers' acceptance of construction robots at three levels: organizational, technological, and governmental.

Firstly, the study reveals that most workers could passively accept the introduction of robots as long as their reasonable income is guaranteed. To facilitate workers' acceptance of robots at the development stage of robotics, more attention should be paid to managing work interfaces for optimal human-robot collaboration. Besides, construction organizations should accept potential risks associated with the introduction of robots, such as schedule delays and quality defects. Furthermore, it is essential to ensure that workers' incomes will not be diminished by robots, which could be achieved by improving contractual agreements or providing subsidies to workers.

Secondly, site manager interviews indicate that companies typically compel workers to use robots without considering worker ideas and feedback. Together with the findings of the case study, several strategies are proposed for the design and advancement of construction robotics: firstly, the design needs to be fully integrated with practical experience and the needs of workers, with ongoing iterative updates; secondly, there is no necessity to pursue the complete automation of robots unless they reach high maturity and intelligence, and it is important to combine the respective advantages of humans and robots to develop intelligent auxiliary equipment to assist workers in improving efficiency; thirdly, priority should be given to the promotion of robots with high technological readiness and real-world performance to enhance acceptance.

Thirdly, enhanced government support could potentially increase workers' acceptance of construction robots. The government should vigorously promote the development of construction robotics. This may be achieved by enhancing government-industry-academia collaboration, transferring useful research findings to industry practices (Faisal et al., 2017), and implementing other measures. As previously mentioned in this paper, the technological performance of robots greatly affects workers' acceptance of them. Besides, the government should provide economic and policy support to construction companies that are implementing construction robots. It would be beneficial for the government to supervise these companies to ensure the rights and income of workers. Additionally, it is advised that the government should provide workers with advanced technical training to enhance their capacity to adapt to the transformation of automation and robotics in the construction industry.

6 Conclusion

This paper investigates the workers' attitudinal acceptance of construction robots. The research combines a critical literature review, a participatory case study with a residential project, and semi-structured interviews with site managers. The study reveals five major dimensions influencing the acceptance of robots by workers and proposed a new acceptance framework of workers' acceptance of construction robots. In addition to individual differences, technological performance and output quality of robots are significant concerns for workers. Furthermore, external influences such as organizational support and social influences have a significant impact on workers' acceptance of construction robots. A comprehensive analysis of these factors concludes that workers' acceptance of robots fundamentally depends on whether the use of robots can bring benefits to workers, such as saving time, reducing labor, and increasing income. Strategic recommendations are also derived for the future development of construction robots.

The study enriches the theory of robot acceptance in the construction industry from the perspective of construction workers by proposing a new framework of workers' acceptance of construction robots. This research contributes to providing a novel perspective on understanding construction robot adoption from end-users, which should assist robotic technology suppliers in promoting human-centered design, building contractors in introducing robotic systems, and related institutions in publishing favorable guidance for the development and application of construction robots. However, the study has the limitation that workers in only one project in the Greater Bay Area were involved and the findings may not be generalizable to other regions and contexts. Therefore, future work will be twofold. Firstly, the study will engage practitioners from different regions and projects with various demographic profiles to increase sample scale and diversity to obtain more representative and generalizable findings. Secondly, a quantitative follow-up study will be conducted to validate the proposed framework and explore the interrelationships between the influencing factors.

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