

Towards Human-Robot Collaboration in Construction: Current Cobot Trends and Forecasts

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Abstract

Collaborative robots, or cobots, provide opportunities for their use in a range of complex scenarios in different industries, including construction. As a variant of industrial robots commonly used in automation, cobots incorporate inbuilt safety measures, lower costs, and easier operator programming. This article questions the state of recent peer-reviewed research regarding the uptake and implementation of collaborative robotics in the construction industry. A ‘horizon scanning’ review of literature is presented in this article to uncover recent trends and forecasts in cobotics research specific to the construction industry. The horizon scan targets examples of human-robot collaboration (HRC) and other human-robot interactions (HRI) focussed on construction tasks. By examining where HRC has been applied in construction, we identify which drivers, enablers, and barriers that influence the future of construction cobots. Human-readable task models coupled with vision systems, such as augmented reality or haptic feedback and wearable interaction devices are strong enablers in how HRC can be better adopted. Most existing research into producing diversity in robot interaction methods for HRC prescribes to overcoming static approaches, which is well suited to answering the ever-changing nature of the construction sites. On the other hand, the dynamic nature of construction sites and worker perceptions impact the uptake of new technologies in industry where cobots are often mistaken for highly automated industrial arms. Based on these findings, the need to build trust through successful use cases and case studies that demonstrate successful outcomes and productivity evaluations are necessary to overcome the barriers to cobot adoption in the construction industry.

Keywords: Human Robot Collaboration (HRC), Collaborative Robotics, Construction, Horizon Scan, foresight methods.

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1 Introduction

The construction industry is a major contributor to worldwide economies. Globally, construction spending is estimated to be \$10 trillion annually and accounts for 13% of the world’s GDP¹. Despite this, construction is often plagued by well-documented inefficiencies ‘on-site’, which is compounded by high-risk, low productivity, and difficulty in fulfilling jobs². Additionally, the construction industry has an itinerant workforce, where it can be difficult to retain skilled workers for long periods of employment^{3,4}.

While technology is often considered to offer a solution to aid or cure these issues in many industries – in construction, the industry remains conservative in promoting new technologies⁵. In similar sectors such as manufacturing, technology has been the vanguard of applied research that influences industry to support the workforce while increasing the quality of products and output quotas.

Robotics is one such technology, originating with automation in factories and developing into configurable systems to replace repetitive jobs or simple tasks. However, the application of robot technology in the construction industry is widely lacking⁵. Lack of robot adoption is frequently attributed to the dynamic nature of construction with rapidly changing sites, persistent safety hazards, and constantly evolving project attributes⁵.

Researchers have started to engage with developing construction robotics for niche applications. These novel approaches capitalise on the benefits of using robots - such as performing repetitive, precise tasks, or computational data-driven complexity in assembling materials⁵. While the positive application of construction robots is evident, the uptake of implementing robotics ‘on-site’ is relatively slow in comparison, while other industries make quicker advances in introducing robots to their respective workspaces.

Recently, there has been an increased interest towards developing variations of industrial six-axis robots – called collaborative robots, or cobots^{6,7}. Designed to work beside human workers, cobots are capable of safe human-robot interaction (HRI) during the robot’s operation in a shared workspace^{6–8}. Cobots exist to assist, complement, and augment human work – rather than replace humans and fully automate their tasks^{7,9}. Many attributes of cobots are well-suited for helping construction workers including their capacity for utilising different tools and easy programming which affords flexibility in work tasks¹⁰. This ability to be allocated into different roles responds favourably to the dynamic change of construction sites. Ongoing documented issues in construction that cobots could assist, includes; human assistance factors, strenuous or hazardous tasks, efficiency, and reliability^{11–15}.

Approaches in designing cobot systems for work tasks focus on the interrelationships between cobots, humans, the shared environment, and the task or product to be manipulated – often referred to as socio-technical systems^{16,17}. This type of approach goes beyond a pure technology lens and holistically places the human’s work activities, their health and safety at the forefront of human-centred methods^{16,17}. This current way of thinking emphasises safe interaction between cobot and human^{18,19}.

Despite these developments towards human-centred cobot design, there is limited evidence for where current trends indicate future directions for cobots in the construction industry. This article investigates the future-facing trends in construction cobots, specifically targeting examples of human-robot collaboration (HRC) as a type of interaction between humans and robots. This research queries where HRC has been applied in construction, and which drivers, enablers, and barriers influence future adoption.

The study uses a method of forecasting future industry direction called horizon scanning, to gather data trends in emerging technology research fields. Cobotics and HRC in construction were targeted for early detection and prediction of future research. Our contribution provides a thorough review of research concerning human and robot collaboration construction activities. As both HRC and robotics in construction are growing research and industry interest areas, it provides value to academia and industry to acknowledge the current focus of construction cobot applications and anticipate future trends.

The structure of this article is as follows; an introduction to construction issues, and a brief background of cobots and HRC. The research design and method of reviewing publications are described, followed by a discussion and conclusion.

2 Theoretical Background

2.1 Collaborative Robots – Cobots

The concept of cobots has changed from the mid-90s when it was first conceptualised as an assistive machine collaborating on simple tasks²⁰. The current definition places the cobot as a robot intended for direct interaction with humans within a shared space. Cobots are frequently characterised by lightweight materials, organic forms, limitations of speed or force and reliance on sensors and software for safe activity. However, current cobot definitions consider cobots as a special type of industrial robots²¹, i.e. so-called cobot manipulators (such as robotic arms), which collaborate with humans in a production context²². However, there is a recent trend towards a broader understanding of cobot types and forms. The form and type of cobot can depend on the context of use and features. Although, in construction research, robotic arms are most frequently used, unmanned ground vehicles cobots are also investigated for services like logistics.

Some cobots might assist by performing easy, tedious, or unhealthy tasks and allowing a skilled worker to focus on a more profitable task^{23,24}. Other cobot applications work closely with humans on the shared labour of lifting, picking, placing, and assembling materials^{25–27}. Thus, cobots aim to remove the rigid barriers typical in industrial automation and provide flexibility in human environments. The application of cobots into workspaces while offering many opportunities also come with challenges regarding the provision of safe spaces for humans and the design of efficient and ergonomically optimised workspaces^{17,28}. One consideration is that cobots are often installed where they are required, and subject to being placed without barriers into existing human environments²⁹. Complimentary systems, such as vision and touch sensors, augmented human interfaces, and artificial intelligence (AI) are frequently explored in research as approaches to assist cobotics interact safely with humans.

2.2 Human-Robot Collaboration

Human-robot collaboration (HRC) forms both the goal, and the foundation of any cobot system. It refers to the activities between humans and robots working collaboratively to complete a project task in a specific work environment¹⁰. Conceptually, any HRC task should capitalise on the strengths of the human (e.g. decision-making, problem-solving, and complex sensory-motor skills) and the attributes of the robot (e.g. precision, efficient repetition, controlled use of force, high productivity)¹⁰. The ability for humans to work with cobots that provide additional strength and repeatability offers alternative avenues for increased efficiencies and productivity while improving human health and safety³⁰.

The ISO standards for use of collaborative robots (ISO/TS 15066)²² describes four approaches of ensuring safe operation of cobots in workspaces. To qualify, one or more of the following approaches need to be implemented: (1) safety-rated monitored stop, (2) hand guiding operation, (3) speed and separation monitoring, and (4) power and force limiting²². The simplest collaboration activities appears to replicate automated solutions complete with separation of robot cell and task, from human workplace and task³¹. Other investigations of HRC bring to account the complexity of a modern cobotic system, consisting of many components, non-linear relationships between components, and being reconfiguration capable³². Currently, there is a drive towards cooperation activities which will allow humans and cobots to physically interact and simultaneously share a workflow, space, and task. These approaches use retrospective analysis of existing HRC systems, to re-design and ultimately propose future iterations of HRC. Moving beyond system analysis strategies such as sequential division of task for either human or robot roles, other approaches demonstrate successful re-designing tasks from human-centred approaches to help guide future human-cobot systems.

Recent cobotic frameworks such as those proposed by Kopp et al.⁶ have acknowledged and proposed categorisation that differentiates HRC activities along cobot system types. The typology of these interactions – shown in Figure1 – displays a range varying from full automation, activity separation, sequential shared tasks, and cooperation resulting in actual collaboration. These typologies have been used to help classify the collected publications that are reviewed in the horizon scan. The framework aids in uncovering types of HRC currently being investigated in peer-reviewed journals.

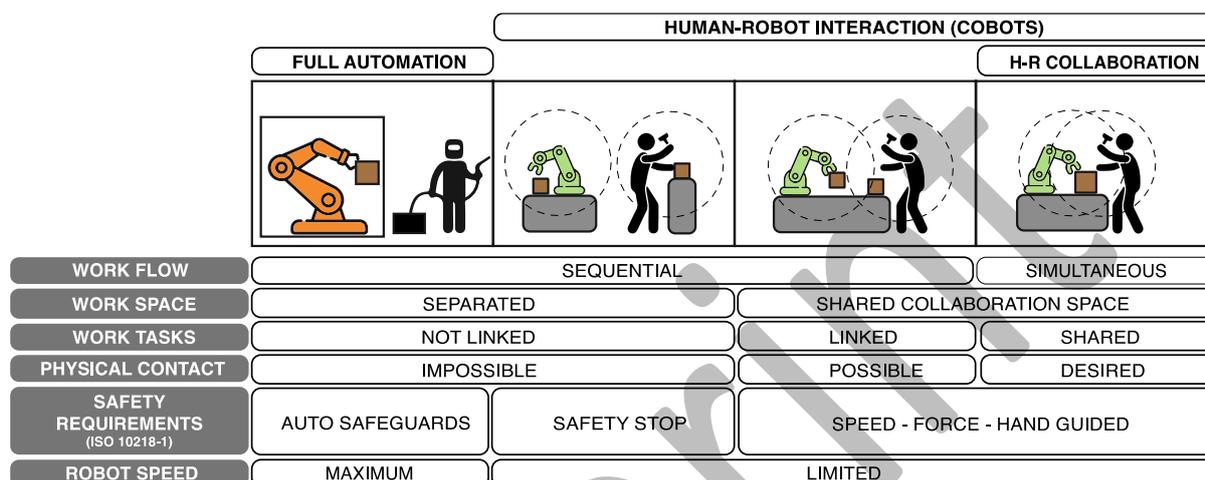


Figure 1 – Types of human-robot relationship. Adapted from Kopp et al.⁶

3 Research Design and Methods

This study uses two methods of data collection to combine the analysis of a structured database search with an open-ended search. In the first step, the PRISMA method was used to select publications for review, and extract data for coding³³. The second step used a horizon scan analysis to ‘snowball’ and gather relevant cited literature for predicting future trends³⁴. Both these methods are described in following sections. The research database Scopus was used to find relevant publication results. Scopus was chosen because it is the most accepted and frequently used database for HRC related research, with coverage of approximately 71 million multidisciplinary publishing items, and 1.4 billion references.

3.1 PRISMA and Coding

The PRISMA approach identified and systematically selected papers on the focal topic³³ – in our case, research on human-robot collaboration, HRC, collaborative robots or cobots within the construction field. Variations of these target words or solo searches produced restrictive numbers of papers (i.e. less than 20 results), or broader keywords and topics not relevant to our study (i.e. construction of robots). In Scopus, we searched title, abstract, and keywords using the following search term: *((collab* W/1 robot* OR cobot*) OR ((human-robot AND collaboration) OR HRC) AND construction)*.

We limited our search to publications in English language as well as peer-reviewed journal articles to ensure a sufficient level of research quality. This resulted in 123 documents. Their titles and abstracts were reviewed to exclude irrelevant research (e.g. sports science, medicine, material science etc.). Duplicates of publications, mislabelled keywords, or wrongly categorised records were also removed. This led to 52 publications for the subsequent detailed analysis.

The 52 documents were subjected to a first-round pass of systematic reviews; to gather key points, extract pertinent data, and develop a coding scheme of qualitative themes (Table 1), using both deductive and inductive coding analysis³⁵. The second-round review analysed the extracted data, categorising publications with codes. Each document established codes to represent: the research type conducted, human-robot relationship defined, and robot types used. The code variables are shown in Table 1.

Table 1: Code variables

Research Type	Human-Robot Relationship	Robot Type
Applied (e.g. on-site)	Collaboration (HRC)	Collaborative robot
Laboratory	Cooperation (HRI)	Industrial arm robot
Theory / Concept	Coexistence (HRI)	Other robot type (i.e. UAV)
Algorithms / Control Models	Automated (e.g. CPS, programmed toolpath)	Multiple robots
	Simulated (computer)	N/A
	Simulated (XR environment)	
	Multi-modal method	
	N/A	

3.2 Horizon Scan

Following the PRISMA selection and coding, in the second part of the data collection, the horizon scan allowed us to gather highly relevant papers citations targeted via the review process – this is often referred to as ‘snowball’ selection or a chain-referral non-probability sampling of recent publications^{34,36–38}. The citation papers provide support for the findings and highlight further avenues of investigation or knowledge within a narrow field of developing research.

For this reason, a horizon scan is not a conventional approach to a literature review. There is no painstaking evaluation over a longer duration – instead, the literature captured relating to HRC and construction is aimed to be recent, interdisciplinary, and adequately capture the most recent foundational research that highlights future directions. Horizon scanning is useful for capturing early stage of development in nascent research topics²⁶. The resulting list of references provides a vivid collection of publications for the reader to form their own connections and conclusions.

4 Results and Coding

The PRISMA selected articles contained the earliest publications from 2016, and a noticeable increase in journal articles from 2019 onwards. Three graphs showing the types of research, human-robot relationship and focal robot are shown in Figure 2. Most of the studies reported in these articles took place within laboratories or controlled environments (n = 26), noticeably the lowest number of studies were applied directly to construction workplaces (n = 4). Papers proposing and evaluating theories or concepts behind human-robot behaviours placed second making up about a quarter of studies (n = 13). Numerous documents focussed on algorithms, or the control systems designed to command robot activities (n = 8).

Analysis results of the types of human-robot relationships studied in the collected articles showed the most common methods of research was on automated robots (n = 11). Occasionally, a study might use a combined human interaction that led to an automated solution – these types of articles

are considered as multi-modal methods ($n = 4$). Several documents focussed on theory of social robotics, system design, or mathematical models, and surprisingly did not address any specific definitions HRC – listed as “not applicable (N/A)” ($n = 13$). Simulations accounted for almost a fifth of the publication topics, including simulations via computer ($n = 8$), or virtual and augmented interactive applications ($n = 3$). These values are represented in a graph, Figure 2. A selection of

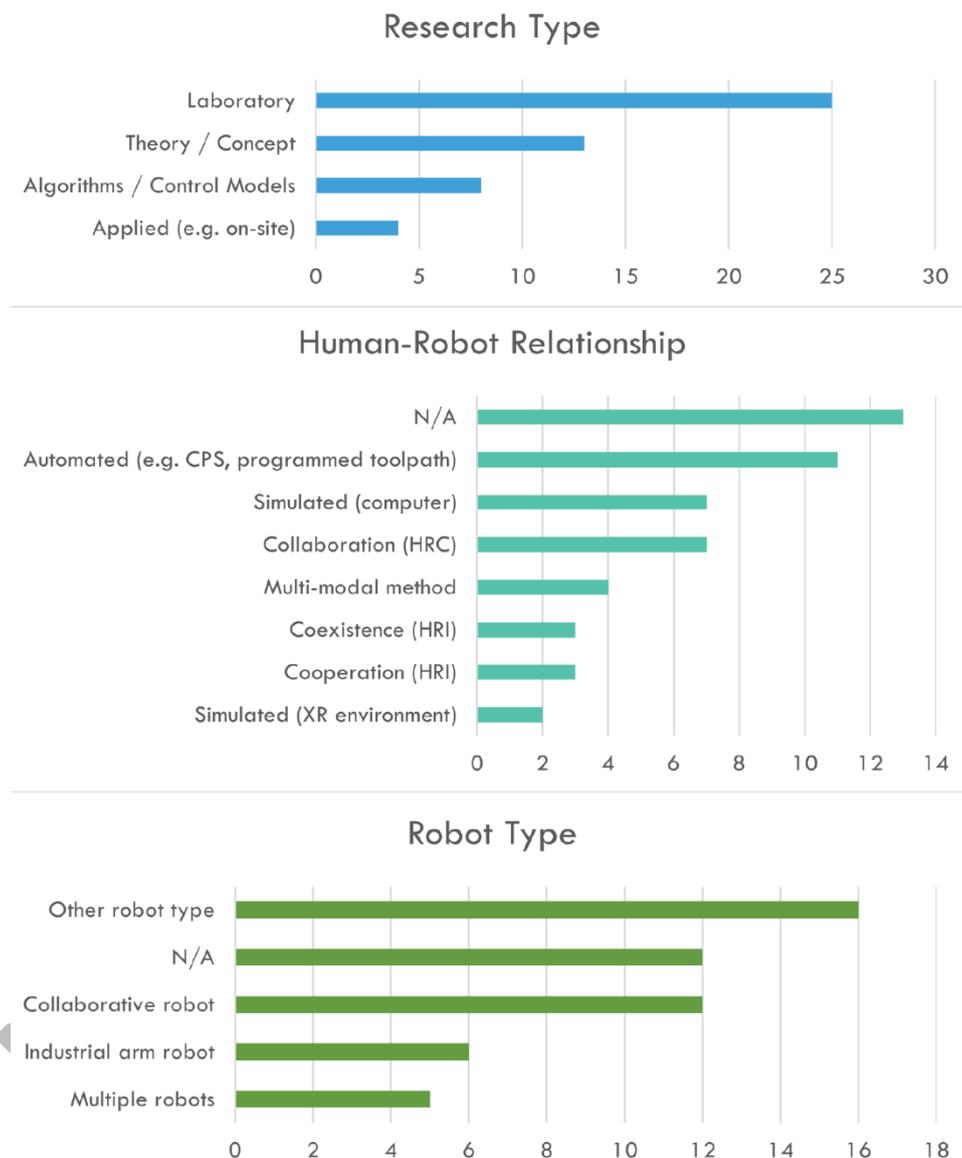


Figure 2: Graph representation of results from coding analysis.

codes that were used in the analysis of the articles were deduced from the framework proposed by Kopp et al.⁶, and these provided types of Human-robot interaction (HRI) research including examples of human-robot coexistence ($n = 3$) and cooperation ($n = 3$). Studies that we consider as examples of HRC were found in a modest number of collaboration studies ($n = 7$).

Coding for robot type uncovered which robots were being targeted in construction for HRC research. Once again, theoretical, or mathematical papers negated to apply the research to specified robots ($n = 13$). Many studies focussed on unmanned ground vehicles or unmanned aerial vehicles ($n = 16$). A few studies used industrial six-axis robots ($n = 6$), and many opted to focus on commercially available six or seven-axis cobots ($n = 12$). Some studies investigated combinations using multiple robots of varying types ($n = 5$), see Figure 2.

5 Discussion

5.1 General challenges of construction sites for cobots

The analysis highlighted several characteristics of a construction site in comparison to a factory environment, which can cause challenges when applying cobots. A key issue is the dynamics of a construction site⁵ affecting the position of building structures and other machinery as well as changing weather and lighting conditions that can affect cobot sensors. This is closely related with the challenge of cobot localisation and contextual awareness of a cobot, including both the position of the cobot and the precise position of the end effector³⁹. This is further complicated by the possible instability of mobile cobot platforms especially on uneven and unstable grounds, which also include holes as fall hazards. Dirt, dust and fluids can cause a contamination hazard, which could affect mechanical joints as well as visual sensors. Working in close proximity to other heavy machinery like jackhammers and their resulting vibrations can affect sensors, platform stability and resulting work precision. Aside from those machinery and excavation holes as potential fall hazards for cobots, there is a multitude of persistent safety hazards⁵. A common safety risks of cobots also in manufacturing is the improper use of unsafe tools, which jeopardise the inbuilt safety features of a cobot, such as using a sharp tool that circumvents a potential force limitation of a cobot. This often is a result of insufficiently trained operators. Given the high amount of untrained workforce in construction⁴⁰, this risk could be amplified. Although being usually fenced, construction sites are usually more open than a factory site and involves a higher diversity of contractors and sub-contractors. This increases the risk of untrained personnel coming close to a cobot or crossing its operation space, which could both risk injuries as well as decreased operation efficiency if the cobot frequently needs to stop or replan its paths of movement. These challenges formed the basis for the following considerations of where and how to use cobots in the construction industry.

5.2 Traversing Lab to Site

Our horizon scan shows there is evidence for reservation in applying HRC within the construction industry. The traditionally conservative nature of the construction towards emerging technology, suggests that research has difficulty crossing over from laboratory-tested prototypes to practical on-site applications^{41,42}. However, the industry can benefit on current trends in robotics, and supportive technologies like augmented reality and robotic vision^{43–45}. Other industries, like manufacturing or mining technology, have explored HRC for longer^{46,47}, but cross-industry knowledge and learning has not been utilised systematically.

In construction, traditional techniques are still prevalent – trades like carpenters, bricklayers, plasterers, and painters still use methods, tools, and materials that have existed for centuries. These jobs are labour-intensive, easily encumbered by outside factors, and beset by health risks - some with long lasting implications⁴⁸.

One of the main drivers for implementing cobots on construction sites would include performing labour-intensive, repetitive tasks in the field to reduce health hazards to workers. Construction companies would benefit by redistributing workers from cobot-assigned tasks, towards other tasks that humans are better suited to perform, such as complex technical tasks⁴⁹. Reducing the cognitive load of workers helps to mitigate error and control production quality⁵⁰. Other human factors involve issues in productivity – worker turnover, absenteeism, accidents and injury, changing workload^{51,52}. The construction industry relies on human decision making and is predicted to be difficult to automate fully⁵² – hence the capability for cobots to make a larger impact.

5.3 HRC rapidly emerging in parallel to automation

What has been identified in the horizon scan is most investigations focused on automated robot systems for reducing worker involvement on construction activities. Some automated systems are co-developed as components of Cyber-Physical Systems (CPS), controlled by artificial intelligence such as machine learning, or data-driven algorithms^{53,54}. To date, many automated systems have produced construction robotics that isolate worker interaction. The findings show that lab-tested types of construction robots seem to be getting closer to being practically realised in the construction market^{55–57}.

Despite the influx of automated examples, HRC shows evidence of strong contention to enable a subtype of construction robotics to become commonplace on building sites. One driver of construction cobots includes prioritising better and efficient interaction for human-cobot communication and operation. There is popularity in developing diverse human-in-the-loop approaches^{58,59} – that requires human interaction to operate. Learning by Demonstration (LbD) is established as one method of interaction, that is practical for simple repetitive tasks^{60,61} such as plastering, painting, and bricklaying - and can be done rather easily without requiring extensive programming skills.

Multi-modal methods of human-robot communication will enable further confidence with human workers, particularly natural language processing (NLP) or speech to text (STT) allowing workers to speak their commands directly to a cobot^{62–64}, which would make working with cobots even more intuitive and easier than LbD. Although still early stage research, neurological linked hardware bear the future potential of using ‘brain commands’ to provide a unique method of communicating or showing activity intention to a cobot^{25,65}. Human-readable task models, including control, localisation, and perception algorithms^{62,66,67} coupled with vision systems^{68,69}, such as augmented reality, and proximity sensors⁷⁰ will continue to be strong enablers in how HRC can be better adopted. Haptic feedback and wearable interaction devices will provide levels of cobot-to-human communication of intended activity^{71–73}.

5.4 Diversity in Cobot Types and Implementation

Most of the research into producing diversity in robot interaction methods for HRC prescribes to overcoming static approaches, which is well suited to answering the ever-changing nature of the construction site. These explorations aim to reduce the barriers of bringing HRC into construction by reducing the need for high programming efforts to command a cobot. E.g. one approach aims to increased flexibility in programming cobots using interactive assistants to teach them to do tasks^{74,75}. Many of these teaching systems focus on common human activities such as drawing to allow humans to communicate their cobot commands⁷⁶. Recent learning frameworks are proposed and tested for future HRC approaches, and often focus on learning human actions to aid predictive systems⁷⁷. Examples also exist of novel methods of construction and adaptive space-making demonstrating the benefit of using such customised robot systems within projects^{53,78,79}.

Bibliometric studies show diversity in the types of construction robots designed⁸⁰. Recent examples of diverse robotic systems have been applied to using multi-robot collaboration. Explorations use multiple mobile robots for wall building⁸¹. Heterogenous methods combining industrial multi-axis robots and UAVs (i.e. drones) also demonstrate the flexibility of robot solutions in tackling the dynamic construction environment⁵³. The findings show that cobots are often desired to be mobile and moved to the tasks where they are needed^{29,82}. Other HRC research typologies that have been pursued include wearable robotic exoskeletons, designed to assist workers in transporting heavy objects^{48,83}.

A frequent approach to construction related research suggests that specific tasks are targeted In construction areas such as masonry⁸⁴, timber carpentry and joinery⁸⁵, welding⁸⁶ and earth works⁸⁷

are common investigations. Bricklaying has demonstrated some well-known examples of practical building^{55,56,88}, as well as well-developed and tested commercial options such as Hadrian X⁸⁹. Hilti, a manufacturer of construction tools, has demonstrated successful operation with an automated mobile concrete drilling Jaibot⁹⁰. However, commercialisation of these systems still must overcome the perceptions of novelty within industry. Other methods of creating wall partitions include large-scale 3D printing robots show promise but are not yet shown the optimism in the profession as an alternative to traditional wall building^{56,81,91}.

While these projects exemplify automation in construction, they are examples of systems that can be HRC compatible – and for many of these example systems the difference would be the exploration of integrating methods of human interactions to systems that are already driven via computer simulations.

5.5 A Role for Real-Time Simulations

A commonality with HRC systems is the use of computer simulations, usually a precursor to the system that controls the physical cobots or run independently of such systems¹⁹. Already there are many examples of simulation based HRC research, and these will continue to be a large enabler in developing cobots for on-site application. The main positive for using simulations including not needing to interrupt current work progress is to experiment. Although simulation is not a complete replacement for in-situ testing – the benefits to using a simulation helps to minimise costs of multiple experiments, and even allows for rapid testing of dynamic changes to the proposed cobot design. Immersive environment simulations (e.g. using AR, VR environments) are a growing resource in calculating accurate outcomes for cobot proposals²⁸. Path planning can be visualised in such a system, and often a digital twin can be utilised to communicate real-time information in the working environment^{32,92}. Challenges to using simulations, particularly digital twins include mapping dynamic environments⁸⁷. However, AR has shown practical success as an interface for skilled workers to utilise robots for technical craft skills such as plastering⁵⁷ and carpentry⁹³. Simulations have shown to contribute to productivity increases through testing of human-cobot tasks⁹⁴. The virtual environment approach has demonstrated success in building human trust in working beside a cobot and discovering the role of personal space and ongoing technology exposure for cobot acceptance¹⁸.

5.6 Supportive Research for Flexible Applications

The current and future-facing trends uncovered by the horizon scan in this article shows similarities in HRC research across industries. The manufacturing industry has a notable larger community of researchers focussing on collaboration with robots, and it is predicted that construction research that has gradually experimented with automation will similarly increase its focus on HRC towards the construction site.

Growth in supporting technologies (e.g. robotic vision, RFID) aims to provide additional functionality for cobots and provides an enabler for practical applications in dynamic workspaces⁹⁵. Predictive algorithms that track hand motions and gaze⁶⁶ are types of supportive research that promote natural human interaction with cobots. Meanwhile SLAM algorithms help to map a constantly changing environment and providing vital data, especially for mobile robots on-site^{19,96}.

A notable area of HRC research looks at end effectors for providing flexibility to cobot related tasks. End effectors provide the means for robots to act upon their environment, and many research projects explore creating new tools. To overcome task specificity, these projects aim to increase dexterity⁹⁷, as well as flexibility in workspace configuration and disassembly⁹⁸, flexibility in application of robot to task²⁵. One approach increases the flexibility of cobot application, by mimicking the versatility of the human hand using soft robotics^{97,99,100}. Other approaches aim to capture maximum efficiency of a singular purpose. Examples in construction include screwing gypsum boards on the ceiling¹⁰¹ and painting high walls¹⁰².

5.7 Barriers of Implementing HRC in Construction

The findings show that typical barriers that exist show that market competitiveness is a driver for industry success – often summarised as “the race to the bottom” for cost proposals in construction tenders. Ultimately this standard of industry greatly influences adoption, particularly with costs of designing, testing, and integrating a cobot on site⁸. Project costs, which are frequently low-profit, and high-risk in industry make it difficult to implement high-cost, high-risk ventures like cobots. Additionally, moving from cobot-ready environments into dynamic construction sites require successful projects of implementation, evaluations of productivity, and outstanding project outcomes^{25,98}. Continued research into supportive technologies will help remove perceived barriers that allow cobot-human communication. Furthermore, worker perceptions influence the uptake of new technology in industry, and cobots are mistakenly grouped together with automated, industrial arm robots. Building trust to use a cobot, and prior human-robot experiences influence safety framework models and technical adaptations to workflow^{18,29}.

6 Conclusion and Predictions

In this horizon scan we have shown how a major contingent of HRC research into construction does not currently take place on building sites, but within laboratory environments or using computer simulations. Construction, like many industries, has an uneasy perception of robotics in their workspace – driven by the fear that workers will be replaced by automated machines. Generally, construction is behind the curve with technology adoption, but with shortages of skilled workers, and pressures to build faster and efficiently, construction could turn toward robotics sooner.

HRC is rapidly developing, and this is evident with the interest in research into supporting peripheral technologies that have direct influence on the functionality of cobot systems.

While the scope of this review is not sufficient to present a complete view of the cobot landscape, it peeks at the future direction of nascent research that shows promise in HRC. One conclusion drawn from the research suggests that a holistic approach to understanding the human role and other technologies in collaborative robot systems will have a greater impact on future cobot designs. The article is a contribution to academia as a current snapshot of where HRC is currently situated with construction research. While the practical implications of bringing cobots into construction are documented, there is a lack of exemplar projects necessary to convince the industry to take the next steps of bringing cobots onto site for more than the occasional high-profile project. The increasing market of prefabricated buildings and homes will also drive opportunities for cobots in both the manufacturing of building components and cobots assisting with assembly of prefabricated buildings.

On building sites, it is likely that a variety of cobots could be implemented successfully. UGVs could transport materials and remove construction waste, and drones could be used to aid with documenting the metrics of building, such as measuring accuracy, datum calibrations, and real-time changes to the environment. Wearable exoskeletons would benefit activities that require strength, or confined spaces which is difficult for larger machinery to access. Overall, cobotic arms would perform multiple roles on site, using interchangeable tools, and being utilised rapidly between diverse jobs as cutting drywall panels, placement assembly, bricklaying, painting, or plastering. Allowing cobots to help assist humans or perform these tasks will eventually increase the productivity of the industry and demonstrate that the initial financial cost of providing a cobot on site will in time, and with better research and integration, deliver return on investment, and reduce construction labour costs.

Next steps of this line of research suggest a deeper dive in scanning future trends in collaborative robots for construction will be conducted by reviewing conference proceedings, with emphasis on the most recent HRC examples using on-site robots.

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