# New Risks for Workers at Heights: Human-Drone Collaboration Risks in Construction

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## ABSTRACT

Poor safety and low productivity have pushed the construction industry to increase the use of technology and automation. Consequently, robotic systems such as aerial and ground robots are becoming increasingly popular in modern construction sites. As construction is still a heavily human-driven industry, these robots need to collaborate, interact, and share their work environment with human workers. This integration raises novel occupational safety and health issues for jobsite personnel. In this conceptual paper, human-robot interactions and their potential collaboration areas will be discussed, focusing on robot types and their application areas. Next, the health and safety risks associated with human-robot interactions on construction sites will be discussed. This discussion will mainly focus on physical risks, attentional cost, and psychological impacts of such interactions on workers who work directly or indirectly with or around robots. Finally, a discussion will be provided on considerations and recommendations to ensure the safe integration of robots in construction.

## INTRODUCTION

Recently, the construction industry has had a shortage of skilled laborers to fulfill its ever-increasing needs. This shortage has forced construction workers to work additional hours to meet project schedules, a factor that has been shown to affect workers' levels of fatigue, which in turn reduces safety performance, judgment, and decision-making (Dawson and Fletcher, 2001). These factors increase the likelihood of workplace injuries (Dawson and Fletcher, 2001) and potentially even fatalities. This, in addition to other factors, makes construction one of the most hazardous industries to work for, as the industry accounts for approximately one in every five workplace fatalities (United States Department of Labor, 2019). With construction environments being characterized as dynamic and complex, associated statistics are not likely to surprise many, but they are serious enough to encourage construction researchers to explore innovative technologies with the aim of improving both construction safety and jobsite productivity.

The automotive and industrial manufacturing industries were some of the early adopters of automated robots, used to increase efficiency through reduced costs and labor hours. The construction industry is also beginning to develop and adopt robotic technology with the goal of making up for the known labor shortage and high rate of workplace injuries. The areas where automation and robotics are expected to make an impact involve heavily repetitive processes or tasks that expose workers to hazards. As there is no shortage of hazardous and repetitive tasks to be found on a construction site, it is expected that jobsites in the future will have many ground and aerial robots working and assisting workers with a variety of tasks. The idea of such human-robot collaboration would have seemed closer to science fiction in decades past but is quickly becoming a reality. Improvements in robotics, engineering, and the development of the necessary sensors, which are becoming more affordable, are helping to make the hardware possible. Advancements in Artificial Intelligence (AI) and machine learning have paved the way for ground and aerial robots to be used in a wide variety of disciplines. Construction, in particular, has recently started to adopt such technologies for day-to-day practices. For example, the construction industry has recently begun using aerial and ground robots to perform masonry work, excavation and earthwork, inspecting hard to reach areas, hazardous environments, and to generate true-to-life 3D models of built structures using sophisticated laser-scanning sensors. It is expected that the aerial and ground robots will populate and permeate jobsites soon, with future applications ranging from post-disaster hazard assessment and safety performance to bricklaying and painting facades.

As the advantages provided by aerial and ground robots continue to be realized within the construction industry, their adoption will only continue to increase. Despite the noted advantages of integrating robotic technology into the construction industry, the deployment also brings in the potential for additional workplace injuries and fatalities. Robot deployment could have a negative impact on workers through physical risks, attentional costs, and psychological impacts. The goal of this paper is to discuss the potential for such novel occupational and safety hazards brought on by this new technology. Knowledge of the risks of aerial and ground robots will help to create a roadmap for future research to help with the safe integration of robots within the construction industry.

## ROBOTS AND THE FUTURE OF CONSTRUCTION

Historically, the construction industry has been slow to adapt and adopt major technological improvements. This has had a negative impact on the ability of the industry to make any drastic gains in increasing efficiency and productivity (Roberts, 1987; Mitropoulos and Tatum, 2000). Given the lack of technological innovation and the lackluster results in improving statistics on safety and productivity, there is a need to adopt new technology that can help on both fronts. The addition of automated processes and machinery will help in eliminating the need for human workers in hazardous environments, with the added benefit of being able to work longer, without the need to rest.

With the known benefits of automating processes to improve the efficiency, safety, and profitability of other industries, it is expected that construction will follow suit as technologies become more economically viable and technologically adept. The construction sites of the future are envisioned to be permeated with aerial and ground robots working to monitor and assist in all aspects of the construction process from the preconstruction to the post-construction phases of a project's lifecycle (Figure 1). Table 1 lists some of the robots corresponding to different application areas expected to play important roles in future jobsites. Aerial vehicles will be able to serve as vital communication tools for sharing visual information related to progress monitoring, safety, and security in real-time. They will help carry materials and tools to workers who require them, and for carrying large payloads to assist in the vertical construction process, reducing the need for cranes and scaffolds. Ground robots will be capable of carrying out the excavation work precisely to the desired specifications without any human involvement. As the project progresses, additional robots will be called upon to perform the masonry work required to erect walls with efficiency and precision that could not be achieved by humans. The ubiquitous nature of aerial and ground robots expected in future construction projects will help to address the growing labor shortage that the market is experiencing, but it is not expected to replace humans entirely. Construction being a human-driven industry, there will still be a need for humans to collaborate with these robots in order to monitor and assist with tasks that robots cannot perform.

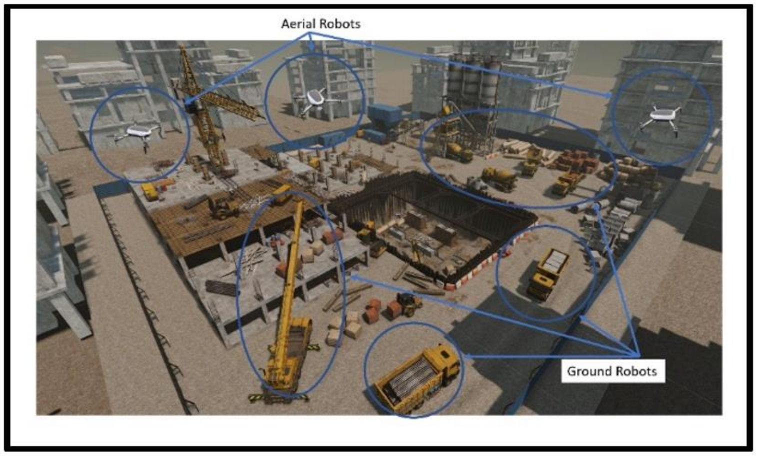


**Figure 1. Future Construction Jobsite**

**Table 1: Robots in Future construction jobsites**

| Robot | Application Area | Description |
|---|---|---|
| Rotary-wing UAV equipped with cameras & sensors | Progress Monitoring, Post-disaster assessment, Surveillance, Mapping, Building & Infrastructure Inspection, Safety monitoring, 3D Modeling. | Rotary-wing UAVs present a unique opportunity through the presently available technology to perform a wide array of visual data gathering tasks while being controlled by a pilot, operating in an autonomous or semi-autonomous fashion. |
| Rotary-wing Delivery UAV | Carrying objects around the construction site. | UAVs intended for carrying and handling materials present possibilities for carrying heavy payloads used to erect the building, they can also be used to deliver materials to workers in need, reducing the necessary walking time for workers to gather them. |
| Masonry Robot | Building walls. | Masonry robots are able to build walls using larger masonry units than humans can lift; being equipped with sensors allows them to perform work with a high degree of precision and relative speed. |
| Excavator Robot | Pre-construction site work. | Excavator robots are capable of being given a set of plans and carrying out the responsibilities to achieve the desired end result. They can also be remotely controlled by humans. |
| Finishing Robot | Concrete & Façade Finishes. | Robots used in surface finishing can reduce the need for workers to perform tasks at a height where they are prone to fall hazards. |
| Quadruped Robot | Site inspection and material handling. | The development of quadruped robots allows for easier movement across rough terrain compared to wheeled robots and they can also carry materials. |
| Load Hauling Robot | Carrying material. | In the earthwork process of readying a site for construction, a lot of material needs to be moved into or off of the site for proper grading. The use of an autonomous vehicle for this operation could save drivers from having to wait around to be filled and could free up their time for other tasks. |

## Aerial Robots

One such technology that the construction industry has adopted in recent times is the use of Unmanned Aerial Vehicles (UAVs), also commonly referred to as drones, which will be referred to as aerial robots in this paper from here forward. The construction industry has been the fastest-growing adopter of such technology in recent years, and their use only continues to grow each year (Drone Deploy, 2018). They are a versatile piece of technology and as such, their usage is quite variable. The main advantages of integrating aerial robots into construction processes are their ability to reach areas of a site that might be unsafe or not possible for humans to reach, and they can do it in much less time and at a lower cost when compared to typical means (Zhou and Gheisari, 2018; Albeaino et al., 2019). At present, their applications are largely focused on the gathering of visual data through a range of onboard sensors and cameras, which can be used for mapping, progress monitoring, safety inspections, building inspections, and much more (Albeaino et al., 2019). It is expected in the future that these aerial robots will take a more hands-on role within the construction process, helping to construct buildings without the need for scaffolding or cranes. This will allow for structures to be designed and executed in ways that had not been possible before (Stamp, 2013).

## Ground Robots

In addition to aerial robots, there has also been a rise in the use of ground robots to help increase the efficiency of jobsite operations. With skilled labor at a premium, automating components of the construction process will allow teams to continue to deliver projects in a timely, cost-effective manner. At present, a wide array of robotic devices are being introduced and implemented in the realm of construction ground robots. Developments are being made that allow standard excavating and bulldozing equipment to become unmanned, intelligent operators, capable of being given a set of plans and left to carry them out on their own. The technology used in self-driving cars is also being applied to the creation of large, autonomous load-hauling vehicles which can navigate around the job site with the help of AI. While the ease of navigation over terrain comes as part of being such a large vehicle, smaller wheeled or tracked ground robots can have difficulty when operating unfamiliar or uneven terrain. The recent developments of quadrupeds, or four-legged robots, such as “Spot” by Boston Dynamics, have the advantage of being able to navigate and traverse uneven or harsh terrain with ease (Boston Dynamics, 2020). Large robots capable of precisely carrying out masonry work are also being brought into use in construction. These robots are capable of greater precision and speed because they are controlled by sensors and can lift much larger materials than humans ever could. The use of collaborative robots, which work together with a human in the same space, working together to accomplish a common goal, has grown in use across the manufacturing industry for a wide array of applications (Grand View Research, 2019). This novel application, which works to harness the efficiency and precision of robots and the decision-making and flexibility of humans in the manufacturing process (Djuric et al. 2016), could prove to be an effective avenue of pursuit for the construction industry to further integrate robots into the industry. Attempting to implement a system, which operates in a largely invariable environment (such as a factory), in a dynamic construction environment poses several challenges. However, such systems could prove to be effective use cases for on-site pre-fabrication type construction projects. Ultimately, the goal in striving to automate workflows in construction is to reduce idle time and improve efficiency, so that workers can focus on other tasks, while the repetitive or hazardous processes are handled by non-humans (The Robot Report, 2019).

## HEALTH AND SAFETY CHALLENGES

Just as the use cases of aerial and ground robots in construction vary, so too does the level of human-robot interaction from case to case. The roles of humans and robots in working together will differ based on the kind of task that ought to be accomplished and the capability of the technology available. As defined by Tezza et al. (2019), humans can act as active controllers, where they are directing the robot via a user interface, and the drone is simply following the commands. In another case, humans may act as recipients, where they are not directly controlling the robot itself, but they may be receiving something from it, like a package or some sort of visual communication. More technically advanced, autonomous robots will not require the use of a human to control them during their operation but would require humans to act as supervisors in the role through either planning the route for them to follow, or to monitor the robot as it is moving about (Tezza et al. 2019). It is expected that moving forward, aerial and ground robots will continue to grow in their role as active collaborators, helping to perform physical tasks such as painting or carrying materials around the jobsite. Considering the rate at which robot usage and technology are increasing, there is a need to explore and create a framework for which their integration can be made more seamless, and safe for all involved in the industry, while considering the known risks of their usage.

In any case, they are used, aerial and ground robots present safety risks to the humans which surround them on the jobsite. As such, it is of vital importance to study the effects of the various risks associated with their adoption. The categories of hazards/risks generated using these robots to be examined will cover (1) physical risks, (2) distraction, and (3) emotional costs. The limitations of robot deployment on construction jobsites have been outlined by Martinez et al. (2021) in a review of the applications of drone deployment. Such limitations found that the biggest impacts holding back their usage have been low-quality visual sensors, pilot skills and training requirements, struck-by accidents, workers distraction, signal interferences, short battery life, weather conditions, and jobsite obstacles. These limitations can become contributing factors to construction industry injuries and fatalities if their shortcomings are not addressed through the development of better technology (related to visual sensors and battery life) and increased training for robot controllers and workers alike. The following sub-sections discuss various types of risks that robots pose to humans on construction job sites.

### *Physical Risks*

When it comes to aerial and ground robots, whether they are human-controlled, semi-autonomous, or fully autonomous we must consider the potential for physical risks that they pose on a jobsite. If the goal of utilizing them is to improve efficiency and reduce exposure to hazardous environments by human workers, then additional hazards brought on by their presence must be understood and mitigated to ensure their cost does not outweigh their benefit. One of the primary physical risks of robots moving about a dynamic construction environment is the potential for a struck-by hazard. In the case of an aerial robot, this struck-by would also be classified as a falling object hazard. In the instance of using an aerial robot for collecting visual information on a job site, the degree of risk and the likelihood of a struck-by/falling hazard would increase during the construction or post-construction phase of a project, when more workers or building occupants are present compared to the pre-construction phase. In considering the physical of ground robots, struck-by incidents are possible throughout the lifecycle of a construction project. In using autonomous or semi-autonomous robots to perform excavating and earthwork operations, heavy equipment could come in contact with humans, whether they are on the ground, in vehicles, or operating machinery, adjacent to the robot. The impacts of such interactions could cause serious injury or fatalities, given the size of the robots.

### *Distraction*

The introduction of new technology into the construction domain is going to turn heads, and distract workers intrigued by the novel addition to their surroundings. Since the human brain only has a limited amount of attentional capability that can be harnessed (Kahneman, 1973), when a new, distracting stimulus is introduced into a workers' environment, their ability to perform in other tasks requiring their attention is likely to decline (Weisberg and Reeves, 2013). Given the dynamic atmosphere of construction sites, with many moving parts and tasks occurring simultaneously, often in close proximity, attempts have been made to assess the attentional allocation of workers to determine their ability to identify the hazards around them (Jeelani et al. 2016; Hasanzadeh et al. 2017). Identifying hazards on a construction site is primarily a visual task (Jeelani et al. 2016) and workers' hazard recognition performance can have a significant impact on the likelihood of workplace injury. If hazards are identified correctly, there is a higher degree of likelihood that they will be remedied before a workplace injury takes place. In using aerial and ground robots to perform safety inspections, their intended goal of identifying safety hazards and concerns in need of mitigation could be difficult if their presence itself is creating a safety hazard, by being a distraction to workers. In the use of autonomous robots where little human supervision is required, humans intended to be supervising the robot could become distracted by the lack of attention needed by them to supervise the robot, if they place too much trust in the system.

### *Emotional Cost*

In using robots equipped with cameras and sensors on jobsites, which will be recording information pertinent to their task, other non-essential information will also undoubtedly be gathered, workers are prone to developing a feeling that they are continuously being watched or monitored while performing their tasks. This would occur whether or not the robots are using technology designed for monitoring worker progress or safety, as they would have no way of knowing what the robot's intended purpose is. This type of robot presence can invoke in workers a feeling that they are constantly being watched, which can provoke anxiety and stress in workers, negatively impacting their overall mental health (Amick III & Smith, 1992). There also arises the fear of being struck-by a robot, which presents a different risk than being struck-by a robot and can lead to additional stress on construction workers. The increased cognitive demand of working in an environment that only grows in the level of stress workers are exposed to can increase the time pressure workers perceive to be under and have a negative impact on the rate at which workers are able to accomplish their tasks (Dawson & Fletcher, 2001). Being exposed to such psychological stresses day in and day out while at work can lead to workers suffering from mental and psychophysiological illnesses resulting from chronic emotional and biological arousal (Amick III and Smith, 1992).

## FUTURE RESEARCH

At present, the usage and potential for aerial and ground robot integration in the construction are broad. With aerial robots becoming widely adopted by construction teams and ground robots starting to make their way into the industry, the future looks bright. However, the potential problems that could arise from the introduction of such novel technological innovations around workers, present potential issues for workers in terms of occupational safety hazards. While the impacts can be speculated upon in the literature, there is a need to develop a better understanding of how these impacts will play out in a real-world context. Given that a real construction environment could prove too dangerous for carrying out this research, the use of Virtual and Augmented Reality simulations present an opportunity for determining and effectively measuring how real construction workers respond to this novel technology being introduced into their environment. The use of Virtual and Augmented reality simulations allows for repeatable experimentation that can be performed anywhere in the world and safely "transports" participants to a construction site. Knowledge of these newfound interactions will pave the way for developing a better understanding of how aerial and ground robots affect workers in terms of physical risks, attentional costs, and psychological impacts. Once better understood, training programs can be developed to help workers get a better feel for how to safely work around robots.

From a technological standpoint, if aerial and ground robots are to be safely integrated into the construction realm, there is also a need for the development of more robust visual sensors and increased battery life in order to reduce the potential for struck-by accidents and to allow for future usage where robots will be handling more robust payloads. There is also a need for improved pilot training programs to reduce the risk of physical injuries to workers and to improve the trust that workers can place in the robots operating around them.

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