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Attentional Impact of Drones on Construction Sites

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Drones are being widely deployed in construction, and the interaction between them and construction professionals is expected to increase even more in the future. However, the deployment of these aerial robots near construction professionals could be associated with additional risks affecting the safety and health of the workplace. This study explores the attentional impact of drone presence at different distances from construction professionals on the jobsite. Through a user-centered virtual reality-based experiment, construction professionals were asked to accomplish a construction task with the presence of drones while having their eye movement tracked. Results showed that the drone presence has an impact on participants' attentional states and that these aerial robots have attracted some of the construction professionals' attention. Participants' attentional state was also impacted by the drone operational distance, with professionals in close proximity from the drone looking fewer at the aerial robot, and for shorter durations, as opposed to those located at a farther distance. The contributions of this study are to ensure safe human-drone interaction in construction by informing industry personnel of the potential safety impacts of drones on jobsites and assisting in the formalization of specific regulations for the use of aerial robots in the industry.

Key Words: Drone, Attentional Allocation Impact, Construction Safety, Human-Drone Interaction, Proxemics

Introduction

The construction industry has recently started to integrate automation and robotics into day-to-day tasks to address skilled labor shortage, decreased productivity rates, and project inefficiencies (Davila Delgado et al. 2019). This integration stems from recent advancements, which enabled efficient technology development and sensor miniaturization (Javaid et al. 2021). Given that the construction industry always depends on human ingenuity and decision-making to accomplish different tasks, robots are currently being regarded as assistive and collaborative tools, rather than entities envisioned to replace human workers on jobsites. Compared to traditional methods, research has shown that robots in construction are able to efficiently collaborate with human workers to accomplish different construction tasks. In particular, drones have been recently used for a wide range of applications on jobsites, with construction being one of the top commercial adopters of this technology (Albeaino et al. 2019). Drones' wide deployment in construction stems from their flexibility and location-independency, the cost and time savings, as well as the safety improvements associated with their onsite usage, enabling them to be applied across all project phases, from pre-construction and construction to post-construction (Zhou et al. 2018). Application examples include site mapping and layout planning (Jiang et al. 2020), earthwork volumetrics (Siebert and Teizer 2014), progress monitoring (Ibrahim and Golparvar-Fard 2019), structure inspection (González-deSantos et al. 2020), safety management (Martinez et al. 2021), and building maintenance (Mutis and Romero 2019). This trend in drone technology adoption is projected to continue, and aerial robots are expected to become active collaborators, assisting human workers in various construction tasks such as bricklaying and material handling (Goessens et al. 2018; Zhang et al. 2022).

The unprecedented usage of drones in construction necessitates exploring the safety impacts of these aerial robots on humans working on construction jobsites. Construction in general, is a dynamic and hazardous work environment, and interacting with drones in such situations might expose workers to additional unsafe situations that have not been explored yet. For example, drone usage on jobsites has been associated with physical or contact risks, physiological risks, and attentional costs (Jeelani and Gheisari 2021). Namian et al. (2021) asked construction professionals about the safety challenges of drones on construction sites, and showed that these aerial robots are associated with various risks, including distractions. A negative construction professional attentional state could have adverse consequences on the workplace's health and safety. Distraction in particular, has been shown to affect construction professionals' ability to recognize hazards and perceive risks on jobsites (Cohen et al. 2017; Namian et al. 2018). Such factors not only cause some onsite hazards to remain unidentified, but also jeopardize construction professionals' safety performance and potentially result in unsafe practices that could lead to jobsite injuries and even fatalities (Ke et al. 2021). The introduction of drones to the jobsite could cause some professionals to divert their attention from the task at hand and onto the aerial robot. Therefore, understanding the potential impact of drones on construction professionals' attentional state is of particular importance, especially since these aerial robots are becoming more prevalent on jobsites.

There have been many studies on the drone application trends, benefits, and barriers within the construction industry (Albeaino and Gheisari 2021), and some researchers have even identified and theoretically discussed the potential safety challenges associated with the usage of this technology on jobsites (Namian et al. 2021; Xu and Turkan 2022). However, conducting experiments to empirically evaluate the safety implications of drones on construction jobsites is yet to be performed. The aim of this study is to investigate the attentional impacts of drones on construction jobsites. Whiles drones have been shown to potentially cause other risks such as physical and physiological risks (Jeelani and Gheisari 2021), the scope of this study is limited to evaluating the attentional costs associated with the presence of drones at different distances from construction professionals on the jobsite. More specifically, this study seeks to answer the following research questions: (1) Does the drone presence impact construction professionals' attentional state on jobsites? and (2) Does the drone operation distance impact construction professionals' attentional state on jobsites? To answer these research questions, a between-subject experiment was conducted, where recruited professionals had to accomplish a construction task in Virtual Reality (VR) with the presence of drones at either the (1) proximal distance or the (2) distal distance. These two distances were selected based on: (1) Hall's defined interaction distances (e.g., 1.5, 4, 12, and 25 ft) (Hall 1969); and (2) current and future drone applications in construction, with some requiring human-drone interactions at close distances and others at farther distances. Measures such as the Fixation Count (i.e., number of times users had looked at the drone) and Fixation Duration (i.e., average total duration each user spent fixating on the drone) were collected, analyzed, and compared between two drone distance groups. By exploring how construction professionals' attentional behavior is affected by the presence of drones at different operational distances (i.e., proximal and distal), this study provides industry personnel and agencies with a better understanding of the potential safety impacts associated with these aerial robots on jobsites. This ultimately helps overcome current non-specific drone regulations (Xu and Turkan 2022) by assisting in the formalization of specific and comprehensive regulations for the use of drones in construction.

Study Procedure

The aim of this study is to evaluate the potential impact of drones on construction professionals' attentional states. To accomplish this aim, the following two-step procedure was adopted (Figure 1): Step (1) –VR development; and Step (2): Assessment. In Step (1), the safety literature and the Occupational Safety and Health Administration (OSHA) incident investigation summaries were queried to identify most common high-risk activities and locations that could potentially become even more hazardous with the drone presence. The identified and selected high-risk scenario was then relied upon to develop a VR environment of a real-world construction jobsite while simulating the high-risk scenario with the presence of drones. Construction professionals were then recruited in Step (2) to empirically evaluate the impact of drones on their attentional states while accomplishing a task in the developed VR scenario.

Scenario Selection and VR Development

Jobsite injuries and fatalities occur mostly due to falls from roofs, ladders, and scaffolds, as evidenced by the safety literature and the OSHA incident investigation summaries in the US (Mendes et al. 2022; Nadhim et al. 2016). For this reason, a scaffolding scenario was identified and selected to be simulated in VR, especially since: (1) scaffolding operations cover most construction operations (e.g., inspecting, painting, roofing, carpentry); and (2) the introduction of drones to such operations – which have already been considered hazardous (Kang et al. 2017) – might expose professionals to additional hazardous situations. A slab was being prepared for formwork installation and concrete placement in the scaffolding scenario. Formwork installation and concrete placement activities were specifically selected since these operations have been typically associated with injuries and fatalities caused by, for example, trips, slips, nailing and hammering, material handling, and struck-by incidents (Hallowell and Gambatese 2009; Lipscomb et al. 2006; Rozenfeld et al. 2010).

The technical development of the VR scaffolding scenario consisted of converting 3D models of various construction jobsite components (e.g., buildings, machinery, scaffolds, formwork, reinforcing steel members) into .FBX files and importing them into an environment in Unity® (Figure 1). The scaffolding, slab, and formwork components were arranged to simulate formwork installation and concrete placement activities while being on scaffolds. Additional 3D models of different construction workers accomplishing various formwork installation and concrete placement activities (i.e., nailing, hammering, rebar tying, slab cleaning, scaffold members transporting) as well as cranes, vehicles, and other machines and equipment were also programmed, animated, and incorporated into the environment. To enhance the realism even more, special visual effects such as one simulating real-world dust and vehicle tire tracks were also applied. Proper sounds were also assigned to different equipment and machinery while enabling spatial audio effects. Drone sounds used were ones from a DJI® Phantom 4 Pro, one of the most popular platforms used in the construction industry (Albeaino and Gheisari 2021). A total of two VR scenes were created, with the only difference being the drone operational distance from the user. The selected drone operational distances were as follows: (1) Proximal: drone operating at 1.5 ft, simulating drone applications requiring close interaction with construction professionals; and (2) Distal: drone operating at 25 ft, simulating drone applications requiring farther interaction distances. The drone operational distances were selected based on: (1) Hall's defined Human-Human interaction distances (i.e., 1.5, 4, 12, and 25 ft) which are widely used in the Human-Drone interaction literature (Albeaino et al. 2022; Tezza and Andujar 2019); and (2) the current and future drone applications in construction, with some of them (e.g., material delivery, aerial construction) requiring human-drone interaction at close distances (e.g., 1.5 ft – proximal), and others (e.g., earthwork operations, site planning) necessitating interactions at farther distances (e.g., 25 ft – Distal). Except for the proximal and distal distances (i.e., 1.5 ft and 25 ft), the drone maintained a fixed height throughout the scene duration and remained within the users' field of views.

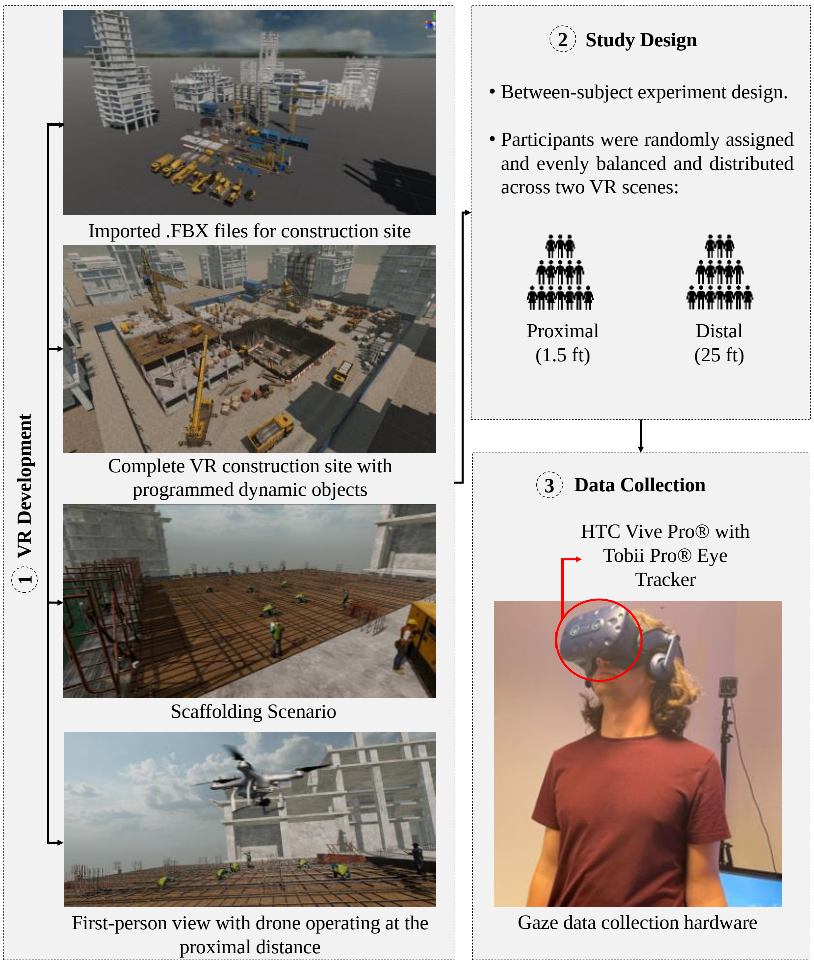

Figure 1. Adopted Procedure

Assessment Procedure and Attentional Metrics

Upon their agreement to participate in the experiment and signing the consent form, recruited participants were asked to fill out a demographics questionnaire and were then randomly assigned to one of the two drone distance VR scenes (i.e., Proximal and Distal). Participants were also asked to place and calibrate the HTC® head-mounted display (HMD) along with its built-in Tobi Pro® eye tracker to ensure proper gaze data collection before starting the experiment. Once in the VR scaffolding environment, participants were asked to act as jobsite supervisors and monitor construction workers' productivity by counting the number of scaffold members that a construction worker carries from one place to another. To ensure that they remain engaged during the experiment, subjects were also required to answer a few questions about the environment. Participants spent a total of three minutes in VR. During the first minute, no data collection was performed, as users were provided with an opportunity to explore and get familiar with the VR construction environment and the HMD. During the second two minutes, gaze data collection was performed while participants were in the process of accomplishing the construction task in VR with the presence of the virtual drone. The study was approved by the University of Florida Institutional Review Board (IRB #202102439) prior to participant recruitment and data collection.

The metrics used to evaluate participants' attentional states while accomplishing their tasks in VR were: (1) Fixation Count, which was determined by calculating the number of times users had looked at the aerial robot (Holmqvist et al. 2011); and (2) Fixation Duration, which was determined by summing up the total duration each user had spent fixating on the distractor (i.e., drone) (Bednarik and Tukiainen 2006). This duration was calculated based on a C# script, which provided timestamps of instances when users were looking at the drone and not on their task. More specifically, and using the collected gaze timestamps, each fixation duration was obtained by deducting the last instance before the user had shifted their gaze away from the aerial platform, from the first instance the user had looked at the drone. A fixation was only counted if its duration exceeded 100 ms (Bednarik and Tukiainen 2006). Both of these metrics are indicative of distraction and attentional diversion from the task at hand and onto the drone. Upon experiment completion, users were asked, through an open-ended question, to provide their opinion about the VR experiment and the presence of drones on jobsites. Participants' demographics and open-ended feedback were collected using Qualtrics® and data was analyzed in Matlab. This data analysis software was selected due to its accessibility to the research team and its complex data analysis capabilities.

Results and Discussion

Participant Demographics

A total of 44 subjects were recruited to participate in the experiment, assigned randomly and evenly distributed to the Proximal (N=22) and Distal (N=22) drone distance groups. Participants' demographics showed that the subjects from both groups share similar background (Table 1). Overall, recruited participants were split between undergraduate (N=23, 52%) and graduate students (N=21, 48%) and were mostly males (N=34, 77%). More than half were 18 to 24 years old (N=25, 57%) and the majority had less than one year of construction experience (N=27, 61%).

Table 1.

Participant Demographics

Parameter		**Proximal (N=22)**	**Distal (N=22)**
Gender	Male	15 (68%)	19 (86%)
	Female	7 (32%)	3 (14%)
Age	18 to 24 years	14 (64%)	11 (50%)
	25 to 31 years	7 (32%)	7 (32%)

	32 to 38 years	1 (4%)	3 (14%)
	More than 39 years	0 (0%)	1 (4%)
Education Level	Undergraduate	14 (64%)	9 (41%)
	Graduate	8 (36%)	13 (59%)
Construction Experience	0 to 1 year	16 (73%)	11 (50%)
	1 to 5 years	5 (23%)	7 (32%)
	More than 5 years	1 (4%)	4 (18%)

Attentional Impact of Drone on Construction Professionals

Independent samples t-test was performed on the collected participant fixation counts and fixation durations to answer the questions of: (1) whether drones impact construction professionals' attentional state on jobsites, and (2) whether the drone operation distance impact construction professionals' attentional state on jobsites. Obtained results are summarized in Table 2. The analysis showed that users had allocated some of their attention from the task at hand onto the drone at least 14 times, for a total duration of at least 11 s within a 2-minute VR duration. This provides some evidence that the drone has the potential to impact construction professionals' attentional state while accomplishing different construction tasks. The results also show that construction professionals looked at the drone significantly more (i.e., fixation count, p=0.004) and for significantly longer durations (fixation durations, p=0.019) when the aerial robot was at a distal distance, rather than when being operated at closer distances from them. The data therefore provides evidence that the drone operation distance has impacted construction professionals' attentional states.

Table 2.

Impact of drones on participants' attentional states

Attentional Measures	**Proximal Distance Mean ± SD**	**Distal Distance Mean ± SD**	**p-value**
Fixation Count	13.59 ± 11.19	27.50 ± 17.83	0.004*
Fixation Duration (s)	10.79 ± 9.94	19.40 ± 13.10	0.019*

The results indicate that drones have attracted some of the professionals' attention, and that participants of the proximal distance group looked at the aerial robot less, and for shorter period durations, as opposed to those of the distal distance group. This could be due to the fact that when the aerial robot was at farther distances, participants were not familiar of or able to identify what the drone's intention and role were on jobsites, factors that could prevent them from anticipating the next drone movements and trusting less the aerial robot (Haring et al. 2014; Szafir et al. 2014; Tezza and Andujar 2019). Being at farther distances, participants may perceive the drone as a performance monitoring or surveillance tool. This effect of not being familiar with or able to fully identify what the drone's intention and role were on jobsites may potentially result in participant trusting less the robot, and even provoke higher distraction levels among construction professionals by negatively impacting their perception towards the aerial robot. Additional studies are warranted to investigate the effect of robot intent and role on onsite construction professionals. Participants' responses to the post-experiment open-ended question somehow validated the fact that when users were more knowledgeable and familiar with the robot's role and intent during the experiment, they became more comfortable with its presence, with some subjects indicating that the longer they were exposed to the aerial platform, the more familiar and comfortable they were.

Distraction or attentional diversion has been shown to negatively impact construction professionals' safety performance and potentially result in jobsite injuries and fatalities (Ke et al. 2021). However, determining whether the amount of distraction (as measured by the fixation count and fixation durations caused by drones in this experiment) has practical safety consequences and significance in the real world warrants additional exploration. Additional studies must rely on additional gaze metrics (e.g., on-task and off-task fixations, saccade velocity, saccade amplitude) to measure, with and without drone presence, construction professionals' situation awareness, task attention, and the resulting effect on their safety performance. This ultimately helps in better identifying drones' potential to cause distraction on construction jobsites. In addition, the responses to the open-ended post-experiment question also revealed that almost all the subjects in the proximal distance condition were concerned about the close flying proximity of the aerial robot, indicating that the aerial robot was "loud", made them "nervous", "uncomfortable", "distracted", and "surprised". Such comments were much less common for participants of the distal distance group, who mostly perceived the robot positively, indicating that its presence was "normal", "under control" and that they were not distracted by them. Therefore, future studies should focus on exploring other factors (e.g., robot trust, perceived safety, cognitive load, anxiety) and rely on more construction-specific task performance metrics to fully understand the safety implications associated with human-drone interactions in construction, especially those at close distances.

Conclusion

The goal of this study was to evaluate the attentional costs associated with the presence of drones at different distances from construction professionals on the jobsite. Through a between-subject VR-based experiment, recruited professionals were asked to accomplish a construction task with the presence of an aerial robot at either a proximal or a distal distance while having their eye movements tracked and analyzed. Results showed that drones have an impact on subjects' attentional states, with participants allocating some of their attention onto the aerial robot. The results also revealed that the construction professionals looked at the aerial robot more and for longer durations when operating at farther distances from them. The study findings provide industry personnel and agencies with a better understanding of the attentional risks associated with the presence of drones on jobsites. This ultimately helps in establishing construction-specific drone regulations and ensuring safe interactions between humans and drones in construction.

This study is limited by the nature of the experiment itself, which was conducted in VR. It would be worthwhile to replicate and perform this study within the context of a real construction site; however, safety concerns prevent that from happening at present. In addition, this experiment's participants were asked to perform a relatively simple task of counting the number of trips a worker made across an area of interest in front of them, and were also asked questions about the workplace environment surrounding them. While these questions about their surroundings ensured participants' engagement during the experiment, subsequent studies could attempt to have construction professionals perform more difficult construction tasks, at different levels of human-robot collaborations, and based on other drone distances as defined by Hall (1969) (i.e., 4 ft and 12 ft), and study the resulting impact on their attentional states. Additional studies are also warranted to explore other known risks (i.e., physical and physiological) associated with drone presence on jobsites using other subjective and objective measures to ensure safe human-drone interaction in construction.

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