Drone-Induced Distraction on Construction Sites: A Quantitative Analysis of Flight Configurations

Wei Han[1], Liqun Xu[1], Mahfuza Maisha Mouri[2], Wei-Yin Loh[3], Fei Dai[2], Zhenhua Zhu[1]

[1]Department of Civil and Environmental Engineering, University of Wisconsin - Madison, USA
[2]Wadsworth Department of Civil and Environmental Engineering, West Virginia University, USA
[3]Department of Statistics, University of Wisconsin - Madison, USA
whan59@wisc.edu, liqun.xu@wisc.edu, mm00286@mix.wvu.edu, loh@stat.wisc.edu, fei.dai@mail.wvu.edu, zzhu286@wisc.edu

Abstract –

Drones are increasingly used in construction projects to facilitate tasks such as progress tracking, safety monitoring, and quality inspection. Despite their advantages, the presence of drones may introduce distractions that compromise workers' ability to identify hazards, thereby elevating the risk of accidents. While limited studies have conducted quantitative assessments of drone-induced distractions among construction workers, the interplay between specific drone flight configurations and the degree of distraction remains underexplored. This study investigated the influence of varying drone flight configurations on workers' attentional focus through quantitative experiments. Seven virtual construction site scenarios were developed to simulate both the visual and auditory stimuli associated with drones. A total of 17 participants engaged in simulated construction tasks within these scenarios, utilizing virtual reality systems and an omnidirectional treadmill. Their situational awareness was evaluated through a detailed analysis of gaze fixation times and counts. The results indicated that the presence of drones significantly distracted participants, with distraction levels intensifying as the drones approached closer. These findings contributed to the understanding of how drone proximity impacts worker attention and safety and established a basis for refining safety protocols in construction environments where drones are increasingly employed.

Keywords –

Unmanned aerial vehicles (UAVs); Visual attention; Eye-tracking; Virtual reality; Worker safety

1 Introduction

The increasing applications of drones in construction projects have gained significant attention from the industry due to their potential to enhance efficiency and safety. However, concerns have emerged regarding the safety risks and hazards that drone operations may introduce to construction sites. These risks extend beyond the physical hazards of collisions with workers, equipment, or site infrastructure within drone operating zones [1]. The presence of drones has the potential to divert workers' attention, leading to visual, auditory, and cognitive distractions [2]. For example, Union Pacific Corp railroad workers reported being distracted by drones flying over rail yards, causing them to look upwards rather than focusing on their tasks, even in the presence of 200-ton locomotives and railcars in motion [3].

The impact of distraction on workers' focus has been widely documented in other domains. For example, Mark et al. showed that external interruptions in office environments could delay workers' return to full task concentration by up to 25 minutes [4]. Similar interruptions were observed in construction settings, where distractions caused by drones can impair hazard recognition and safety risk assessment [5] [6]. Such distractions increase the likelihood of errors, endangering both the distracted worker and others on-site [7].

The workers at heights are vulnerable to drone-induced distractions since the drones often fly above buildings on construction sites. These distractions may cause workers to overreach or lose balance on elevated platforms cluttered with tools or areas lacking protections such as unguarded edges and openings. Consequently, the risk of falls, slips, and trips increases, often resulting in serious injuries or fatalities. The Bureau of Labor Statistics (BLS) reported that falls, slips, and trips accounted for 38.4% of all fatalities and 47.4% of nonfatal injuries in the construction industry in 2022; and most fatal falls, slips, and trips happened to those workers at heights who fell to a lower level [8]. Moreover, a survey of over 1,200 safety professionals identified distraction as the leading cause of these incidents [9].

Although previous studies have acknowledged the safety challenges posed by drones in construction, much of the existing research relies on surveys, expert opinions, and conceptual analyses, with limited experimental data to evaluate the extent of drone-induced distractions [10], [11]. To address these limitations, Albeaino et al. provided initial experimental data, demonstrating that drones can cause measurable distractions among construction workers [12]. However, the influence of specific drone flight configurations on distraction levels remains unexplored.

This study aims to address this gap by examining how drone flight height and approach direction affect workers' safety and attention. These variables were chosen because they are key factors influencing the degree to which drones capture workers' attention. For instance, a drone's flight height can alter its visibility and audibility, while the approach direction (e.g., from the front or back) may impact how quickly workers become aware of its presence. To investigate these effects, a few virtual construction environments were developed, and participants were tasked with performing material handling activities. Gaze fixation times and counts were collected to evaluate visual attention toward hazardous areas. By analyzing this data, our study provided a quantitative assessment of how drone flight configurations influence workers' hazard awareness, contributing to a deeper understanding of drone-induced distractions and their implications for construction site safety.

2 Literature Review

2.1 Drone Application in Construction Sites

Drones, or unmanned aerial vehicles (UAVs), are aircraft that can be remotely controlled or autonomously flown to perform various tasks on construction sites. Equipped with sensors such as RGB, multispectral, thermal, or LIDAR, drones can quickly capture substantial aerial data [13]. This data can be transmitted to computers through drone software, enabling users to analyze and interpret it efficiently. These capabilities enhance construction project efficiency, support better project management, and improve the thoroughness of inspections.

Drones have numerous applications in construction, including topographic mapping, equipment tracking, remote monitoring, and worksite inspection. For topographic mapping, drones significantly reduce the time needed to survey a site's landscape by covering large areas quickly. The high-resolution images captured can be converted into 3D models to identify site challenges and assist with layout planning before construction begins. For instance, Jiang et al. [14] advanced image-based modeling techniques for real-time 3D construction site modeling, proving effective for rapid layout planning in hoisting projects. Additionally, drones help track equipment locations on-site, record operational errors, and monitor construction quality. Sun [15] proposed a UAV-based system to track road construction machinery, enhancing paving quality. Furthermore, drones allow companies to visually inspect large structures or those in hard-to-reach areas more efficiently and at a lower cost. For example, de Melo et al. demonstrated that UAV-collected visuals can improve safety inspections by providing better visibility of job site conditions [16].

2.2 Drone Safety Analysis in Construction Sites

The Federal Aviation Administration (FAA) has implemented regulations for remote pilot certification and operational guidelines for small unmanned aircraft in civil applications, aiming to address safety concerns associated with drones in commercial settings [17]. From April 21, 2021, the FAA permits drones to operate over people, contingent upon the level of risk they pose to individuals on the ground [18]. While these regulations provide a foundational standard for safe drone operations in workplace environments, they do not specifically account for the potential distractions drones may cause, particularly for workers working at heights.

Recently, the potential safety risk related to drone applications on construction sites attracted more attention. Based on the survey of 56 and 69 construction experts and professionals, drone-induced distraction is one of the primary safety concerns in construction projects [10][11]. Moreover, Jeelani and Gheisari investigated different drone applications on construction sites and identified their negative impacts on related workers' health and safety [2]. Fan and Saadeghvaziri identified drone-induced distraction as a key challenge in the planning, design, construction, and maintenance of civil infrastructure [19]. Costa et al. also highlighted that drone-induced distraction may cause issues with workers, concentration, safety, and productivity [20]. These earlier qualitative studies showed that drone-induced distraction can impact construction worker safety.

Thus, further studies started to quantify how drone-induced distraction, because it can provide more solid evidence for the decision-making process of drone use on construction sites. For example, Monte Carlo simulations were used to quantify the direct and indirect risks of drones to construction workers [21], [22]. Although the simulations can provide valuable insights, they did not study the actual reactions of the workers. Thus, Albeaino et al. conducted human study experiments to investigate the impact of drone-induced distractions on workers [12]. The study revealed that participants spent approximately 18 seconds observing the drones during a 2.5-minute task, highlighting the considerable potential for distraction in active work settings.

2.3 Drone Distraction Studies Using Virtual Reality

To study how drones distract construction workers and impact safety, we need to observe worker responses with and without drone distractions. Since real-life testing poses safety risks, we use virtual reality (VR) to simulate high-risk environments safely [23]. VR replicates real-world conditions in a controlled, risk-free manner and has been shown to produce results closely aligning with real-world experiments in both behavioral outcomes and self-reported measures [24]. It has been widely used in transportation and construction safety research to assess drone-induced distractions on drivers and workers.

In the transportation domain, Barlow et al. employed a VR-based driving simulator to investigate the impact of drone flights near roadways on participants' visual attention and their potential contribution to distraction [25]. Their findings led to the recommendation of a policy requiring drone operations to maintain a minimum distance of 25 feet from the edge of a lane. Similarly, the Oregon Department of Transportation utilized a VR simulator to conduct a randomized factorial experiment evaluating the effects of three independent variables—lateral offset, flight path, and lane use—on driver distraction caused by drone operations near roadways. The study revealed that the frequency and duration of glances at drones increased when drones were positioned closer to the roadway, with unsafe glances exceeding 2 seconds observed at lateral offsets of 0 feet, 25 feet, and 50 feet [26]. In another study, Ryan et al. employed a driving simulator featuring an actual driver's seat within a real vehicle and a screen positioned in front of the driver. Their findings indicated that drivers were distracted by drones, with critically long glances observed in 11% of cases [27]. These studies collectively demonstrated that VR and simulator-based approaches are effective tools for examining drone-induced distractions in driver participants. They used monitors to display the virtual environments for the drivers.

In the construction domain, the researchers adopted VR headsets to facilitate human-subject experiments and training. VR headsets allow construction worker participants to engage deeply with virtual construction environments, creating a highly immersive setting for studying distraction effects. Jeelani and Gheisari utilized virtual reality to simulate a construction site for conducting experiments aimed at evaluating the impact of drone presence on workers' attention and stress levels. The findings indicated that unmanned aerial vehicles (UAVs) could distract workers, especially when operating at distances of 12 feet and 25 feet. However, the drones did not have a significant effect on workers' emotional or psychological distress [28]. Albeaino et al. employed virtual reality to create a simulated construction site, enabling the evaluation of the attentional impact of drones on construction professionals at varying distances. The study revealed that drones positioned at greater distances resulted in more frequent and prolonged visual fixations on drones, emphasizing their potential to distract workers and providing insights into safer operational distances for drone use on construction sites [29].

Most of the existing studies focused on how the presence of drones diverts participants' visual attention from their primary tasks. However, they did not explore how this diversion of attention affects participants' ability to recognize and identify hazards.

2.4 Experimental Design for Drone-Induced Distraction

To study the human's visual attention to drone-induced distraction, the approaches of human study experiments from previous studies can be divided into two categories. First, some studies adopted between-subject design [2], [12], [29]. A between-subjects design is a research method in which different groups of participants are exposed to distinct experimental conditions, allowing comparisons to be made between groups without the influence of repeated exposure [30]. Second, other studies adopted within-subject design [25], [26], [27]. A within-subjects design, also known as a repeated-measures design, is a research method in which the same participants are exposed to all experimental conditions, allowing researchers to compare their responses across different treatments while controlling for individual variability.

The studies collected the participants' fixation time and/or count to analyze their visual attention during distractions. Studies using a within-subject design exposed participants to the same set of conditions, which may cause sequence effects, where the order of exposure impacts the outcomes. Thus, usually, participants will experience the same set of conditions but with different sequences. The design helps the researchers to investigate if there is any sequence effect. Some of the studies fit the variables for evaluation into and linear mix model to check if the sequence effect is significant or not. Then, the variables are further analyzed by analysis of variance (ANOVA) to determine the significance of variables across different conditions.

3 Problem Statement, Objective, and Research Question

Existing studies emphasized the potential hazards posed by drone-induced distractions for construction workers. Although they have investigated several aspects of drone-related distraction, a systematic examination of the influence of specific drone flight configurations on workers' situational awareness remains unexplored. Thus, this study aims to analyze workers' visual attention to hazards in response to drones operating at varying heights and directions. The research question of this research is: "How is the amount of distraction related to drone flying height and direction?"

4 Experiment Design and Implementation

4.1 Procedure

Figure 1. A participant performing material handling tasks in a virtual construction environment using a VR headset and omni-directional treadmill.

In the beginning, participants were provided with an IRB-approved consent form, which they were required to read and sign before participation. The consent form detailed the purpose of the study, emphasizing its focus on drone safety in construction site environments. As shown in Figure 1, participants were equipped with a VR headset (Meta Quest Pro) and positioned on an omni-directional treadmill (ODT) (KAT Walk C2+). The VR headset facilitated full immersion in virtual construction environments developed using Unity. The virtual environments provide a realistic and immersive experience by incorporating real background construction noises and drone flying sounds. Using Unity further enhances this realism by enabling spatially accurate drone sounds, allowing participants to hear the drone's flying noise in stereo based on its distance and location. The ODT enabled participants to navigate the virtual environments by physically walking, replicating the physical demands of real-world construction tasks. After a 5-minute training process, the participants then move on to the official experiment scenes.

For our experiment settings, they included three independent variables, namely, drone presence (Yes and No), height of drone (16, 48, and 82 ft.), and direction of drone (Back and Front). Three heights of drones were chosen since they are the working heights of the drones for visual inspections [31]. By these three independent variables, there were a total of six combinations of drone height and direction, along with a seventh condition where no drone was present.

For our experiment design, a repeated measures design was adopted to minimize variability across participants and enhance the reliability of the findings [32]. Thus, each participant was exposed to all seven scenes in a randomized order to minimize learning effects and bias. To be more specific, participants were randomly divided into seven groups. The participants in different groups experienced different sequences of scenes. The design of the sequence in each group follows a Latin Square design [33], which ensured an approximate balance in the sequence of scene presentations.

In each scene, participants were tasked with carrying a 16.5" x 12" x 14" box along a designated route from a starting location to an endpoint twice. During the task, a virtual drone (DJI Mavic 3 Pro) appeared randomly in one of the two trials. The selections of drone type and required task are made in consultation with Mortenson, a construction company, to ensure the relevance of construction practice. Figure 2 illustrates a virtual construction scene, where the participant's route is depicted by the yellow lines (dashed and solid). To ensure the drone appears from either the front or behind the participant, each virtual construction site included a straight segment of the route, represented by the solid yellow line. The drone's flight path is marked by the red dashed line.

Figure 2. A sample of the virtual construction site

4.2 Data Collection, Processing, and Analysis

This study aims to investigate the situation awareness of workers through their visual attention to hazards. Thus, eye gaze fixation time and count on danger areas were chosen as our dependent variable for analysis. The danger areas included openings and edges and the fences around them in the virtual environment.

During the experiment, the participants' gaze points were collected by VR headset with a frequency of 100 Hz. The raw data consisted of gaze points recorded sequentially over time, resulting in a total of 57,600 data points. For each scene, fixation time and count were computed by summing the fixation events occurring within predefined danger areas. This approach enabled the determination of the total fixation time and count on danger areas for each scene.

To analyze the effects of different drone flying configurations on participants' fixation time and count, a repeated measures linear mixed model was applied. Due to the occurrence of zero fixation times and counts, the model was applied to the natural logarithm of fixation time plus one (*ln*(TP1)) and fixation count plus one (*ln*(CP1)) to enhance the normality of residuals. TP1 denotes "time plus one," while CP1 represents "count plus one." The model included six variables, with participant variability treated as a random effect. Fixed effects included the sequence of scenarios experienced, drone flight configurations, their interaction, and a constant term. A Type III ANOVA was used to evaluate the statistical significance of each fixed effect, particularly the influence of drone flight factors. Results were considered statistically significant if the p-value was less than 0.05. All analyses were performed using the lme4 and lmerTest packages in R [34], [35].

5 Preliminary Results and Discussion

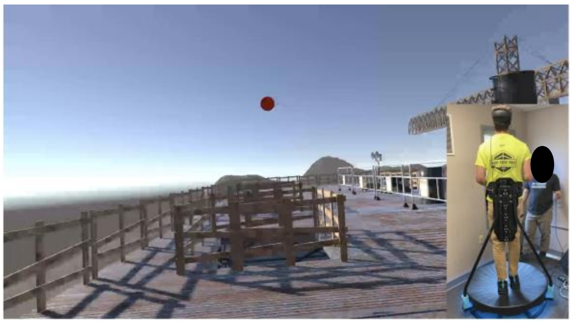

Figure 3. A sample of a construction worker doing our experiment using a VR headset and an ODT.

So far, a total of 17 test participants (12 males and 5 females) were invited, including construction interns, professionals, managers, and workers. Figure 3 illustrates the first-person perspective of a construction worker, represented as our test participant, performing a material handling task within a virtual construction environment. The red dot in the figure indicates the participant's eye gaze point.

From the preliminary results, there were three findings. First, Figure 4 shows the participants' 95 percent confidence intervals for fixation time on danger areas in all 7 different scenes. In the horizontal axis, "F" means the drone flying from the participants' front, and "B" means the drone flying from their back. The number after the latter means the drone flying heights in feet. Since the fixation time in no drone scene is significantly higher than in all the other scenes, drones reduced participants' fixation time on danger areas. Second, Figure 5 compares the participants' 95 percent confidence intervals for fixation time on danger areas in different drone flying heights. The fixation time on danger areas of a drone flying at 82 feet is much higher than a drone flying at 16 feet. Drones flying at lower heights (16 feet) significantly reduced fixation time on danger areas. Figure 6 shows the comparison of the 95 percent confidence intervals for fixation time on the sky in different drone flying directions. The presence of drones approaching from the front results in a significant increase in fixation time on the sky. Overall, the findings suggest that participants experienced greater distraction when the drone approached from the front below 48 feet.

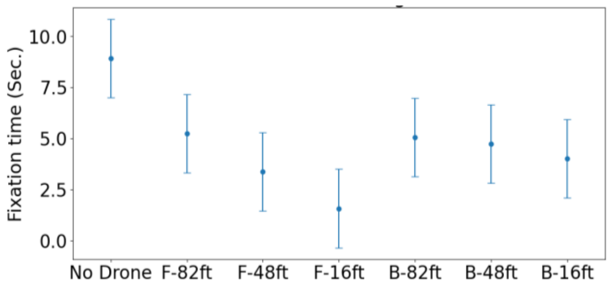

Figure 4. Fixation time on danger areas in different scenes.

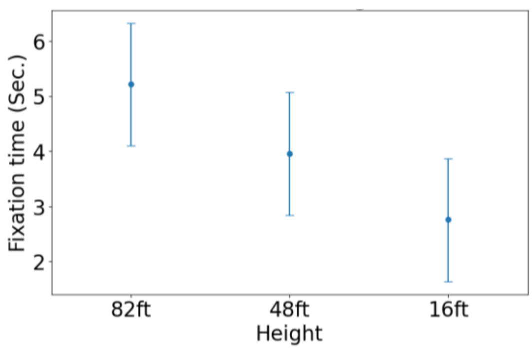

Figure 5. Fixation time on danger areas in different flying heights.

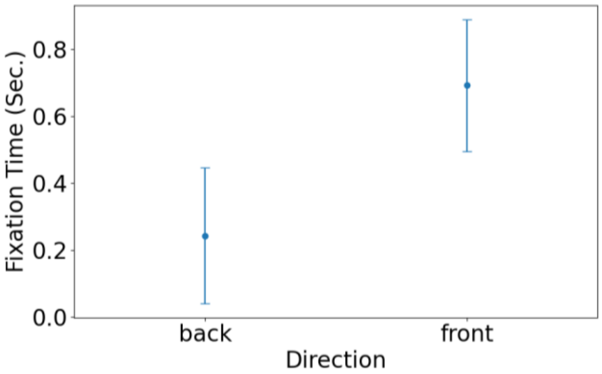

Figure 6. Fixation time on the sky in different flying directions.

6 Discussion

The findings of this study contributed to understanding the influence of drone flight height and direction on the visual attention of construction workers. Specifically, our results indicated that participants experienced greater distraction when drones approached from the front, particularly at lower altitudes (16 ft and 48 ft). These findings aligned with prior research demonstrating that drone interventions can disrupt workers' visual focus, while also extending the literature by examining how specific drone conditions modulate the degree of distraction.

When drones approached at heights of 16 feet and 48 feet, the participants' fixation time on danger areas significantly decreased, potentially impairing their ability to maintain attention on hazardous zones. This has critical implications for construction site safety, as diminished focus on danger areas increases the risk of accidents such as slips, falls, and trips. Furthermore, post-experiment interviews revealed that half of the participants reported feeling distracted by the presence of drones, reinforcing the need to address drone-related safety concerns in dynamic construction environments.

Despite these important contributions, this study has few limitations. First, the experiment only used a single type of virtual drone in the experiment. Drones differ in attributes such as sound, size, and intended purpose, all of which could influence distraction levels. For instance, larger drones with louder noise might induce greater distraction compared to smaller, quieter drones. Future research should investigate the effects of various drone types to assess their specific contributions to worker distraction.

Second, the study focused on a material handling task. However, construction work encompasses a wide range of activities, such as operating vehicles or heavy machinery, where the consequences of drone-induced distractions may vary. For example, the impact of distractions on excavator operators or truck drivers may differ significantly from their effects on workers performing material handling tasks. Future studies should explore a broader array of construction tasks to provide a more comprehensive understanding of how drone interventions affect worker safety across diverse job roles.

Third, to maintain experimental control and isolate the effects of drone distractions, we designed the virtual environment with a simplified construction setting. A more complex and dynamic environment could introduce additional variables, such as moving equipment or other workers, which may confound the results. By minimizing unnecessary distractions, we ensured that participants' visual attention responses were primarily influenced by drone presence rather than other environmental factors. However, real construction sites might be more complex, and future studies should incorporate more realistic elements to enhance the ecological validity of the findings.

7 Conclusion

This study provided valuable insights into how drone flight configurations affect construction workers' visual attention, particularly their focus on hazard areas. Using a VR-based experiment, the research showed that drones significantly distract workers, especially when flying at lower heights (16 ft and 48 ft) or approaching from the front. These conditions reduced fixation times on danger areas, impairing hazard recognition and increasing accident risks. The results underscores the need for carefully planned drone operations and defined safety parameters in construction environments.

Despite its contributions, this study has several limitations that highlight opportunities for future research. The experiment utilized a single type of virtual drone and focused solely on material handling tasks, limiting the generalizability of the findings to other drone models and construction activities. Additionally, to isolate the effects of drone distraction under different flight configurations, the virtual environment was intentionally simplified, excluding other potential distractions such as moving machinery and additional workers. Future studies should examine how different drone attributes impact workers across various construction tasks within more complex and dynamic site conditions to enhance the applicability of the findings.

The findings highlight the need for safety protocols to mitigate drone-induced distractions, such as restricting drone altitude, flight paths, and directions, especially in high-risk areas. While workers may adapt to drones over time, new or inexperienced workers may still face distraction risks from drone. These insights can inform training programs that expose workers to drone distractions before they start to work on a real construction site. Which can help them adapt in advance and reduce the risk of safety incidents from unexpected attention shifts.

8 Data Statement

All data collected from our test participants during the study are proprietary or confidential in nature and may only be provided with restrictions. Specifically, the de-identified data can only be requested by the National Institute for Occupational Safety and Health, UW-Madison regulatory and research oversight boards and offices. Some or all code generated or used during the study are available from the corresponding author by request.

9 Acknowledgments

This research was supported by the National Institute for Occupational Safety and Health (NIOSH), and the authors would like to express their gratitude for NIOSH's valuable contribution. The research was also supported by projects 1R21OH012455-01A1 and 5R21OH012455-02. The findings and conclusions presented in this paper are solely those of the authors and do not necessarily reflect the views of NIOSH. The authors are also grateful to M. A. Mortenson Company and their workers for participating in our experiment. Any mention of specific companies or products is for informational purposes only and does not imply endorsement by NIOSH, Mortenson, or the authors.

References

[1] John Howard, Vladimir Murashov, and Christine Branche, "Can Drones Make Construction Safer?" Accessed: Dec. 03, 2023. [Online]. Available: https://blogs-origin.cdc.gov/niosh-science-blog/2017/10/23/drones-construction/

[2] I. Jeelani and M. Gheisari, "Safety challenges of UAV integration in construction: Conceptual analysis and future research roadmap," *Saf Sci*, vol. 144, p. 105473, 2021, doi: https://doi.org/10.1016/j.ssci.2021.105473.

[3] The Wall Street Journal, "Drones Are Watching: Railroad Irks Workers With Unmanned Aircraft." Accessed: Dec. 03, 2023. [Online]. Available: https://www.wsj.com/articles/drones-are-watching-railroad-irks-workers-with-unmanned-aircraft-1521028800

[4] G. Mark, V. M. González, and J. Harris, "No task left behind?: examining the nature of fragmented work," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2005, [Online]. Available: https://api.semanticscholar.org/CorpusID:3079084

[5] M. Khalid, M. Namian, and C. C. Massarra, "The Dark Side of the Drones: A Review of Emerging Safety Implications in Construction," 2021. [Online]. Available: https://api.semanticscholar.org/CorpusID:237875604

[6] N. Mostafa, A. Alex, and F. Jing, "Effect of Distraction on Hazard Recognition and Safety Risk Perception," *J Constr Eng Manag*, vol. 144, no. 4, p. 04018008, Apr. 2018, doi: 10.1061/(ASCE)CO.1943-7862.0001459.

[7] E. M. Altmann, G. Trafton, and D. Z. Hambrick, "Momentary interruptions can derail the train of thought.," *J Exp Psychol Gen*, vol. 143 1, pp. 215–26, 2014, [Online]. Available: https://api.semanticscholar.org/CorpusID:15459133

[8] U.S. Bureau of Labor Statistics, "A look at falls, slips, and trips in the construction industry : The Economics Daily: U.S. Bureau of Labor Statistics," May 06, 2024. [Online]. Available: https://www.bls.gov/opub/ted/2024/a-look-at-falls-slips-and-trips-in-the-construction-industry.htm

[9] EHS Daily Advisor, "Understanding How Human Factors Affect Slips, Trips, and Falls." Accessed: Dec. 03, 2023. [Online]. Available: https://ehsdailyadvisor.blr.com/infographic/infographic-understanding-how-human-factors-affect-slips-trips-and-falls/

[10] M. Namian, M. Khalid, G. Wang, and Y. Turkan, "Revealing Safety Risks of Unmanned Aerial Vehicles in Construction," *Transp Res Rec*, vol. 2675, no. 11, pp. 334–347, Jul. 2021, doi: 10.1177/03611981211017134.

[11] M. C. Tatum and J. Liu, "Unmanned Aircraft System Applications in Construction," *Procedia Eng*, vol. 196, pp. 167–175, 2017, doi: https://doi.org/10.1016/j.proeng.2017.07.187.

[12] G. Albeaino, P. Brophy, I. Jeelani, M. Gheisari, and R. R. A. Issa, "Impact of Drone Presence on Construction Individuals Working at Heights," *J Constr Eng Manag*, vol. 149, no. 11, p. 4023119, 2023, doi: 10.1061/JCEMD4.COENG-13861.

[13] Wingtra, "Why and How to Use Drones in Construction and Infrastructure," 2020. [Online]. Available: https://wingtra.com/drone-mapping-applications/drones-in-construction-and-infrastructure/

[14] W. Jiang, Y. Zhou, L. Ding, C. Zhou, and X. Ning, "UAV-based 3D reconstruction for hoist site mapping and layout planning in

petrochemical construction," *Autom Constr*, 2020, doi: 10.1016/j.autcon.2020.103137.

[15] S. Sun, "A new method for monitoring machinery movement using an Unmanned Aerial Vehicle (UAV) system," University of Twente, 2019. [Online]. Available: http://essay.utwente.nl/79827/

[16] R. R. S. de Melo, D. B. Costa, J. S. Álvares, and J. Irizarry, "Applicability of unmanned aerial system (UAS) for safety inspection on construction sites," *Saf Sci*, 2017, doi: 10.1016/j.ssci.2017.06.008.

[17] Federal Aviation Administration (FAA), "Certificated Remote Pilots including Commercial Operators." Accessed: Dec. 04, 2023. [Online]. Available: https://www.faa.gov/uas/commercial_operators

[18] Federal Aviation Administration (FAA), "Operations Over People General Overview." Accessed: Dec. 04, 2023. [Online]. Available: https://www.faa.gov/uas/commercial_operators/operations_over_people

[19] J. Fan and M. Saadeghvaziri, *Applications of Drones in Infrastructures: Challenges and Opportunities*. 2019. doi: 10.5281/zenodo.3566281.

[20] D. B. Costa, R. R. S. de Melo, J. S. Álvares, and A. A. Bello, "Evaluating the Performance of Unmanned Aerial Vehicles for Safety Inspection," in *24th Annual Conference of the International Group for Lean Construction*, Boston, Massachusetts, USA, 2016. [Online]. Available: http://iglc.net/Papers/Details/1286/pdf

[21] I. M. Hashem, F. Ian, Z. Xun, A. Behzad, R. Peyman, and M. Michelle, "Quantitative Assessment of Proximity Risks Associated with Unmanned Aerial Vehicles in Construction," *Journal of Management in Engineering*, vol. 37, no. 1, p. 04020095, Jan. 2021, doi: 10.1061/(ASCE)ME.1943-5479.0000852.

[22] H. Izadi Moud, A. Shojaei, I. Flood, X. Zhang, and M. Hatami, *Qualitative and Quantitative Risk Analysis of Unmanned Aerial Vehicle Flights over Construction Job Sites*. 2018.

[23] H. Xie, E. Tudoreanu, and W. Shi, "Development of a virtual reality safety-training system for construction workers," *Digital library of construction informatics and information technology in civil engineering and construction*, pp. 1–9, 2006.

[24] J. Plomin, P. Schweidler, and A. Oehme, "Virtual reality check: a comparison of virtual reality, screen-based, and real world settings as research methods for HRI," *Front Robot AI*, vol. 10, p. 1156715, 2023.

[25] Z. Barlow, H. Jashami, A. Sova, D. S. Hurwitz, and M. J. Olsen, "Policy processes and recommendations for Unmanned Aerial System operations near roadways based on visual attention of drivers," *Transp Res Part C Emerg Technol*, vol. 108, pp. 207–222, 2019, doi: https://doi.org/10.1016/j.trc.2019.09.012.

[26] D. S. Hurwitz, M. J. Olsen, Z. Barlow, and others, "Driving Distraction Due to Drones," 2018.

[27] A. Ryan, C. Fitzpatrick, E. Christofa, and M. Knodler, "Driver performance due to small unmanned aerial system applications in the vicinity of roadways," *Transp Res Part F Traffic Psychol Behav*, vol. 68, pp. 118–131, 2020, doi: https://doi.org/10.1016/j.trf.2019.12.006.

[28] I. Jeelani and M. Gheisari, "Safety Challenges of UAV Integration in the Construction Industry: Focusing on Workers at Height," 2022.

[29] Gilles Albeaino, Idris Jeelani, Masoud Gheisari, and Raja R. A. Issa, "Attentional Impact of Drones on Construction Sites," *Proceedings of 59th Annual Associated Schools*, vol. 4, pp. 121–129, 2023.

[30] G. Charness, U. Gneezy, and M. A. Kuhn, "Experimental methods: Between-subject and within-subject design," *J Econ Behav Organ*, vol. 81, no. 1, pp. 1–8, 2012, doi: https://doi.org/10.1016/j.jebo.2011.08.009.

[31] G. Morgenthal and N. Hallermann, "Quality Assessment of Unmanned Aerial Vehicle (UAV) Based Visual Inspection of Structures," *Advances in Structural Engineering*, vol. 17, no. 3, pp. 289–302, Mar. 2014, doi: 10.1260/1369-4332.17.3.289.

[32] Saul Mcleod, "Experimental Design." Accessed: Dec. 04, 2023. [Online]. Available: https://www.simplypsychology.org/experimental-designs.html#:~:text=Repeated%20Measures%20design%20is%20an,%2C%20or%20within%2Dsubjects%20design

[33] D. A. Preece, "Chapter 10 - Latin Squares as Experimental Designs," in *Annals of Discrete Mathematics*, vol. 46, J. Dénes and A. D. Keedwell, Eds., Elsevier, 1991, pp. 317–342. doi: https://doi.org/10.1016/S0167-5060(08)70970-1.

[34] D. Bates, "Fitting linear mixed-effects models using lme4," *arXiv preprint arXiv:1406.5823*, 2014.

[35] A. Kuznetsova, P. B. Brockhoff, and R. H. B. Christensen, "lmerTest package: tests in linear mixed effects models," *J Stat Softw*, vol. 82, no. 13, 2017.