

Comparative Analysis of Camera Technologies for Construction Safety Assessments: Potential and Challenges

Kishor Bhagwat^{1,*}, Raghvendra Kotalwar², Diptee Gundwale², Uday Hasbe², Shirish Patil² and Vishal Kolage²

¹Civil Engineering Department, National Institute of Technology Rourkela, India

²School of Construction, National Institute of Construction Management and Research, Pune, India

kishorsbhagwat@gmail.com

Abstract. The construction industry is a major global economic driver, with the success of construction projects having a significant impact on the social, environmental, and economic development of nations. However, the success of many construction projects is hindered by poor safety performance. To improve safety, it is essential to assess it effectively. Past literature has developed various manual methods for assessing safety performance, often based on compliance with safety regulations set by local or global organizations. The advent of camera technology has enabled construction safety professionals to automate the assessment, documentation, and training. However, a comparative analysis of three camera technologies—Stationary Camera, helmet-mounted 360° Portable Camera, and camera-mounted Unmanned Aerial Vehicle (UAV)—in terms of their potential and challenges for safety assessment using a case study approach has been limited. Given the increasing adoption of automation in the construction industry and the need to strengthen the safety assessment process, this study aims to conduct a comparative analysis of these camera technologies for safety assessment. A residential building was selected as a case study, and safety indicators were derived from the Bureau of Indian Standards. The potential of the three camera technologies in safety assessment was tested. The results revealed that the 360° Portable Camera outperforms the other two technologies, demonstrating its full potential for safety assessment. The data collection process also highlighted several challenges associated with the use of these camera technologies. The Stationary Camera showed advantages in areas such as ‘Ease of Use’, ‘Regulatory Restrictions’, ‘Purchase Cost’, and others. The findings provide valuable insights for construction safety professionals, helping them to select the most appropriate camera technology for safety assessment.

Keywords: Construction, Safety Assessment, Camera, Unmanned Aerial Vehicle, Case Study.

1 Introduction

The construction industry is a key pillar in driving the global economy [1]. It plays a vital role in every country, contributing not only to the Gross Domestic Product but also providing employment and infrastructure to meet essential societal needs. Therefore, the success of the construction industry is crucial. Traditionally, the success of the industry has been assessed based on schedule, economic, and quality performance. However, safety performance is often overlooked when evaluating the successful delivery of construction projects. As a result, the construction industry is responsible for over 60,000 fatalities worldwide each year [2]. An additional challenge is the underreporting of accidents, which is prevalent in the industry [3]. This suggests that the actual number of fatalities is likely much higher than reported. Heinrich's investigation into the causes of accidents revealed that, prior to a major incident, there might be 29 minor accidents or 300 near-miss incidents that go unnoticed [4]. Heinrich also emphasized the importance of preventive measures and concluded that 88% of accidents can be prevented by safe behaviors, 10% by safe site conditions, and the remaining 2% are unavoidable circumstances such as natural calamities [4]. In total, 98% of accidents can be prevented through safe practices and conditions on construction sites.

There are several construction safety management practices aimed at improving safe behavior and site conditions. However, without an effective construction safety performance assessment system, progress cannot be made [5]. Recognizing the need for robust safety management in the construction industry, professionals and researchers have developed various tools and techniques. The advent of camera technology and its application across industries has been a significant development. With advancements in technology, camera systems have evolved to include Stationary Camera, 360° Portable Camera, and UAVs. Past studies have explored the use of camera technology and reported its benefits across various sectors, including construction. However, a comparative analysis of the potential and challenges of these camera technologies specifically within the construction domain remains largely unexplored. Therefore, the aim of this study is to investigate the potential of Stationary Camera, 360° Portable Camera, and UAVs in construction safety assessment (CSA).

2 Literature Review

Construction safety management is a crucial element for the successful delivery of a project. In recent years, research has explored the integration of automation in construction safety management, particularly through the use of camera technologies. For example, Zhu et al., [6] employed Stationary Cameras to track the positions of workers and mobile equipment, proposing a strategy using Kalman filters to predict future positions and prevent accidents, such as "struck by" incidents, on construction sites. Yan et al., [7] used Stationary Cameras to estimate overcrowding on construction sites, which can lead to safety issues, productivity losses due to congested or inadequate work areas, and negative worker behaviors. Similarly, Liang et al, [8] used Sta-

tionary Cameras to monitor the positions of workers and equipment to prevent accidents during human-robot collaborative work. Tang et al., [9] also utilized Stationary Cameras to capture video footage of construction sites and developed forecasting methods to proactively prevent collisions between equipment and workers.

In comparison to Stationary Cameras, research on the use of UAVs for construction safety management is relatively limited. For instance, Kim et al., [10] proposed a framework to prevent contact-driven accidents between construction equipment and workers using camera-mounted UAV, computer vision, and deep neural networks. Zhu et al., [11] employed UAV and artificial intelligence for safety monitoring in road construction. Similarly, Liang et al., [12] utilized UAV and computer vision to detect various objects on construction sites, including helmets, excavators, moving vehicles, and workers. Furthermore, compared to UAV, research on the application of 360° Portable Cameras for construction safety management is limited. For instance, previous studies have used UAVs and 360° Portable Cameras for construction progress monitoring [13]. Similarly, Beese et al., [14] employed a 360° Portable Cameras to record wall plastering activities and assess the associated risks. Gerhardt & Broll, [15] used a 360° Portable Cameras in conjunction with artificial neural networks to enhance road maintenance services. Overall, the camera technologies mentioned above have focused on specific aspects of construction safety management, such as collision forecasting and activity monitoring. However, a comparative analysis of the potential of these camera technologies is lacking in the existing literature. Such an investigation is essential from a CSA perspective, and the findings would help safety professionals select the most suitable technology for their needs.

3 Research Methodology

This study followed the research methodology outlined in Figure 1 to achieve its aim. The first step involved conducting a comprehensive literature review to identify key safety indicators, which served as a common basis for the comparative analysis. Next, a real-world case study was selected to assess the potential of the three aforementioned technologies. Further, data analysis was performed to highlight the potential and challenges of adopting these technologies for CSA. The detailed research methodology is presented in the following subsections.

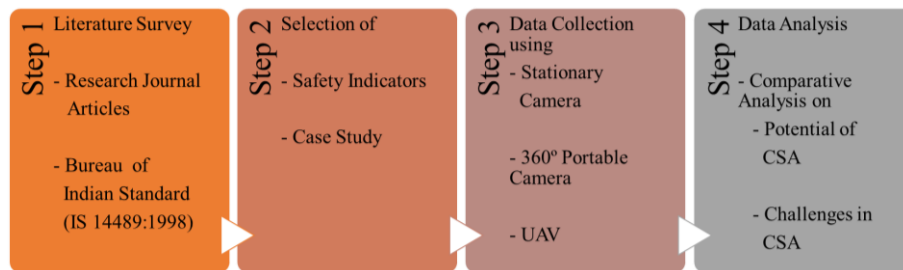


Fig. 1. Research Methodology.

3.1 Identification of Safety Indicators

An extensive literature review was conducted to identify safety indicators within the construction industry. Various sources focused on construction safety highlighted different safety indicators, which varied based on the scope and type of construction project. To narrow the investigation, this study focused specifically on building construction projects, considering factors such as complex structures, short project durations, multi-level contracting system, and other allied challenges [16]. As a basis for the comparative analysis and to align with local conditions, the Bureau of Indian Standard 'IS 14489: 1998, the Code of Practice for Occupational Safety and Health Audits' was considered. A total of twenty-three safety indicators related to building construction projects were identified from IS 14489:1998.

3.2 Case Study Details

A building construction project was selected as the case study for this investigation. At the time of the safety assessment, the building was still under construction, with the sixth-floor slab casting completed. The structure of the building is primarily reinforced concrete, with brick masonry walls. This site was chosen with prior permission from the project manager and client to utilize the three camera technologies for a comparative analysis based on the confidentiality terms and conditions.

3.3 Data Collection

The first technology, Stationary Camera, was installed on the site to capture on-site activities. The Stationary camera monitored the construction site (figure 2(a)), and safety indicators were assessed using a three-point scale: Full Assessment (FA), Partial Assessment (PA), and No Assessment (NA). A Full Assessment (FA) indicates that the safety indicator can be completely assessed using the technology, while a Partial Assessment (PA) means the indicator can only be partially assessed. No Assessment (NA) means the technology is unable to assess the safety indicator. The potential of Stationary Cameras for each safety indicator was assessed accordingly. Next, a 360° Portable Camera was mounted on a helmet, and the entire case study was maneuvered. The 360° Portable Camera recorded the site in video format, and safety indicators were evaluated through the recorded footage (figure 2(b)). Finally, an UAV was deployed for the CSA. The UAV captured the case study area and recorded on-site construction activities (figure 2(c and d)). Data from all three technologies were collected and analyzed, and a relative comparison was made using various summary parameters. The study concluded by reporting the challenges and offering a comparative analysis of the three technologies used in the investigation.



Fig. 2. Data collection using (a) Stationary Camera (b) 360° Portable Camera, and (c & d) UAV.

4 Results and Discussion

Data collection was conducted in the presence of the project manager. Based on the videos and images captured by the Stationary Camera, 360° Portable Camera, and UAV, the potential of each technology in inspecting the safety indicators was discussed with the project manager and reported. A summary of the data analysis, highlighting the potential of each technology in assessing the safety indicators, is presented in Table 1.

The safety awareness program or initiatives through bulletin boards can be partially assessed using Stationary Cameras, fully assessed using a 360° Portable Camera, and partially assessed using a UAV. Unsafe site conditions and hazardous areas can be partially assessed using Stationary Cameras, fully assessed with a 360° Portable Camera, and either partially or not assessed using a UAV. Personal protective equipment (PPE) related safety indicators can be partially assessed with Stationary Cameras, fully assessed with a 360° Portable Camera, and partially assessed with a UAV. Health-related safety indicators can be partially assessed using Stationary Cameras, fully assessed using a 360° Portable Camera, and fully assessed using a UAV. House-keeping-related safety indicators can be partially assessed with Stationary Cameras, fully assessed with a 360° Portable Camera, and partially assessed with a UAV. Post-accident safety indicators, such as the availability of a first-aid kit, can be partially assessed by Stationary Camera and fully assessed by 360° Portable Camera, while they are primarily partially assessed with a UAV. In general, the assessment capabilities of Stationary Cameras can be expanded by installing more units. However, increasing the number of Stationary Cameras may raise privacy concerns. With 360°

Portable Camera, all safety indicators can be fully assessed, though it may not be possible to assess all indicators at all times. Stationary Cameras allow for continuous real-time safety assessments, which is not possible with the 360° Portable Camera. Additionally, using the 360° Portable Camera requires an employee, such as a safety officer or on-site worker, to maneuver through the site. Regarding UAVs, the investigation revealed mixed results. Most safety indicators could only be partially assessed using the UAV, with some not being assessable due to flying restrictions inside the building. Very few safety indicators were fully assessed with the UAV.

Table 1. Potential of camera technologies in CSA.

No.	Safety Indicator	Stationary Camera			360° Portable Camera			UAV		
		FA	PA	NA	FA	PA	NA	FA	PA	NA
1	Are there any strategies, such as bulletin boards, in place to promote health and safety at your building site?		✓		✓				✓	
2	Identify any spillage on the construction site.			✓	✓					✓
3	Are there any working conditions that cause the flooring to become slippery? If so, what safety measures are in place to prevent accidents?			✓	✓					✓
4	Have all the hazardous areas been identified?		✓		✓				✓	
5	Is PPE available and being used?		✓		✓				✓	
6	How are the PPE that employees are given stored?	✓			✓					✓
7	Are the necessary PPEs given to the contractor's employees?		✓		✓				✓	
8	Do you have facilities for localized dust extraction and scrubbing?	✓			✓			✓		
9	Is dust generated during the construction process?		✓		✓				✓	
10	Are there clearly labeled disposable bins available, and are they proper-		✓		✓				✓	

	ly placed?			
11	Are the walkways on the slabs to be built properly designated and free of obstructions?	✓	✓	✓
12	Are the fire alarms clear of obstructions?	✓	✓	✓
13	Are there any trip systems, alarms, or safety interlocks in place?	✓	✓	✓
14	Are there any ambient monitoring systems with hazardous substance leak alarms?	✓	✓	✓
15	Identify the location of assembly points.	✓	✓	✓
16	Have sufficient earthing preparations been made at the terminals?	✓	✓	✓
17	Exists sufficient, secure access to all locations where employees must be employed?	✓	✓	✓
18	Are there adequate storage facilities available?	✓	✓	✓
19	Are there first aid kits available?	✓	✓	✓
20	Is there an on-site occupational safety and health center?	✓	✓	✓
21	Identify the locations, quantities, and types of portable fire extinguishers available on the site.	✓	✓	✓
22	Identify the locations of fire hydrants on the site.	✓	✓	✓
23	What number of emergency alarm systems are available?	✓	✓	✓

A relative comparative analysis was conducted between the three camera technologies during the preparation for and actual data collection process. The parameters considered for comparison included 'Coverage', 'Ease of Use', 'Regulatory Restrictions', 'Weather Restrictions', 'Battery Life', 'Purchase Cost', 'Operational and

Maintenance Cost', and 'Vulnerability to Damage'. The results of this relative comparative analysis are presented in the table 2. In terms of 'Coverage', Stationary Cameras, due to their fixed location, have relatively low coverage. The 360° Portable Camera offers higher coverage compared to the Stationary Camera, while the UAV provides the largest coverage due to its ability to elevate and move dynamically. Regarding 'Ease of Use', the Stationary Camera was the easiest to use, while the 360° Portable Camera was slightly more challenging to manage when mounted on the helmet. The UAV, on the other hand, required a well-trained operator to handle it effectively. For 'Regulatory Restrictions', both Stationary Cameras and 360° Portable Camera can generally be used across most construction sites. However, UAV usage may be subject to regulatory restrictions, particularly in certain areas due to security concerns and airspace regulations. In terms of 'Weather Restrictions', UAVs face more weather-related limitations, especially in monsoon or windy conditions. The 360° Portable Camera has fewer restrictions, especially when used indoors in an under-construction facility. However, it faces similar outdoor weather-related limitations as the UAV.

Regarding 'Battery Life', Stationary Cameras were found to have relatively longer battery life compared to the other technologies. In terms of 'Purchase, Operational, and Maintenance Costs', Stationary Cameras are generally less expensive than 360° Portable Camera. UAVs, however, incur higher costs for purchase, operation, and maintenance compared to both Stationary Camera and 360° Portable Camera. Finally, in terms of 'Vulnerability to Damage', UAVs are more susceptible to damage during operation, followed by the 360° Portable Camera, which has a medium level of vulnerability. Stationary Cameras, being fixed in place, have the lowest vulnerability to damage.

Table 2. Relative comparative analysis of camera technologies on challenges in CSA.

Parameter	Stationary Camera	360° Portable Camera	UAV
Coverage	Low	Medium	High
Ease of Use	High	Medium	Low
Regulatory Restrictions	Low	Low	High
Weather Restrictions	Low	Medium	High
Battery life	High	Low	Low
Purchase Cost	Low	Medium	High
Operational and Maintenance Cost	Low	Medium	High
Vulnerability to Damage	Low	Medium	High

5 Contributions and Limitations of the Study

This study makes both theoretical and practical contributions. Through a comparative analysis of three popular technologies using a case study approach, it investigates their potential and challenges in CSA. This analysis is crucial for understanding how these technologies can be applied and the obstacles they may present. From a practical standpoint, construction safety professionals can use the findings of this study to determine whether to adopt a single technology or a combination of technologies for safety inspections on their projects. Additionally, the study provides valuable insights into the limitations of these technologies, helping construction professionals make informed decisions regarding their use in safety assessments.

This study has a few limitations. First, it focused on a single case study, data from multiple case studies would provide deeper insights and help in generalizing the results. Second, the selection of safety indicators is based on IS 14489:1998. However, incorporating safety indicators from other literature sources could offer additional perspectives on the potential and challenges of using the three technologies in CSA.

6 Conclusion

Current investigation focused on a comparative analysis of camera technologies in CSA, highlighting their potential and associated challenges. The results showed that the 360° Portable Camera had an advantage over both the Stationary Camera and UAV. All considered safety indicators related to safety awareness, hazard identification, PPE, housekeeping, accident prevention measures, and post-accident arrangements for immediate medical aid could be fully assessed using the 360° Portable Camera, compared to the other two technologies. Both the Stationary Camera and UAV showed potential for partially assessing most of the considered safety indicators. Additionally, the relative comparative analysis broadly outlined the challenges of each camera technology. Based on observations during data collection, the Stationary Camera is well-suited for outdoor safety assessments, while the 360° Portable Camera is effective for both indoor and outdoor safety assessments. These findings suggest that both technologies can serve as valuable tools for safety assessments in the construction industry. However, results might vary in case of highway, flyover, bridge, tunnel construction projects.

Future studies can address the limitations of the current investigation and provide further insights into the potential and challenges of the three technologies in CSA. For instance, incorporating a larger number of case studies could enhance the robustness of the findings. Additionally, considering the complexities and unique characteristics of different types of construction projects, further investigations should explore the applicability of these technologies in safety assessments across various construction project types. This study serves as an initial step in exploring the suitability of these technologies for safety assessments in the construction industry. Moreover, the findings can help construction safety professionals develop effective safety assessment plans for their projects by selecting one or more of the techniques discussed here.

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