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Evaluating Stakeholder Awareness and Prioritizing Applications of UAVs Technology for Construction Safety Management

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Abstract: Recent technological advancements have presented opportunities for enhancing construction safety. Among these, unmanned aerial vehicles (UAVs) hold promising potential to revamp safety monitoring, inspection, and implementation. However, their adoption in the Indian construction industry remains nascent. Therefore, this study seeks to evaluate stakeholder awareness regarding the application of UAVs in construction safety management. The investigation unfolds in two phases: (i) evaluating awareness and (ii) prioritizing applications. For these purposes, the study surveyed and interviewed 108 project management consultants (PMCs), contractors, clients, and experts to evaluate their familiarity with UAV technology. Findings reveal that 74.07% of stakeholders possess some awareness of UAVs. Building upon existing literature, eight key applications for UAVs in construction safety were identified. Utilizing the Relative Importance Index (RII) method, these applications are prioritized based on stakeholder input, and a high level of correlation is observed among stakeholder's viewpoints. Notably, safety audits emerged as the highest-ranked application. This valuable insight serves as an evidence base for promoting UAV adoption and fostering improved safety management practices in the Indian construction sector.

Keywords: India, unmanned aerial vehicles, construction safety, relative importance index.

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1. Introduction

The construction industry is disorganised and scattered, facing significant hurdles with respect to other industries, even though economically significant. According to an ILO (International Labour Organization) report, India's construction sector has the highest accident rate in the world, with 165 people injured per 1000 workers. Also, the Indian construction sector alone adds 24.2% of the 48,000 total occupational accidents in India annually **Click or tap here to enter text.**(Patel and Jha, 2016). Advances in personal protection equipment, focused training, safety-aware design, sensor-equipped gadgets, and other areas have enhanced workplace safety. However, despite these advancements, the construction industry remains one of the most hazardous (Loganathan et al., 2017). UAVs are largely used in the defense sector in India, the agriculture industry, infrastructure and energy, insurance, construction, media and entertainment, and minerals. The Indian Unmanned Aircraft Vehicle (UAV) market is expected to develop at a CAGR of 18% from 2017 to 2024 (6Wresearch, 2021). UAVs-based solutions have been studied across eight sectors in India, with infrastructure and agriculture seeing the most momentum, in line with worldwide trends shown in Figure 1. Construction safety and progress monitoring, Infrastructure system and component monitoring, post-disaster reconnaissance, and geotechnical engineering are among the top application uses in areas of civil infrastructure where UAVs have had a transformational influence on the level of practice (Greenwood et al., 2019). UAVs are being explored for project tracking, but their application lags in construction safety management. To increase safety, technology is continually growing and being embraced by numerous sectors. However, this hasn't been the case in the construction business, where technology penetration is limited. UAVs are an exciting new technology that may dramatically increase safety while being a low-cost investment for construction enterprises. However, very sparse literature that focuses on the primary aspects impacting the use of UAVs for construction site safety in India is available. Identifying key impacts empowers stakeholders to leverage UAVs for safer construction.

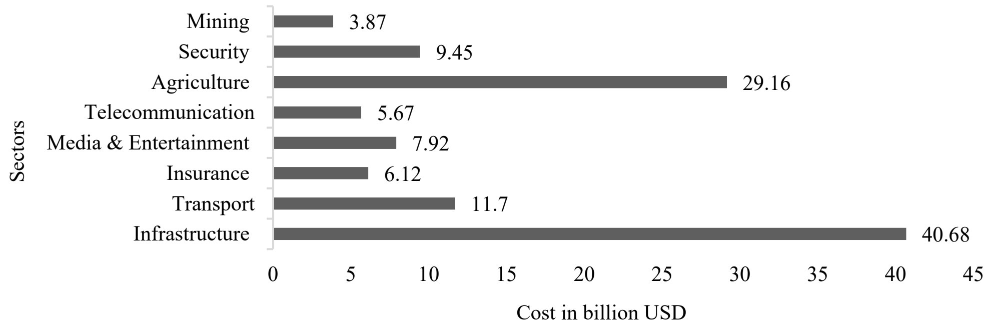

Fig. 1. Global addressable market value of UAVs-powered solutions

2. Literature Review

2.1. UAVs Background

Unmanned aerial vehicles (UAVs), widely known as drones, are aerial instruments that fly with controllers and do not require the assistance of onboard human drivers. UAVs can do tasks that manned aircraft cannot, and their uses result in evident economic savings and environmental benefits while reducing the risk of human deaths. UAVs allow us quick access to photos and real-time streaming. UAVs with camcorders are operated remotely with the help of mobile devices or computers (Tatum and Liu, 2017). When it comes to commercial UAV usage, it's clear that the construction industry has the highest acceptance rate, with 35% of US-based enterprises' sales worth 50 million USD (Zaychenko et al., 2018).

Depending on its intended function, UAVs come in a variety of sizes and configurations. They can be as small as an insect and fit in the palm of a hand to military UAVs as large as a small aircraft. These UAVs differ greatly in terms of performance, but in general, UAVs can fly up to 60 minutes, reach a speed of 65 km/h, and can be controlled from a few kilometres away. However, many UAVs have different characteristics and performance in controlling range, flying time, weight, and speed. As mentioned before, the UAVs' characteristics primarily depend on their function (Ham et al., 2011). UAVs can be classified based on their intended use, such as capturing photos, aerial mapping, security and surveillance, etc. UAVs are widely classified based on their wing arrangements. UAVs are classified into two categories based on the type of airborne platform employed. Rotorcrafts and fixed-wing UAVs are subdivided further, as shown in Figure 2. (Byun et al., 2015).

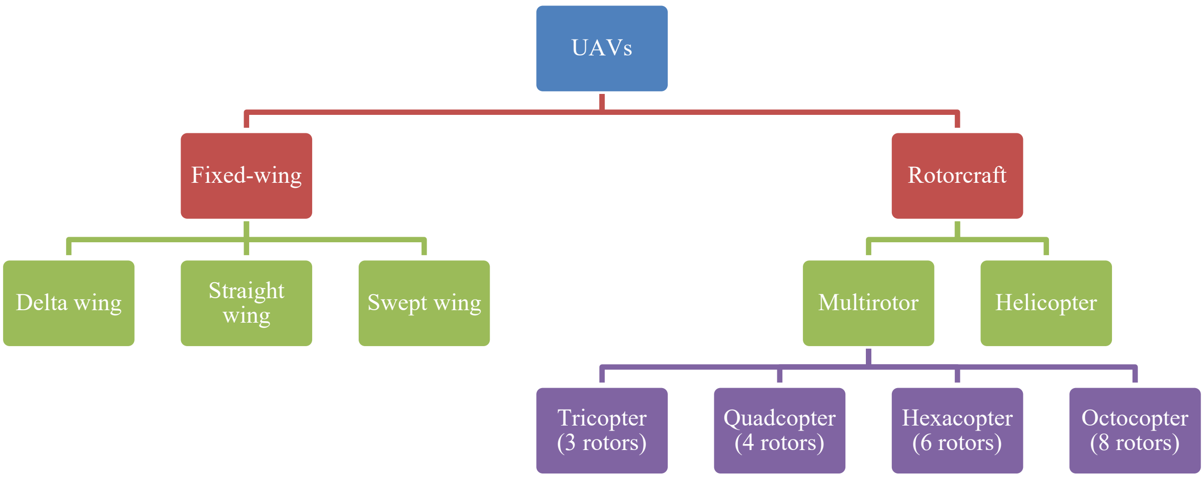

Fig. 2. UAVs Classification Based on Airborne Platforms (Adopted from Byun et al., 2015)

2.2. Regulations on the Use of UAVs in India

The concern of UAVs being used for unlawful purposes is a reality since they may represent a significant danger to people's security and privacy. UAVs, for example, can be used for spying, trespassing, and narcotics and arms smuggling across borders. Two UAVs carrying high-grade explosives launched a terror assault on the Indian Air Force (IAF) facility in Jammu on June 27, 2021. According to The Economic Times (2021), 167 UAV sightings were registered near the western border in 2019, with 77 sightings in 2020. As a result, it is critical to govern their use, ownership, and purpose. The Indian government acted upon it in 2021 with rules published by the Ministry of Civil Aviation under the UAVs (Amendment) Rules in 2022 and The Drone Rules in 2021.

After obtaining licenses and authorizations, there are still several limits to UAV operation. One of the most apparent is that UAVs should never be flown over a prohibited area. The Gazette of India states that unmanned aircraft flights are not authorised in designated airspace above India's land territories or territorial waters. UAVs can only fly at a certain height and speed, in addition to the geographical constraints. These are primarily determined by the type of UAVs. Micro UAVs, for example, cannot fly higher than 60 meters above ground level or faster than 25 m/s. Similarly, small UAVs are restricted to 120 meters above ground level and 25 m/s. No flying clearance is necessary for up to 400 feet in green zones and 200 feet between 8 and 12 kilometres from the airport boundary. From 8 to 5 kilometres in inner yellow zones, ATC permissions are required. The 5-kilometre periphery around an airport or sensitive area is mentioned as a red zone, which is completely flight-prohibited. These different zones are depicted in Figure 3.

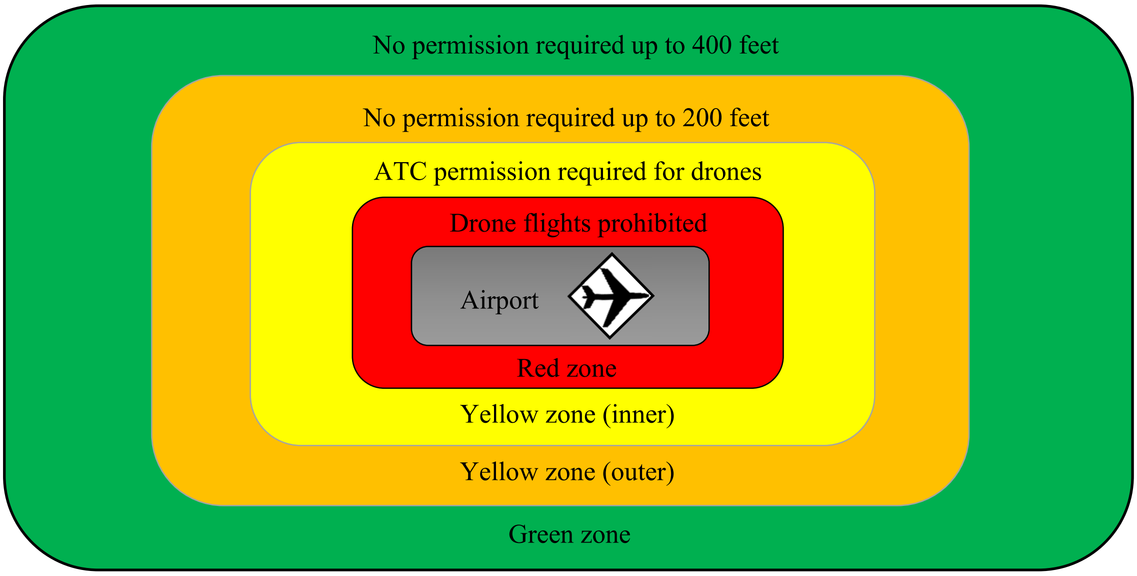

Fig. 3. UAVs zones- permission protocol

2.3. Application of UAVs in Construction Safety

Unmanned aerial vehicles might improve worker safety, reduce material waste, and reduce inspection and surveying costs (Hubbard et al., 2015; Liu et al., 2016). UAVs have been proposed for catastrophe assessment and inspection and maintenance of linear structures such as highways, waterways, and bridges (Erdelj and Natalizio, 2016; Hallermann and Morgenthal, 2014). Experts have identified the following areas as a possible use for UAVs in the construction sector.

Safety inspectors' exposure to risky conditions would be reduced, inspections of the projects would be feasible, and the time necessary for big project inspections would be decreased. (Ashour et al., 2016; Motawa and Kardakou, 2018). Massive inspection tasks, such as dam inspections or high shear wall inspections, might benefit from using the UAVs to gather data for analysis and processing into 3D models, from which safety audits could be undertaken. Additionally, programmes for automating the identification of structural faults and codes for breaches might be created, with inspectors just having to check the violation data (Ashour et al., 2016). The information gathered might also be used to develop suitable paperwork for a project.

UAVs have also been examined as safety inspection equipment on construction sites. UAVs, wireless sensor networks, and information technology are all expected to play a more significant role in safety management in the future (Irizarry et al., 2012). The safety manager had fast access to images from any point on the construction site due to the UAV. A camera-equipped vehicle with a large visual dashboard was found to be equally as valuable for the safety manager as conducting personal observations in plain sight. They also stated that certain traits, including autonomous flying, voice recognition, and a common user experience, should be required in construction safety UAVs. It's worth noting that using UAVs on busy construction sites raises extra safety issues, such as worker distraction and a higher danger of colliding with equipment or people. For a successful UAV incorporation, construction site personnel should be trained (Irizarry and Costa, 2016). These are all important elements to consider when incorporating UAVs into infrastructure projects. The proposed succeeding generation worksite exemplifies this idea (Ham et al., 2011). Sensor cameras are employed in this concept to capture useful photos that track progress, efficiency, quality of construction, and safety needs. Numerous aerial vehicles might be used by professionals to automatically fly about a construction project on specified courses, observing the workplace in real-time from a variety of perspectives (Alizadehsalehi et al., 2020). If the UAVs were equipped with communication capabilities, they might also provide the safety administrator with direct contact with the employees.

Despite clear benefits like safety, quality, speed, and cost savings, the construction sector lags in technology adoption. UAVs, outperforming traditional methods, offer crucial growth potential for the industry. They reduce workplace danger by handling risky tasks like roof inspections, improve quality by capturing detailed aerial imagery, and boost output by streamlining progress tracking. This is only possible through the availability of trained and licensed operators. Since there is a paucity of literature on the issue and the potential applicability is vast. There is a need to investigate the usage of unmanned aerial vehicles (UAVs) in Indian construction.

3. Research Objectives

The primary aim is to evaluate stakeholder awareness and prioritize applications of UAV technology for construction safety management in the Indian industry. Objectives of the study undertaken after conducting a wide literature review in the section are as follows:

- To evaluate the level of awareness and use of UAVs depicting stakeholders' perspective
- To identify potential safety applications of UAVs for their use in safety management
- To prioritize potential safety applications of UAVs relevant for adaptation in safety management

4. Experimental Design

A questionnaire form has been designed for the quantitative study and deployed online and offline. The questionnaire contained eleven small sections with questions being conditional in nature and related to the respondent's profile, awareness, and application. It also included one informative short video for clarity of the respondents. The logic for the awareness-related conditional questions is mentioned with a flow diagram in Figure 4.

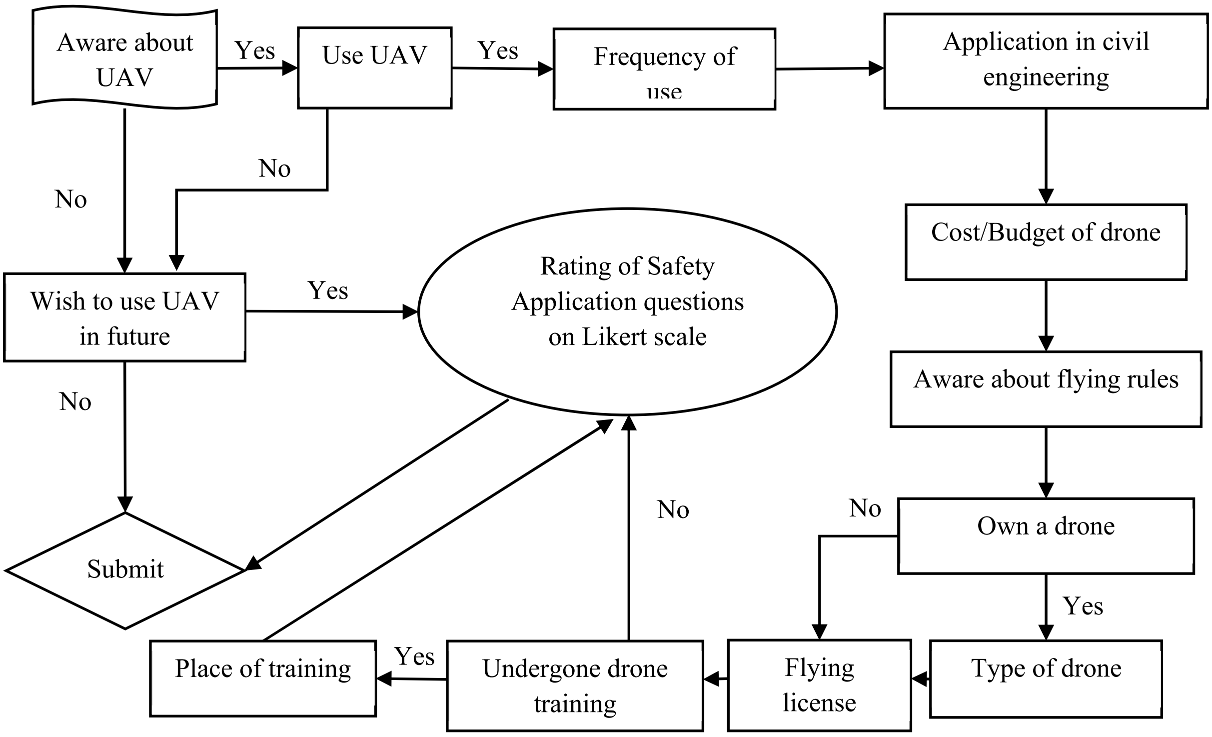

Fig. 4. Logic diagram for conditional questions

Eight questions were presented in the questionnaire under Safety Application and are represented as A1 to A8 in Table 1. The professionals' responses were assessed on a five-point Likert scale (1 to 5). (1 = Strongly Disagree; 2 = Disagree; 3 =Neutral; 4=Agree; 5 = Strongly Agree)

Table 1. Various safety application indicators taken into account for Rating

Code	Safety application indicator	References
A1	Safety inspection	(Alizadehsalehi et al., 2020)
A2	Safety monitoring	
A3	Safety planning	
A4	Hazard detection	
A5	Safety audit	(Umar, 2021)
A6	Safety performance	
A7	Risk mitigation	(Guan et al., 2022)
A8	Post-accident investigations	(Alizadehsalehi et al., 2020)

5. Data Collection

The target population for this study is clients, contractors, and project management consultants (PMCs) in the Indian construction industry with fruitful experience and knowledge about the subject. The target population belonged to a diversified location and background, which helped assess the true awareness level across the Indian scene. The data was gathered through a structured conditional questionnaire, with questions answered by rating on a Likert scale of 1 to 5. The questionnaire was deployed via Google Forms and was sent to over 240 prospective Indian respondents (clients, contractors, and project management consultants (PMCs) through in-person, email, LinkedIn, and over the phone.

The data acquired from 108 respondents and the project's background are discussed in this section. A significant percentage of respondents work on-site or participate in an indirect activity on the site. As a result, PMCs account for 43 (39.82%) responders, while contractors account for 31 (28.70%), and 34 (31.48%) of those who responded were clients (Fig.

5.). All stakeholders represent the insights and awareness of ongoing research and development works in the industry. Thus, the survey data is valuable and reliable. Forty (37.03%) of the respondents have over six years of experience. Furthermore, nearly the same proportion of 38 (35.19%) respondents with one to three years of experience responded, as seen in Figure 5. Based on the above distribution, it can be deduced that this study touched a large number of experienced experts. According to the data, more than 98% of the respondents have the requisite degrees (graduate or higher) necessary for professional registration in India, and 84.26% have more than one year of experience. The nature of the organization respondents belonged to shows that nearly 39 (36.11%) and 69 (63.89%) belonged to government and private firms, respectively. As a result, this helps to identify the responses and awareness based on both perspectives. The respondents averaged eight years of experience, with 98% possessing the necessary professional degrees. This profile suggests that the respondents might be trusted with data for this study.

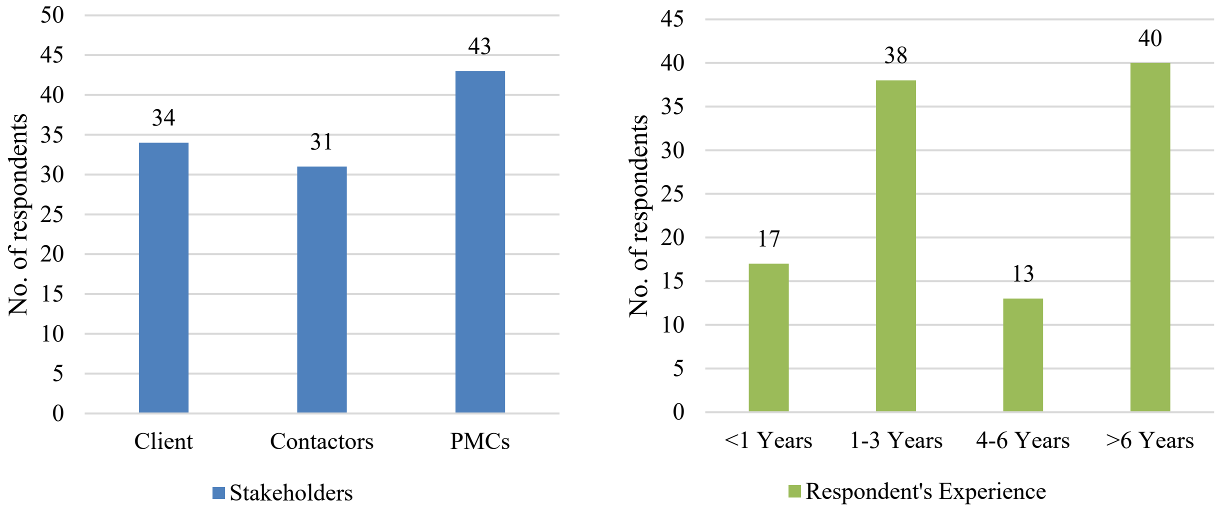

Fig. 5. Pictorial representation of respondent's background

6. Statistical Methods

The data was analyzed using Microsoft Excel and the Statistical Package for Social Science software (SPSS).

6.1. Cronbach's Alpha

Cronbach's alpha is performed as a parameter for measuring the consistency or dependability of a group of responses to a series of questions. As a rule of thumb, $\boldsymbol{\alpha} > 0.7$ is acceptable (Hair et al., 2017). The Cronbach's alpha is computed by using Equation 1.

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum_{i=1}^{k} \sigma_{yi}^2}{\sigma_x^2}\right) \tag{1}$$

where k = number of scale items (here eight safety application indicators), σ^2_{yi} = variance associated with item i, and σ^2_x = variance associated with the observed total scores

6.2. Relative Importance Index (RII)

RII analysis is used to identify the most important variables rated by respondents. It is also an appropriate technique to prioritize variables rated on Likert-type scales. It can be deducted by Equation 2.

$$RII = \frac{\sum_{n=1}^{n=i} W_i X_i}{AN} \tag{2}$$

where W = weight assigned by respondents on the Likert scale, X = frequency of each weight, A = highest weight, and N = number of respondents.

6.3. Correlation Analysis

The Spearman's rank correlation coefficient (SRCC) test is used to determine the degree of relationship between variables (Tripathi and Jha, 2019). It is a nonparametric test that is used to determine rank correlation. A correlation between variables with a significance value of less than 0.05 is considered appropriate. The SRRC formula is shown below in Equation 3.

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2-1)} \tag{3}$$

where, $\boldsymbol{\rho}$ = Spearman's rank correlation coefficient, d_i = the difference between each observation's two rankings, and n = the total number of observations

6.4. Mann-Whitney U Test

This test is required when comparing two groups to check for a significant distribution of data. SPSS software was utilized to perform this study, and The Mann-Whitney U test was used to compare sample data.

- Null hypothesis H0 equals the distributions (shapes) of the two groups are equal.
- Alternative hypothesis H1: The distributions (shapes) of the two groups are not similar.

If the significance threshold is greater than 0.05, the null hypothesis is accepted, and the results are drawn because the data from the two groups are statistically significant.

7. Findings and Discussion

The findings of the questionnaire survey are presented in this section. This study used Google Forms to send the questionnaire to experts and individuals who interact with the construction industry on a regular basis. A total of 108 survey questionnaire responses were received, and the respondents provided comments and input.

7.1. Reliability Test

To demonstrate the response's acceptability for use in the analysis, a reliability test was undertaken. The Alpha Cronbach's value for safety application was measured to be 0.815 among eight safety application indicators. Since the value is more than 0.7, the data is reliable.

7.2. Awareness and Level of Usage

The extent to which various stakeholders in the construction industry were aware of how UAVs may be utilized for safety purposes was a recurrent issue covered in the survey. The main themes for UAV utilization in Indian construction are current UAV usage, future wishes, and other related attributes. Twenty out of every 27 people who responded were aware that UAVs might be used for construction sector safety. Thus, a total of 80 respondents (74.07%) were aware, and 39 among those aware used UAVs for various purposes in the construction industry. Meanwhile, 41 others knew of this but did not use UAV technology. Out of 28 (25.93%) unaware of UAV technology, 16 (14.82%) agreed to adopt the technology in the future, whereas 12 (11.11%) among them showed no interest in adopting the technology in the future. The awareness level is summarized in Table 2.

Table 2. Results of UAVs level of awareness in the Indian construction industry

Level of awareness		Percentage	
Aware	Aware and use	36.11% (41)	74.07% (80)
	Aware but not use	37.96% (39)	
Unaware	Wish to adopt in the future	14.82% (16)	25.93% (28)
	Doesn’t adapt to use in the future	11.11% (12)	

The study looked at the project's purposes and the ways in which UAVs could be useful in the construction industry. Most respondents mentioned construction safety and progress monitoring, accounting for 27 (39.23%) of the 39 who were aware of and using UAV technology. This is because clients like NHAI and others have made progress tracking mandatory. Seven of 39 professionals (17.94%) who utilize UAVs for projects in construction do so very frequently, whereas twelve (30.77%) do so frequently. This frequent use is due to the mandatory monthly use made by clients. The cost range and future budget of construction enterprises and professionals owning UAVs were examined. Out of 39 utilizing the UAV technology maximum, 19 (48.72%) had invested in the price range of USD 760 to USD 1960 (₹75,000 to ₹1.5 lakhs). This demonstrates huge investments have been made in hi-tech UAVs, which is a welcoming sign. Moreover, multirotor UAVs (81.2%) and helicopters (18.2%) are among the types of UAVs professionals utilize in the construction industry. In addition, the survey shows that very small fractions of users own a valid flying license (26.3%), and very few utilizers (21.1%) have undergone formal and informal training on flying UAVs. The majority of the training (75%) was done in private training institutes and others on their own through online modes (25%). This data depicts that there is an urgent need to spread awareness and regulate training and license-related issues for the safe flying of UAVs to avoid being a hazard leading to accidents in the workplace.

7.3. Relative Importance Index (RII) Analysis

RII values were obtained using Microsoft Excel software and represented in Table 3. The frequency of responses received on the Likert scale for safety application is demonstrated in Figure 6.

Table 3. Overall RII Ranking

Code	Safety application indicator	RII	Rank
A1	Safety inspection	0.824	4
A2	Safety monitoring	0.835	2
A3	Safety planning	0.817	6
A4	Hazard detection	0.828	3
A5	Safety audit	0.854	1
A6	Safety performance	0.817	5
A7	Risk mitigation	0.791	7

A8	Post-accident investigations	0.780	8

Safety audit (A5) was placed at the top as an application area. Construction professionals believe that measuring UAVs based on safety audits has a visual and observational component, but also gathers evidence via documents and digital records in multimedia. Retaining digital records aids in ensuring an unbiased safety audit. Furthermore, it protects auditors from the influence of local line management. Respondents believe that UAVs are used for safety monitoring (A2) as a viable option due to their ease of maneuvering, exceptional flexibility, low cost, and capacity to record from a bird's-eye perspective and monitor from a remote position without the need for personal presence. For construction site hazard detection (A4), construction staff placed a high focus on UAVs employed with a range of sensors that alert ahead of time for hazardous situations, materials, and unsafe structures without putting workers at risk. Safety inspection (A1) was ranked fourth on the list. For safe UAV integration, construction site staff must be trained. Construction staff put a modest amount of emphasis on UAV-based safety inspections, which provide quick access to photos from anywhere on the job site, although training of construction workers is required. Despite having the same RII values, safety performance (A6) ranked higher than safety planning (A3) due to its lower standard deviation. Safety performance (A6) directly measures the effectiveness of UAVs in achieving safety goals, such as reducing accidents or injuries. This tangible outcome will likely be prioritized over safety planning (A3), a more process-oriented measure focusing on the quality of planning documents and procedures. By identifying and mitigating potential hazards, safety planning can help to reduce the number of accidents and injuries that occur. This can lead to improved safety performance. Risk mitigation (A7) and post-accident investigations (A8) areas came in seventh and eighth position, respectively. Respondent indicated that these two areas had minimal potential for application but could be done in the future with technological and sensor upgrades.

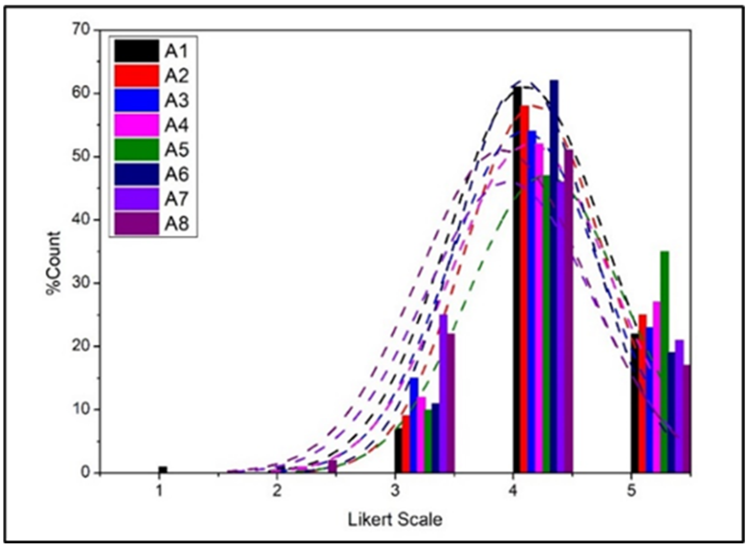

Fig. 6. Frequency distribution of safety applications rated on Likert's scale

7.4. Correlation Analysis

The degree of agreement among project participant groups was checked using the Spearman's rank correlation coefficient (SRCC) test in SPSS software version 26. Three groups were chosen for the test: contractors, clients, and project management consultants (PMCs).

Table 4. Spearman's rank correlation coefficient (SRCC) results

Types of stakeholders	Correlation
Client and Contractor	0.007
Client and PMC	0.021
Contractor and PMC	0.002

A significant level satisfying criteria of value greater than 0.01 represents the correlation between the two groups and values less than 0.05 indicate an acceptable correlation. This result, presented in Table 4, indicated that all three participants had a higher level of agreement with using UAVs for safety management on construction sites in Indian construction projects. It also indicates that Clients–Contractors and Contractors–PMCs have a high degree of agreement on ranking. Moreover, Clients–PMCs have an acceptable correlation.

7.5. Mann-Whitney U Test Analysis

Before comparing RII, it becomes necessary to verify whether the mean value of samples or the distribution of data is statistically different before comparing each stakeholder's rating. Using SPSS software version 26, the Mann-Whitney U test was used to examine the distribution of data between two groups. The test included key project players such as the clients, contractors, and project management consultants. Each stakeholder must rate indicators in order to pass this test. Table 5 indicates that PMCs–Contractors, Clients–Contractors, and PMCs–Clients have a significance level greater than 0.05 in all areas, indicating that the null hypothesis is retained and the data distribution is the same for both groups.

Table 5. Mann-Whitney U test results

Asymp. Sig (2-tailed)								
Application	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
Clients and Contractors	0.951	0.582	0.658	0.773	0.474	0.702	0.529	0.484
Contractors and PMCs	0.900	0.808	0.933	0.194	0.329	0.410	0.839	0.762
Clients and PMCs	0.993	0.602	0.604	0.335	0.775	0.654	0.51	0.607

7.6. Comparative RII Analysis

Spearman's rank correlation coefficient (SRCC) was used to assess agreement among stakeholders and was found to be significant. The Mann-Whitney U tests were performed, and the results were satisfactory for comparing ranks among stakeholders. It was observed that there is a strong correlation in perception among contractors, consultants, and clients regarding the application, adoption, and utilization of UAVs for safety applications in the construction industry. According to the comparative RII study, Table 6 represents the RII ranking comparison of stakeholders for safety applications. Among the key findings, safety audit (A5), hazard detection (A4), and safety monitoring (A2) are unanimously identified as high-priority areas by all three stakeholders. According to respondents, safety inspection (A1), safety performance (A6), and safety planning (A3) are perceived as moderately important for safety management applications but are considered areas that require further improvement. This indicates a shared belief among stakeholders that enhancements in these three aspects could contribute to more effective safety management. In contrast, risk mitigation (A7) and post-accident investigations (A8) emerge as the least prioritized by all stakeholders. This suggests a potential consensus among contractors, clients, and PMCs that these areas may require less immediate attention or are currently perceived as less critical in safety management applications. The comparative RII rankings provide valuable insights into different stakeholders' collective perceptions and priorities, guiding potential strategies for improvement and allocation of resources in safety management within the represented context. All three stakeholders put the safety audit (A5) application first. Thus, applications are in line with the overall rankings. Moreover, the comparative rankings are presented in Figure 7.

Table 6.1 RII Comparison of Stakeholders for UAVs safety application area

Code	**Application areas**	**Clients**		**PMCs**		**Contractors**	
		RII	**Rank**	**RII**	**Rank**	**RII**	**Rank**
A1	Safety inspection	0.809	5	0.831	3	0.836	4
A2	Safety monitoring	0.826	4	0.846	2	0.855	3
A3	Safety planning	0.835	3	0.821	5	0.818	5
A4	Hazard detection	0.843	2	0.826	4	0.873	2
A5	Safety audit	0.861	1	0.851	1	0.891	1
A6	Safety performance	0.800	6	0.815	6	0.782	7
A7	Risk mitigation	0.765	8	0.790	7	0.800	6
A8	Post-accident investigations	0.791	7	0.774	8	0.745	8

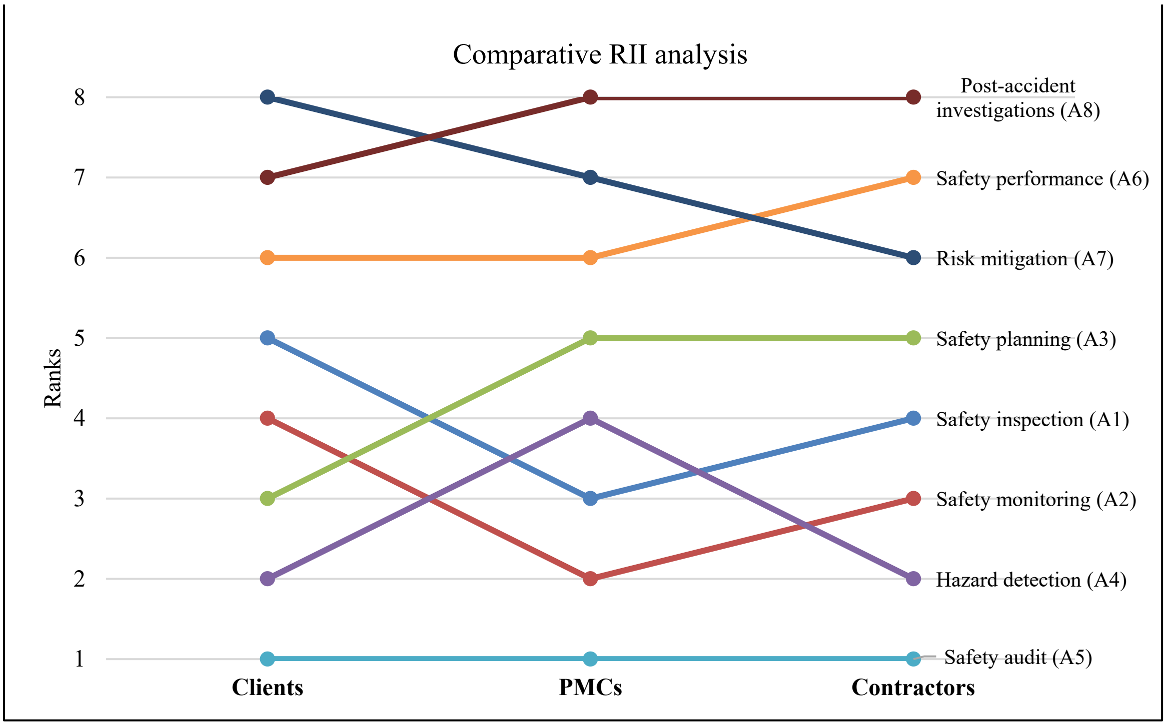

Fig. 7. Comparative RII among three stakeholders

8. Conclusions and Further Research

The initial goal was to determine the degree of awareness and acceptance of unmanned aerial vehicles (UAVs) in the Indian construction sector. This was accomplished by asking open-ended questions using a Google Forms questionnaire survey. Out of 108 responses received by Indian construction stakeholders, the study revealed a surprisingly high level of recognition (74.07%) despite a current low utilization rate (39%). Interestingly, even among those unaware (24.93%), a significant portion (14.82%) expressed future interest, suggesting growth potential. Further, eight potential safety applications of UAVs were identified from the literature study for its application in safety management. Overall Relative Importance Index (RII) analysis identified "safety audits" as the most crucial application for propelling UAV adoption in construction safety management. This finding provides valuable insights for promoting the wider adoption of UAVs for safety management in the Indian construction industry. The high level of agreement among stakeholders and high correlation indicates a positive environment for implementing UAV-based safety solutions. Comparative RII rankings were performed to offer valuable insights to guide improved strategies in safety management. Stakeholders' priorities for safety applications converge on safety audit, hazard detection, and safety monitoring as top priorities, while safety inspection, safety performance, and safety planning warrant improvement. Risk mitigation and post-accident investigations receive the least focus, suggesting potential areas for future development. Notably, all stakeholders prioritized "safety audits", reinforcing the overall ranking's significance.

These findings may influence the construction industry to invest in UAVs, making workplaces safer and benefiting both the companies and the workers. It will enable people to make more informed R&D choices to enhance UAVs to meet the demands of the construction sector. It will also assist the Indian government in various schemes and policies to reduce deadly work-related accidents.

While implementing UAVs for construction site safety seems promising, understanding the financial value proposition is crucial for viability. This calls for a real-case study to quantify the actual costs of UAV investment, addressing the knowledge gap hindering wider adoption. Repeating the study across diverse regions could reveal cost variations, informing global construction and UAV companies. Additionally, scholars could validate, refine, or challenge our findings with larger datasets, solidifying the research's impact. Cost-benefit studies can bridge the gap between safety potential and financial feasibility, clearing the path for UAVs to revolutionize construction safety management.

Author Contributions

Harshil Halvadia contributes to conceptualization, methodology, software, analysis, data collection, draft preparation, and manuscript editing. Kashyapkumar A. Patel contributes to conceptualization, validation, analysis, and manuscript preparation. Dilip A. Patel contributed to mentoring the research team and presenting the work. All authors have read and agreed with the manuscript before its submission and publication.

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