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Article

Exploring Barriers to Unmanned Aerial Vehicle (UAV) Technology for Construction Safety Management Using Mixed-Methods Approach

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Abstract: Construction safety is critical, and unmanned aerial vehicles (UAVs) have emerged as a transformative tool to enhance safety management in the sector. While UAVs are widely recognized for their efficacy, limited research has specifically addressed the barriers to their integration into construction safety management systems. This study aims to identify, prioritize, and analyze the interrelationships among these barriers to aid in their effective resolution. Using a mixed-methods approach, this research combines a systematic literature review (SLR) to identify barriers and a questionnaire survey to prioritize and examine their interconnections. The findings reveal significant barriers, including restricted airspace, inadequate safety regulations, limited flight durations, collision risks, insufficient piloting skills, lack of UAV awareness, resistance to new technologies, human errors, training needs, and legal constraints. Restricted airspace emerged as the most critical barrier, strongly linked to flight duration limitations and piloting proficiency. This study also highlights regional disparities: respondents from developed nations emphasized collision risks, legal restrictions, and resistance to new technologies, while those from developing countries focused on restricted areas, limited flight time, and piloting expertise. These findings emphasize the importance of addressing region-specific challenges and tailoring strategies to facilitate UAV integration, paving the way for safer and more efficient construction practices.

Keywords: barriers; unmanned aerial vehicle (UAV); construction safety management; systematic literature review; mixed-methods approach

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1. Introduction

The construction industry has had a long-standing reputation as one of the most dangerous ones due to the high rate of workplace fatalities and occupational maladies. This phenomenon results from the construction industry having one of the highest rates of both teams [1,2]. Those in the construction industry frequently occupy an inferior position on the socioeconomic power spectrum and have significantly higher disability and mortality rates than those in other industries [3] According to research by the Centre for Construction Research and Training [4], the construction industry in the United States has a fatality rate of 11.1 per 100,000 employees and an injury rate of 239.5 per 10,000 full-time workers. These rates are significantly higher than the national average.

There is a possibility that accidents on construction sites will cost society a great deal of money [5,6]. According to the findings of a previous research study conducted in Hong Kong between 2004 and 2008, over HKD 10 million per year was spent on compensation for accidents that did not result in fatalities. In addition to increasing efficiency and competitiveness, reducing disputes and conflicts, and increasing profitability in a shorter period of time, improving construction safety conditions offers several other benefits. All of these advantages directly result from improved safety conditions in construction [7]. According to Alruqi et al. [8], every construction company must prioritize their employees' health and safety. To improve construction site safety management, there is an immediate need for an innovative technique, piece of equipment, or new safety management system that can effectively reduce the number of incidents and is also quick, inexpensive, and simple to implement. This initiative aims to improve the administration of construction site safety. The utilization of unmanned aerial vehicles has the potential to be highly effective in this field.

Unmanned aerial vehicles, also known as UAVs (unmanned aerial vehicles), are a technology that is progressively becoming more prevalent in the safety management of construction sites [9]. In 2016, the global market value for commercial unmanned aerial vehicles was estimated to be USD 5.8 billion, and experts in the construction industry anticipate that this figure will increase to USD 130 billion by 2025. Unmanned aerial vehicles (UAVs) were initially developed for military use. Unmanned aerial vehicles have demonstrated exceptional performance in civilian applications, such as infrastructure management (including building and infrastructure inspections), traffic surveillance, material transport (including the delivery of food, medical supplies, and packages), search and rescue operations, and security surveillance [10]. According to a study conducted by Jeelani and associates in 2021, the construction industry has the greatest rate of UAV adoption among civilian applications. The use of unmanned aerial vehicles (UAVs) in managing construction projects has increased twice in just one year. According to research conducted by Liang et al. [11], the increasing use of unmanned aerial vehicles (UAVs) in construction safety management may be due to several factors, including cost-effective purchase fees, improved navigation capabilities, autonomous flying function, extended battery life, and a wide variety of onboard sensors. Unmanned aerial vehicles, or UAVs, have been designated crucial components in digitalizing the built environment [12].

Unmanned aerial vehicles (UAVs), commonly called drones, are gaining popularity in the construction industry. UAVs may be utilized during all three phases of the typical project life cycle, namely the planning phase, the execution phase, and the completion phase. Throughout the project planning phase, UAVs can map construction sites for planning purposes. Additionally, unmanned aerial systems can analyze the data collected during the planning phase. Unmanned aerial vehicles (UAVs) may be used during the execution phase to monitor the progress of construction, administer the logistics of the work site, and inspect the working conditions of construction employees to prevent fatalities. A study found that using unmanned aerial vehicles (UAVs) to monitor construction sites could save money for safety managers [13]. UAVs can conduct maintenance and structural integrity tests during the concluding construction phase.

However, unmanned aerial vehicles (also known as UAVs) have a variety of uses in construction safety management. Whether in a developed or developing nation, using unmanned aerial vehicles (UAVs) in the administration of construction projects is still restricted and fraught with obstacles. According to Alizadehsalehi et al. [14], most project managers in the United States have decided not to use unmanned aerial systems (UASs) because they do not believe it necessary to modify their construction safety system to use UASs. They reached this conclusion because they did not consider modifying their construction safety system necessary. In contrast, few construction companies in South Africa choose to utilize UAVs due to factors such as low-performance expectations and inconvenience conditions [9]. Integrating unmanned aerial vehicles (UAVs) into construction safety management still faces several challenging obstacles [15].

To determine which barriers construction firms should focus on and which might impede the integration of UAVs into the current construction safety management system, this study is trying to solve three research questions:

RQ1. What are the barriers to the utilization of UAV-based technologies for construction safety management?

RQ2. What is the prioritization of the identified barriers?

RQ3. What are the relationships among the identified barriers?

To answer the above research questions, the three research objectives are as follows:

RO1. Identify the barriers hampering the adoption of UAV-based technologies for construction safety management.

RO2. Prioritize the identified barriers in terms of their importance levels

RO3. Illustrate the relationships among the identified barriers

This research has the potential to fill in the gaps regarding how using UAV technology could benefit the construction industry because there are numerous publications examining the applications of UAVs. However, few articles analyze the challenges that UAV technology faces in construction management and demonstrate the connection between these challenges. This dissertation can serve as a roadmap for future research, allowing researchers to delve more thoroughly into how to enhance the use of unmanned aerial vehicles (UAVs) in construction management. This may enable construction companies to improve their safety management performance in the construction workplace, reducing the incidence of safety accidents, creating a better working environment, shortening workdays, and lowering safety management costs.

2. Contextual Background

2.1. Safety Problems and Issues in the Construction Industry

The construction industry is indispensable to our society and economy. The engineering and construction industries accounted for approximately 6% of all jobs in the United States in 2018 despite having an annual expenditure of USD 1231 billion [12]. Nonetheless, the construction industry has a high and consistent mortality rate, making it one of the most dangerous in the economy [16]. The construction industry is responsible for approximately 20% of worker fatalities in the United States despite comprising less than 5% of the workforce [15]. The mortality risk for construction employees is three to six times greater in developing nations than in developed countries [10].

Moreover, the costs associated with such injuries may be exorbitant. It is anticipated that the annual cost of fatal and nonfatal injuries in the construction industry will exceed USD 48 billion. This cost affects the victims, their families, enterprises, and communities [10]. There are many potential causes of injury or mortality among construction employees. On construction sites, fatal accidents typically result from four primary causes. The 2021 research of Martinez classifies these fatalities as follows: falls (33.5%), being struck by an object (11.1%), electrocution (8.5%), and entanglement (5.5%). These four causes account for more than half of all construction-related fatalities (58.6%) [11].

However, if we are to discuss the primary reasons for the elevated mortality rate, there are two possibilities to consider. The first is that the construction industry is inherently dangerous; it entails strenuous physical labor in a constantly changing and evolving environment. Work at high heights and proximity to potentially hazardous equipment are typical in such environments [17]. Additionally, it is essential to remember that the construction industry operates at a different pace than other industries and that each construction project has unique complexity and safety concerns. Employees in the construction industry may encounter more uncertain duties and risks than those in other industries with well-defined job descriptions and consistent work environments, such as those with repetitive tasks and consistent work environments. Consequently, they are susceptible to a wide range of threats, and it is challenging to conduct comprehensive hazard assessments and implement appropriate controls for each activity [14].

Statistics on construction site accidents, fatalities, and injury mechanisms are scarce in impoverished nations. In terms of workplace safety, developing countries have a dismal track record, according to Umar's findings. Only in 2012, 520 workers from India, Bangladesh, and Nepal were slain in Qatar due to accidents and deplorable working conditions [18]. Similar to the findings in the United States, the report asserts that accidents from height are the primary cause of death among construction employees. In contrast to the outcomes observed in industrialized nations, accidents in developing countries are frequently the result of a lack of knowledge about potential hazards, reckless behavior, poor working conditions, and inadequate training. Therefore, there is a need for cutting-edge equipment or a novel system that can significantly improve construction site security management. Using unmanned aerial vehicles could be highly beneficial.

2.2. Application of UAVs in Construction Safety

Drones, or unmanned aerial vehicles/systems (UAVs/UASs), are aircraft that fly without a human pilot. They may be operated by a human operator from a distance, or they can function independently following their own set of rules or AI-based instructions [10,13]. Construction UAVs are becoming more popular due to their capacity to reach inaccessible or hazardous regions and do jobs in a timely and risk-free manner [11]. As a bonus, unmanned aerial vehicles (UAVs) may be used at every step of the building process, from planning to design to construction to cleanup.

2.2.1. Pre-Construction Applications

When executed correctly, pre-construction safety planning can help reduce risks, prevent accidents, and guarantee that construction sites are secure places to work [17]. However, there has not been much published research on UAVs yet, and it could help enhance job site safety. Alizadehsalehi et al. [14] indicate that little has been written about using UAVs for safety monitoring on construction sites. The impact of unmanned aerial vehicles on risk management is not discussed.

According to Onososen et al. [10], site mapping, surveys, and site planning are two prominent pre-construction applications that could benefit greatly from using unmanned aerial systems (UAS) or drones. UAVs have the potential to not only save money but also eradicate significantly more errors than conventional site mapping and surveying techniques [14]. Site planners may aid site planners in accumulating visual data in building process scheduling, layout, and logistics using UAVs. Combined with augmented reality (AR), this technology enhances construction site operations' pace, safety, and efficacy.

2.2.2. Construction Applications

Throughout the construction phase, UAVs can be utilized extensively for safety inspection, monitoring, and control at construction sites [15]. Previous research on UAVs in construction safety focused on safety inspection, monitoring, and management.

Unmanned aerial vehicles (UAVs) have the potential to transform the inspection of construction sites. Irizarry et al. [19] conducted the first study of its kind. They devised two evaluations—a technology interface analysis and user perception regarding the UAS visual assets for safety inspection—to assess the effectiveness of using UASs to support construction site safety inspections. According to research by Melo et al. [20], unmanned aerial systems (UASs) may aid in building inspections and decision-making. In 2014, Gheisari et al. [21] were the first to propose using UASs for safety examinations. Subsequent research has demonstrated that when properly equipped, UASs can expedite data collection from inaccessible areas, saving time for safety managers [16]. In a 2019 study, ref. [22] identified three factors that can influence the performance of UASs during construction site inspection: effective workplace surveillance, straightforward problem identification, and agility in addressing potential hazards. Gheisari et al. [21] investigated the feasibility of deploying UAVs for safety inspections using a user-centric approach. These methods included soliciting responses and opinions from safety personnel regarding using UASs in various safety-related activities. The comments of managers indicate that UAVs have the potential to improve safety monitoring and control procedures.

Melo et al. [20] evaluated the viability of using UASs for safety inspection on construction sites, and their findings indicated that the collected data can assist the inspection process by enhancing the visibility of working conditions. All previous research demonstrating the utility of UAVs relied on recordings and images captured by UAVs, particularly for threat detection. UAV-collected visual data may substantially reduce the time and money required to manually capture data [17]. Rodrigues et al. [23] developed a smart inspection strategy utilizing unmanned aerial vehicle (UAV) data and digital inspection technology. This cutting-edge method facilitates the analysis of UAS data and the production of surveillance reports.

2.2.3. Post-Construction Application

Post construction, unmanned aerial systems (UASs) are typically used for post-disaster evaluation or building maintenance [24]. According to Jhonattan G. Martinez's [14] findings, UASs may be utilized to assess the devastation caused by natural disasters. UASs have been used extensively for data collection in the aftermath of natural disasters such as hurricanes, typhoons, earthquakes, tsunamis, fires, and landslides [11]. Damaged building materials, components, and failure mechanisms can all be deduced from photographs of the impacted areas.

2.3. Opportunities and Barriers of UAVs in Construction Safety Management

2.3.1. Opportunities of UAVs in Construction Safety

Unmanned aerial vehicles (UAVs) can mitigate the "fatal four" causes of aviation catastrophes. The "fatal four" are the leading causes of catastrophic incidents in the construction industry. Falling, being struck by an object, being electrocuted, and being trapped are the four most hazardous situations. According to the study conducted by Gheisari et al. [21], there is potential for the use of UAVs to contribute to the prevention of mortality due to the first three lethal circumstances, which are falls, being struck, and electrocution. According to the research of Gheisari and Esmaeili [21], one of the most valuable functions of UAVs in construction safety is reducing the risk of accidents caused by improper use of fall protection systems or by working too close to apertures and elevations without adequate protection. The impact protection function of UAVs can evaluate the likelihood of collision incidents involving employees in the vicinity of boom vehicles and cranes.

Gheisari and Esmaeili [21] discovered that reducing the risk of electrocution was the most advantageous use of UAVs in construction safety management. With UAVs, the risk of electrocution from boom vehicles and cranes coming into contact with overhead power lines may be drastically reduced. In conclusion, unmanned aerial vehicles (UAVs) play a crucial role in detecting significant hazards on construction sites, enabling prompt actions to mitigate risks and prevent fatalities. The study found that UAVs can serve as valuable tools for identifying and addressing safety concerns, particularly by allowing for real-time monitoring of construction environments [14].

2.3.2. Barriers to UAVs in Construction Safety Management

Despite their limited use thus far, UAVs have been proven to increase construction site security. Due to the novelty of the technology, the widespread use of UAVs for construction safety is hampered by several obstacles. These impediments may impede the progress of construction safety management or make unmanned aerial vehicles a threat to the safety of construction workers. Therefore, it is crucial to eliminate obstacles. Reviewing pertinent literature, we identified fourteen articles discussing the advantages and disadvantages of unmanned aerial vehicles (UAVs) in construction safety. The remaining two categories include safety issues (such as collision, human error, and distraction), environmental factors (such as weather and light), law regulations (such as law limitations, invasion of privacy, and lack of safety), technical issues (such as battery technology, training requirements, and a limit on the types of projects that can use UAVs), and data collection and analysis (such as large databases, complex data analysis, and modeling quality requirements).

After a comprehensive literature search disclosed the obstacles to be surmounted, they were ranked according to the frequency with which each is mentioned in the cited works. Technical (mentioned 42 times), safety (described 22 times), and legal requirements (17 times) are the three most frequently cited categories of obstacles (Table 1). The literature indicates that the top six obstacles are as follows: weather, collision, legal restrictions, battery technology, training requirements, and piloting expertise. There is an abundance of literature that catalogs these impediments and investigates methods for ranking them. However, a paucity of research articles examine the interaction between these factors. The weather, for instance, is one of the most critical factors that can significantly impact the operation of UAVs in a construction project. When weather conditions are unfavorable, the likelihood that an unmanned aerial system (UAS) mission will fail rises dramatically. Moisture and extreme temperatures can damage a UAV's sensitive components, such as its battery and sensors [16]. The weather, battery technology, and sensor sensitivity all interact. Nonetheless, remarkably few publications investigate how one barrier influences another.

Table 1. Demographic information of respondents.

Background	Experience	Count	Percentage
Years of experience	6–10	20	50.00%
	11–15	14	35.00%
	16–20	2	5.00%
	20+	4	10.00%

Table 1. *Cont.*

Background	Experience	Count	Percentage
Professional Roles	Construction project manager	3	7.50%
	Civil/project engineer	5	12.50%
	Academician	23	57.50%
	Quantity surveyor	2	5.00%
	Planning engineer	2	5.00%
	Drone pilot/technical engineer	1	2.50%
	Contract engineer	2	5.00%
	Innovation manager	1	2.50%
	Consultant	1	2.50%
Countries in which respondents practice(d)	United States/Canada/Australia/Hong Kong/United Kingdom	18	45.00%
	Pakistan/Brazil/Russia/China/South Africa/Turkey/Poland/India/Nepal	22	55.00%
Level of education of respondents	Bachelor's degree	1	2.50%
	Master's degree	15	37.50%
	PhD degree	24	60.00%
The company size of the respondents	Small (1–49 employees)	11	27.50%
	Medium (50–249 employees)	5	12.50%
	Large (250+ employees)	24	60.00%

2.4. Point of Departure

This research aims to show which challenges construction companies should be concerned about for better integration of UAVs into current construction safety management systems to increase construction safety performance. This research will identify and rank the obstacles and discover the relationship between barriers. Additionally, as construction firms from different nations will deal with varying types of challenges, this research will also investigate and compare the differences in barriers between developed countries and developing countries.

3. Methodology

This study was conducted in three phases: a systematic literature review to identify UAV adoption barriers, a questionnaire survey to gather expert opinions, and data analysis using statistical tools to assess and prioritize these barriers (see Figure 1).

3.1. Phase I: Identification of Barriers

To comprehensively explore the adoption of unmanned aerial vehicles (UAVs) within construction safety management, as indicated in Figure 1, a systematic and rigorous methodology was employed to conduct a thorough literature review. The aim was to scrutinize existing knowledge, identify gaps, and provide a structured analysis of pertinent research articles using keywords such as "UAV", "unmanned aerial vehicle", "drone", and "construction safety". The methodology was structured into distinct phases: initial search strategy and keyword selection, utilization of appropriate search engines, and a meticulous screening and selection process [25]. Each phase was designed to ensure the inclusion of relevant and credible sources while aligning with the specific focus of this literature review. The detailed methodology outlined below describes the systematic approach undertaken to achieve the objectives of this study. Moreover, Figure 2 visually illustrates the systematic approach undertaken during the literature review, showcasing the distinct phases involved in exploring UAV adoption within construction safety management. Figure 3 outlines the barriers to UAV adoption within construction safety management, derived from a systematic literature review.

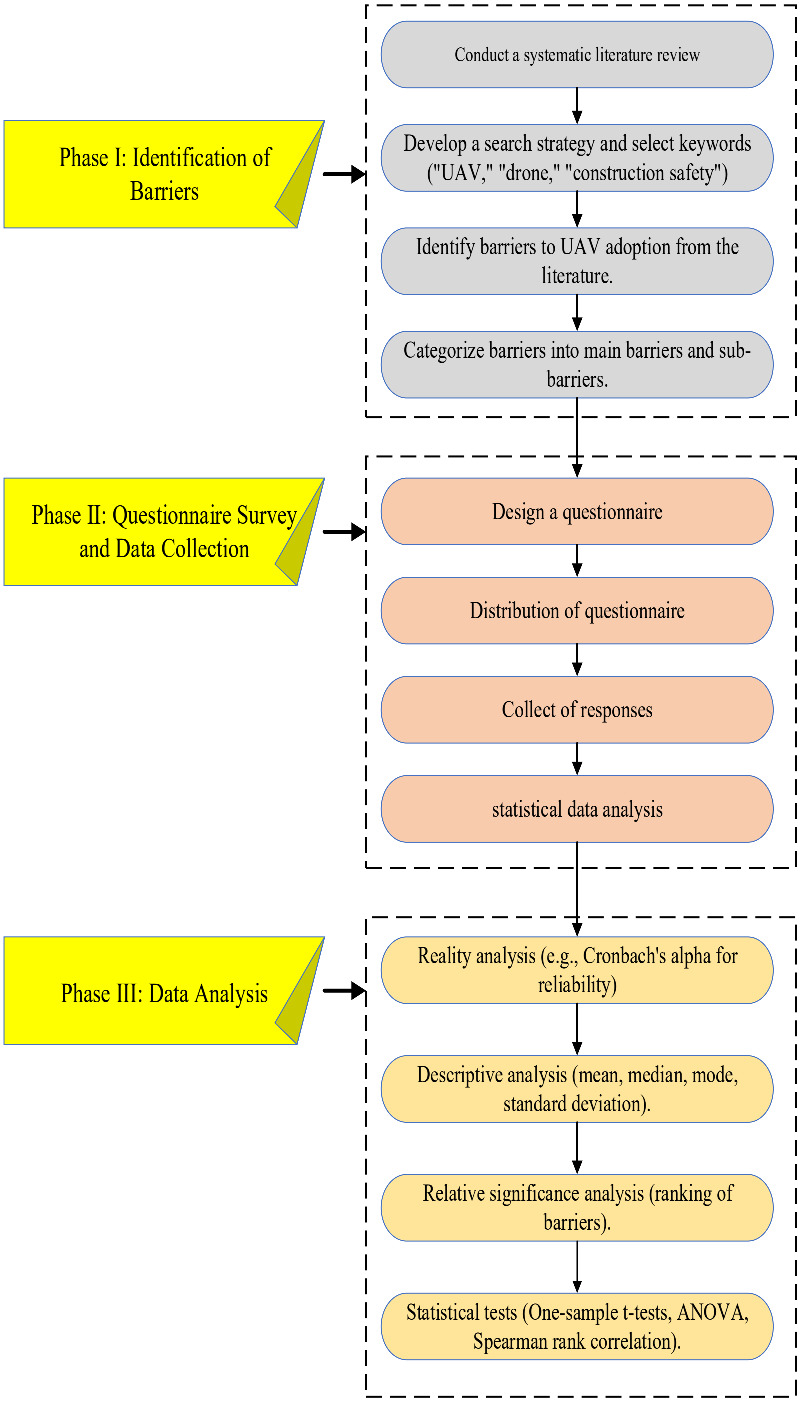

Figure 1. Research methodology.

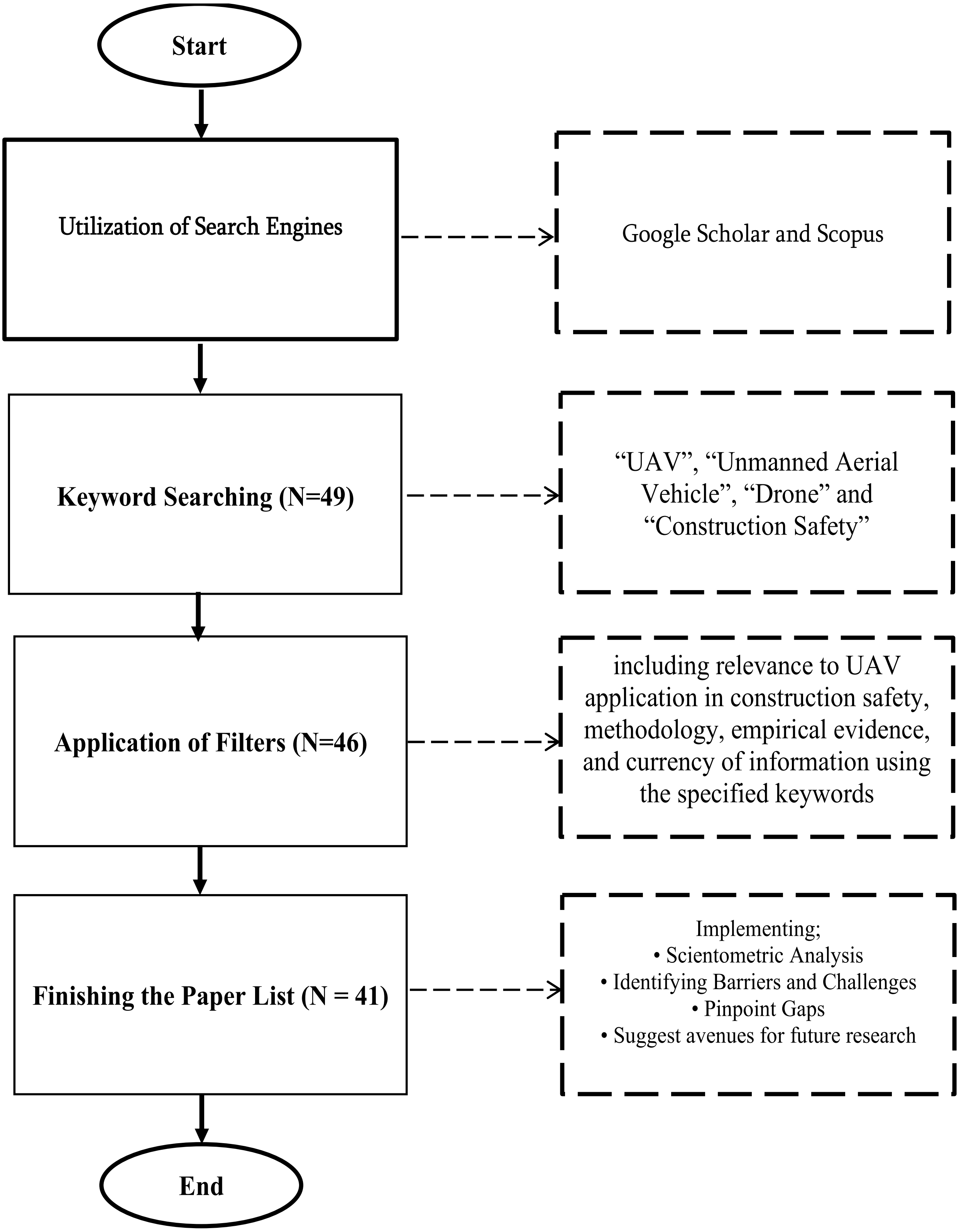

Figure 2. Research methodology flowchart.

3.2. Phase II: Questionnaire Survey and Data Collection

To ensure a diverse and representative sample, participants were selected from multiple countries, educational backgrounds, and company sizes, providing a comprehensive understanding of UAV adoption barriers in construction safety management. This study included respondents from both developed and developing countries, recognizing that regional differences in technology adoption stem from variations in regulations, economic conditions, and infrastructure capabilities [27–29]. A combination of purposive and snowball sampling was employed to reach experts with direct experience in UAV applications. The recruitment process involved outreach through professional networks, industry conferences, construction technology forums, and UAV-specialized associations. Participants were drawn from academia and industry to ensure a balanced perspective. Academics included researchers and professors specializing in construction technology and UAV applications, while industry professionals comprised project managers, safety officers, and UAV operators with hands-on experience.

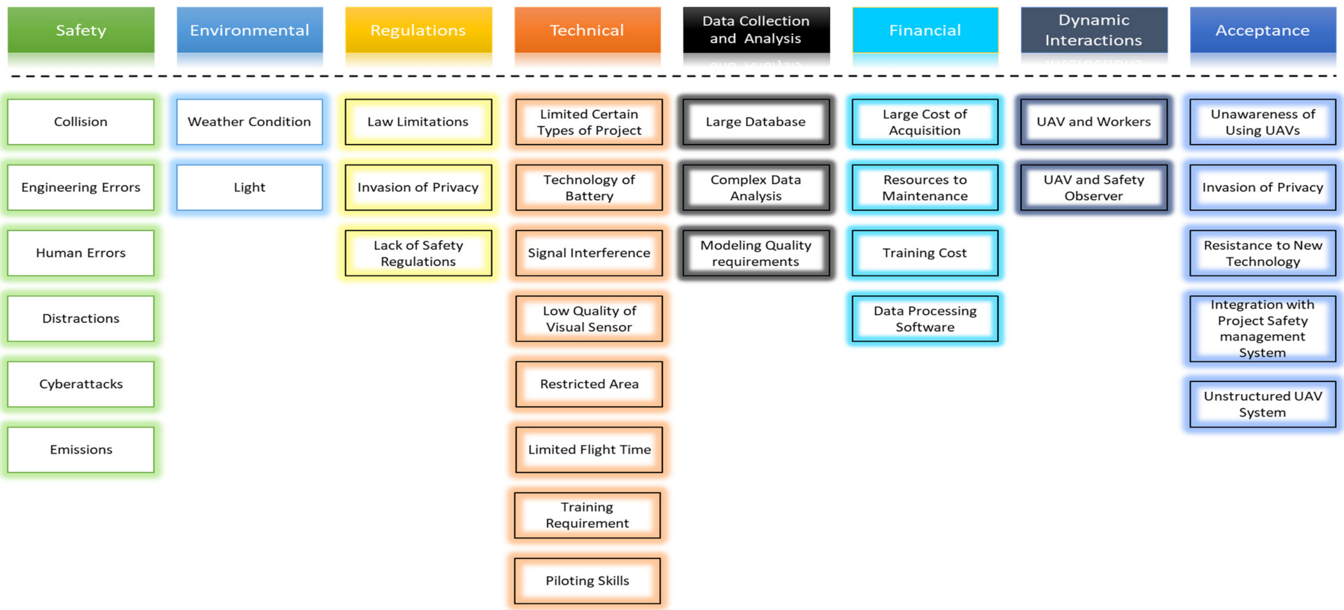

Figure 3. List of 33 barriers to the adoption of UAVs. Note: safety = [12,26]; environmental = [8,10] regulations = [7,20]; technical = [22]; data collection and analysis= [11,15]; financial = [12,15]; dynamic interactions = [17]; acceptance = [13,14].

Additionally, educational and organizational diversity was prioritized by engaging participants with varying levels of education, from bachelor's degree holders to PhD scholars, ensuring insights from both seasoned professionals and emerging researchers. To capture the impact of organizational scale, respondents were selected from small, medium, and large enterprises, considering that firm size influences the resources available for UAV adoption and integration into construction safety protocols [30,31]. Invitations for participation were sent through LinkedIn groups, industry webinars, and UAV-focused discussion panels to reach a wide spectrum of stakeholders.

It is notable that all of the respondents—being categorized as "Academicians"—have substantial industry experience; they have worked on construction projects or collaborated with industry professionals in research projects focused on safety management using the related technology. In fact, in order to select the qualified experts for this research, three questions were designed at the beginning of the survey, including whether (1) the experts had at least five years of experience in the industry or involvement in projects collaborating with industrial partners; (2) the experts held at least an undergraduate degree related to the area of construction; and (3) the experts have been involved in at least one project (either on site or research project) in which UAVs were used for construction safety management. If answers to all these questions were yes, then the experts could continue to the remaining part of the survey; otherwise, the survey stopped at that point. It is also noteworthy that the industrial and academic experts constitute around 57% and 43% of the total proportion, respectively, so as to reach a balance between these two groups. This approach is in line with the relevant body of literature, in which the same technology was used for construction safety monitoring [10,32–35].

In this study, the participants were instructed to assess the 33 obstacles related to the topic. This assessment was conducted using a 5-point Likert scale, where participants were asked to rank the barriers on a scale ranging from 1 (indicating a very low level) to 5 (indicating a very high level). Participants were also requested to highlight obstacles not included in the survey. Three new items were documented, including restricted payload capacity, the purchase charge for network connection infrastructure (sensor), and regulations about foreign manufacturers. The participants also provided insights into their engagement in a practical building project that used unmanned aerial vehicles (UAVs) for safety management. Regarding disseminating the questionnaire surveys, there are two approaches: (1) Correspond with researchers who are actively engaged in investigating the subject matter through electronic mail or the chat interface on the ResearchGate platform [36,37]. (2) Disseminate the questionnaire survey link using social media sites such as LinkedIn by posting it one one's profile and in groups relevant to the domains of construction safety or unmanned aerial vehicle (UAV) applications [38,39].

The data collection process only relied on internet sources, without any direct engagement or consideration of specific construction project visits. The questionnaire survey was administered using the Qualtrics platform and disseminated to the intended recipients, including writers and academics, through email. The replies provided by the participants were then documented for analysis. The research study included the participation of 58 persons from various construction enterprises and academic institutions. A total of 17 participants supplied replies that were deemed incomplete, while 1 participant's responses were considered worthless.

Consequently, these individuals' answers were omitted from further data analysis. The demographic and professional information of the remaining 40 participants was collected via their responses to five questions in Part 1. This information is shown in Table 1. Approximately 45.00% of the participants were employed in developed countries, while the rest of the respondents were employed in developing countries. The educational attainment of the respondents makes it evident that the majority hold doctoral degrees. This suggests that all respondents have a high level of education. The demographic details of the participants, as outlined in Table 1, include country distribution, education level, company size, and years of experience. The company size data reveal that most respondents work in large companies, with the number of participants from small companies being twice as large as those from medium-sized companies.

3.3. Phase III: Data Analysis

Data analysis was performed via IBM SPSS Statistics 27, a statistical data analysis software [40,41]. Its purpose was to identify and prioritize the significance of obstacles to adopting unmanned aerial vehicles (UAVs) in construction safety management and investigate the link between these barriers. Additionally, this study used Microsoft Excel spreadsheets for data management and analysis.

This study has seven sections, namely: reality analysis, descriptive analysis, difference test, examination of the interaction among obstacles, comparison of differences between nations, exploration of differences among firm sizes, and investigation of disparities regarding UAVs project participation. This research used Cronbach's alpha coefficient (α) to assess the internal consistency and reliability of the scale in the context of reality analysis. This study used descriptive analytic techniques to determine several measures of central tendency, including the descriptive mean score, descriptive median score, and descriptive mode score.

Additionally, a relative significance analysis was conducted to evaluate the importance of different barriers. Measures of dispersion, such as standard deviation, were computed to assess the variability of the data. Furthermore, normalization analysis was performed to standardize the scores, and weighted and regular error analyses were conducted to determine the ranking of the barriers. This study employed a one-sample *t*-test to ascertain the presence of statistically significant differences among the examined obstacles [42]. In the section discussing the connection among obstacles, the Spearman rank test may be used to assess the extent of the correlation between barriers [10]. This study used independent sample *t*-tests and one-way ANOVA tests to examine the associations between obstacles and nation, barriers and firm size, and barriers and project engagement [43–45].

4. Result Analysis

4.1. Findings of Questionnaire Survey

4.1.1. Reliability Analysis to Data

Cronbach's alpha coefficient (α) is a widely used measure of internal consistency reliability for a scale or a set of items. It assesses how well the items within a scale are interrelated, indicating the extent to which the items in the scale measure the same underlying construct or concept [46,47]. Cronbach's alpha ranges from 0 to 1. If $\alpha > 0.7$, it is generally considered to indicate acceptable internal consistency for most research purposes. In this research, the Cronbach's alpha is 0.931, calculated using SPSS 27.

4.1.2. Descriptive Analysis

Table 2 displays descriptive analysis weighted relative significance index, mean score, median, mode, normalized value, and rank. These were computed to establish the significance of the barriers that could hinder the use of UAVs in construction safety. The relative importance of all identified obstacles has been reordered based on the mean frequency of the results.

Table 2. Rank of barriers.

Barriers	Count	Weighted	Relative Significance Index	Mean Score	Median	Mode	Normalized Value	Std. Deviation	Std. Error	Rank
B16	40	150	0.75	3.75	4	4	1.00	1.032	0.163	1
B11	40	147	0.735	3.68	4	4	0.95	1.047	0.166	2
B17	40	147	0.735	3.68	4	4	0.95	1.141	0.18	3
B1	40	146	0.73	3.65	4	4	0.94	1.027	0.162	4
B19	40	146	0.73	3.65	4	4	0.94	0.975	0.154	5
B29	40	146	0.73	3.65	4	4	0.94	0.975	0.154	6
B31	40	146	0.73	3.65	4	4	0.94	1.027	0.162	7
B3	40	145	0.725	3.63	3.5	3	0.92	1.079	0.171	8
B18	40	142	0.71	3.55	4	3	0.88	1.061	0.168	9
B9	40	141	0.705	3.53	4	4	0.86	0.96	0.152	10
B7	40	140	0.7	3.5	4	4	0.85	0.877	0.139	11
B32	40	139	0.695	3.48	4	4	0.83	1.086	0.172	12

Table 2. *Cont.*

Barriers	Count	Weighted	Relative Significance Index	Mean Score	Median	Mode	Normalized Value	Std. Deviation	Std. Error	Rank
B33	40	139	0.695	3.47	3	3	0.83	1.132	0.179	13
B4	40	136	0.68	3.4	3	3	0.78	1.057	0.167	14
B2	40	134	0.67	3.35	3	4	0.75	1.145	0.181	15
B30	40	133	0.665	3.32	3	4	0.74	1.095	0.173	16
B23	40	131	0.655	3.28	4	4	0.71	1.261	0.199	17
B24	40	131	0.655	3.28	3	3	0.71	0.96	0.152	18
B14	40	130	0.65	3.25	3	3	0.69	1.006	0.159	19
B25	40	130	0.65	3.25	3.5	4	0.69	1.149	0.182	20
B26	40	130	0.65	3.25	3	3	0.69	1.08	0.171	21
B10	40	129	0.645	3.23	3	4	0.68	1.097	0.174	22
B12	40	128	0.64	3.2	3.5	4	0.66	1.244	0.197	23
B22	40	126	0.63	3.15	3	3	0.63	1.189	0.188	24
B13	40	124	0.62	3.1	3	3	0.60	1.257	0.199	25
B15	40	124	0.62	3.1	3	4	0.60	1.257	0.199	26
B8	40	123	0.615	3.08	3	3	0.58	1.023	0.162	27
B21	40	123	0.615	3.08	3	4	0.58	1.228	0.194	28
B27	40	123	0.615	3.07	3	3,4	0.58	1.095	0.173	29
B28	40	122	0.61	3.05	3	3	0.57	1.176	0.186	30
B20	40	117	0.585	2.92	3	4	0.49	1.328	0.21	31
B5	40	115	0.575	2.87	3	3	0.46	1.067	0.169	32
B6	40	85	0.425	2.13	2	1	0.00	1.09	0.172	33

The result ranks the barriers identified in the questionnaires, revealing that the most significant barrier is restricted areas, with the highest mean score of 3.75 and the highest median score of 4. This indicates that most respondents believe that the use of UAVs in restricted areas can affect the use of UAVs in construction safety management. The second essential barrier is a lack of safety regulations and a limited flight time, with the same mean and median score for each. However, the emissions of UAVs are deemed the least significant barrier, with a mean score of 2.13, and most individuals believe it cannot hinder the adoption of UAVs in construction safety management.

The value 3.31 is the mean of the mean of the identified barriers. Thus, these obstacles can be regarded as crucial to adopting UAVs. The specifications of the average ranking of the barriers are provided in Table 3. Based on the five-point Likert scale, five mean ranges relating to different thresholds are used to capture and interpret the level of importance among the respondents as $\leq$1.50 = very low; 1.51–2.50 = low; 2.51–3.50 = medium; 3.51–4.50 = high; and $\leq$ 4.51 = very high [1]. Therefore, a driving factor with a mean score of $\geq$3.51 is considered "critical" in this study.

Table 3. One-sample *t*-test.

Barriers	t	df	Sig. (2-Tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
B16	4.57	40	0	0.732	0.41	1.06
B11	4.057	40	0	0.659	0.33	0.99
B17	3.726	40	0.001	0.659	0.3	1.02
B1	3.986	40	0	0.634	0.31	0.96
B19	4.193	40	0	0.634	0.33	0.94
B29	4.193	40	0	0.634	0.33	0.94
B31	3.986	40	0	0.634	0.31	0.96
B3	3.651	40	0.001	0.61	0.27	0.95
B18	3.269	40	0.002	0.537	0.2	0.87
B9	3.445	40	0.001	0.512	0.21	0.81
B7	3.592	40	0.001	0.488	0.21	0.76
B32	2.761	40	0.009	0.463	0.12	0.8
B33	2.649	40	0.012	0.463	0.11	0.82
B4	2.389	40	0.022	0.39	0.06	0.72
B2	1.932	40	0.06	0.341	−0.02	0.7
B30	1.875	40	0.068	0.317	−0.02	0.66
B23	1.379	40	0.175	0.268	−0.12	0.66
B24	1.81	40	0.078	0.268	−0.03	0.57
B14	1.57	40	0.124	0.244	−0.07	0.56
B25	1.376	40	0.177	0.244	−0.11	0.6
B26	1.463	40	0.151	0.244	−0.09	0.58
B10	1.296	40	0.202	0.22	−0.12	0.56
B12	1.016	40	0.316	0.195	−0.19	0.58
B22	0.798	40	0.429	0.146	−0.22	0.52
B13	0.503	40	0.617	0.098	−0.29	0.49
B15	0.503	40	0.617	0.098	−0.29	0.49
B8	0.464	40	0.645	0.073	−0.25	0.39
B21	0.386	40	0.701	0.073	−0.31	0.46
B27	0.433	40	0.667	0.073	−0.27	0.41
B28	0.269	40	0.789	0.049	−0.32	0.42
B20	−0.357	40	0.723	−0.073	−0.49	0.34
B5	−0.741	40	0.463	−0.122	−0.45	0.21
B6	−5.036	40	0	−0.854	−1.2	−0.51

4.1.3. Differences Test

In the differences test, this study chose a one-sample *t*-test to find whether the respondents believe that the barriers might impact the utilization of UAVs in construction safety management. The sample *t*-test uses a value of 3, meaning that the barriers to UAV adoption that score greater than 3 can be considered barriers that impede the utilization of

UAVs in construction safety management. When Sig. (2-tailed) ≤ 0.05, it means that there are obvious differences with the value of 3. The details of the one-sample *t*-test are shown in Table 3. All the barriers identified have been re-ordered with their importance based on the mean frequency of the results.

The results obtained from the one-sample *t*-test (based on Sig. (2-tailed) ≤ 0.05) show that 14 barriers have significant mean values, which are larger than the value of 3. On the other hand, one barrier (the emission of UAVs) is considered the least important barrier, and the mean emission is significantly lower than the value of 3. The mean of the barriers is shown in the radar chart in Figure 4.

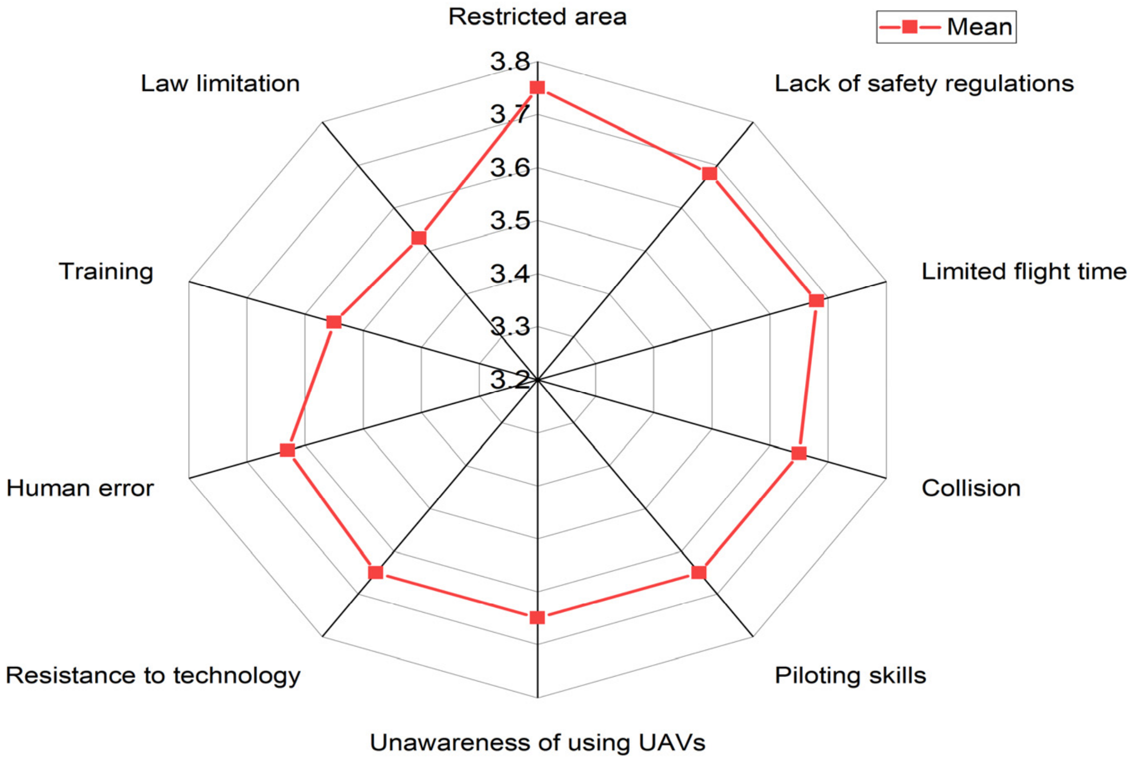

Figure 4. Mean of critical barriers.

Based on the radar chart and *t*-test results for a single sample (displayed in Table 3), ten critical barriers are deemed to be significant, with the following order of importance: (1) B16, restricted area; (2) B11, absence of safety regulations; (3) B17, limited flight time; (4) B1, collision; (5) B19, piloting skills; (6) B29, unawareness of using UAVs; (7) B31, resistance to new technologies; (8) B3, human error; (9) B18, training requirement; and (10) B9, law restrictions.

4.1.4. Relationship Among Barriers

Spearman's rank correlation coefficient is a nonparametric measure of the strength and direction of association between two variables [48]. SPSS 27 was used to conduct the Spearman correlation analysis in this study. The correlation coefficient can quantify the degree of association between two variables. It permits the evaluation of the strength of the association between categorical variables. N represents the number of survey responses in the context of our research [49]. Moreover, the correlation is statistically significant at the 0.01 level (two-tailed). The relationship between significant obstacles is depicted in Table 4.

Table 4. Spearman rank test.

Barriers	Spearman Rank Test	B1	B3	B11	B16	B17	B18	B19	B29	B31
B1	Correlation Coefficient	1	0.655 **	0.477 **	−0.05	−0.009	0.128	−0.05	0.123	0.119
	Sig. (2-tailed)	.	0	0.002	0.76	0.957	0.433	0.76	0.45	0.465
	N	40	40	40	40	40	40	40	40	40
B3	Correlation Coefficient	0.655 **	1	0.377 *	0.021	0.097	0.126	0.2	0.306	0.084
	Sig. (2-tailed)	0	.	0.016	0.899	0.55	0.439	0.216	0.055	0.608
	N	40	40	40	40	40	40	40	40	40
B11	Correlation Coefficient	0.477 **	0.377 *	1	0.07	0.214	0.462 **	0.407 **	0.393 *	0.541 **
	Sig. (2-tailed)	0.002	0.016	.	0.667	0.185	0.003	0.009	0.012	0
	N	40	40	40	40	40	40	40	40	40
B16	Correlation Coefficient	−0.05	0.021	0.07	1	0.649 **	0.296	0.409 **	0.084	0.05
	Sig. (2-tailed)	0.76	0.899	0.667	.	0	0.064	0.009	0.608	0.759
	N	40	40	40	40	40	40	40	40	40
B17	Correlation Coefficient	−0.009	0.097	0.214	0.649 **	1	0.312	0.411 **	0.006	0.013
	Sig. (2-tailed)	0.957	0.55	0.185	0	.	0.05	0.008	0.971	0.937
	N	40	40	40	40	40	40	40	40	40
B18	Correlation Coefficient	0.128	0.126	0.462 **	0.296	0.312	1	0.688 **	0.332 *	0.431 **
	Sig. (2-tailed)	0.433	0.439	0.003	0.064	0.05	.	0	0.037	0.006
	N	40	40	40	40	40	40	40	40	40
B19	Correlation Coefficient	−0.05	0.2	0.407 **	0.409 **	0.411 **	0.688 **	1	0.341 *	0.389 *
	Sig. (2-tailed)	0.76	0.216	0.009	0.009	0.008	0	.	0.031	0.013
	N	40	40	40	40	40	40	40	40	40
B29	Correlation Coefficient	0.123	0.306	0.393 *	0.084	0.006	0.332 *	0.341 *	1	0.362 *
	Sig. (2-tailed)	0.45	0.055	0.012	0.608	0.971	0.037	0.031	.	0.022
	N	40	40	40	40	40	40	40	40	40
B31	Correlation Coefficient	0.119	0.084	0.541 **	0.05	0.013	0.431 **	0.389 *	0.362 *	1
	Sig. (2-tailed)	0.465	0.608	0	0.759	0.937	0.006	0.013	0.022	.
	N	40	40	40	40	40	40	40	40	40

First, the results disclose a significant correlation between human error and the absence of safety regulations and UAV collisions. This result demonstrates that reducing human error and increasing safety regulations can affect the likelihood of a collision. Second, the absence of safety regulations has a strong correlation with collisions and training requirements, piloting abilities, and resistance to new technologies. Thirdly, there is a substantial correlation between restricted area effects and piloting abilities. Finally, a strong relationship exists between resistance to new technologies and training requirements.

4.1.5. Differences Between Countries

The data were evaluated using the independent-sample *t*-test to determine the differences between barriers between developing and developed countries. The results are detailed in Table 5. The independent-sample *t*-test is a statistical hypothesis test that compares the means of two independent groups to determine whether there is a statistically significant difference [50]. In this study, the independent means of two groups (developing and developed countries) were compared to determine whether regional differences exist in the barriers.

Table 5. Independent sample *t*-test of countries.

Barriers	Country	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-Tailed)
B1	developed country	18	3.78	1.114	0.263	0.707	0.484
	developing country	22	3.55	0.963	0.205		
B2	developed country	18	3.17	1.2	0.283	−0.914	0.366
	developing country	22	3.5	1.102	0.235		
B3	developed country	18	3.56	1.247	0.294	−0.364	0.718
	developing country	22	3.68	0.945	0.202		
B4	developed country	18	3.56	0.984	0.232	0.838	0.407
	developing country	22	3.27	1.12	0.239		
B5	developed country	18	2.67	1.085	0.256	−1.121	0.269
	developing country	22	3.05	1.046	0.223		
B6	developed country	18	1.83	1.043	0.246	−1.558	0.128
	developing country	22	2.36	1.093	0.233		
B7	developed country	18	3.56	0.922	0.217	0.358	0.722
	developing country	22	3.45	0.858	0.183		
B8	developed country	18	2.83	1.098	0.259	−1.367	0.18
	developing country	22	3.27	0.935	0.199		
B9	developed country	18	3.83	0.786	0.185	1.897	0.065
	developing country	22	3.27	1.032	0.22		
B10	developed country	18	3.39	1.037	0.244	0.851	0.4
	developing country	22	3.09	1.151	0.245		
B11	developed country	18	3.72	0.958	0.226	0.255	0.8
	developing country	22	3.64	1.136	0.242		
B12	developed country	18	3.06	1.392	0.328	−0.659	0.514
	developing country	22	3.32	1.129	0.241		
B13	developed country	18	2.83	1.339	0.316	−1.221	0.229
	developing country	22	3.32	1.171	0.25		
B14	developed country	18	3.11	1.132	0.267	−0.786	0.437
	developing country	22	3.36	0.902	0.192		
B15	developed country	18	2.94	1.11	0.262	−0.703	0.486
	developing country	22	3.23	1.378	0.294		
B16	developed country	18	3.61	1.145	0.27	−0.766	0.448
	developing country	22	3.86	0.941	0.201		
B17	developed country	18	3.5	1.295	0.305	−0.875	0.387
	developing country	22	3.82	1.006	0.215		
B18	developed country	18	3.61	0.979	0.231	0.326	0.746
	developing country	22	3.5	1.144	0.244		
B19	developed country	18	3.5	0.924	0.218	−0.877	0.386
	developing country	22	3.77	1.02	0.218		
B20	developed country	18	2.5	1.339	0.316	−1.89	0.066
	developing country	22	3.27	1.241	0.265		
B21	developed country	18	2.61	1.29	0.304	−2.274	0.029
	developing country	22	3.45	1.057	0.225		
B22	developed country	18	2.89	1.323	0.312	−1.266	0.213
	developing country	22	3.36	1.049	0.224		
B23	developed country	18	2.89	1.41	0.332	−1.75	0.09
	developing country	22	3.59	1.054	0.225		

Table 5. *Cont.*

Barriers	Country	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-Tailed)
B24	developed country	18	2.89	1.079	0.254	−2.442	0.019
	developing country	22	3.59	0.734	0.157		
B25	developed country	18	2.72	1.127	0.266	−2.859	0.007
	developing country	22	3.68	0.995	0.212		
B26	developed country	18	2.72	1.074	0.253	−3.086	0.004
	developing country	22	3.68	0.894	0.191		
B27	developed country	18	3.06	0.998	0.235	−0.1	0.921
	developing country	22	3.09	1.192	0.254		
B28	developed country	18	2.78	1.06	0.25	−1.338	0.189
	developing country	22	3.27	1.241	0.265		
B29	developed country	18	3.61	0.85	0.2	−0.225	0.823
	developing country	22	3.68	1.086	0.232		
B30	developed country	18	3.17	1.043	0.246	−0.824	0.415
	developing country	22	3.45	1.143	0.244		
B31	developed country	18	3.83	0.924	0.218	1.022	0.313
	developing country	22	3.5	1.102	0.235		
B32	developed country	18	3.39	1.092	0.257	−0.449	0.656
	developing country	22	3.55	1.101	0.235		
B33	developed country	18	3.17	1.2	0.283	−1.588	0.12
	developing country	22	3.73	1.032	0.22		

Different regions have diverse perspectives on the obstacles of complex data analysis, maintenance resources, training costs, and data processing software. With a mean score between 2.61 and 2.89, these obstacles are deemed insignificant in developed nations. In developing countries, however, these obstacles are significant (see Figure 5). Maintenance funds, training expenses, and software for data processing are significant obstacles for developing nations.

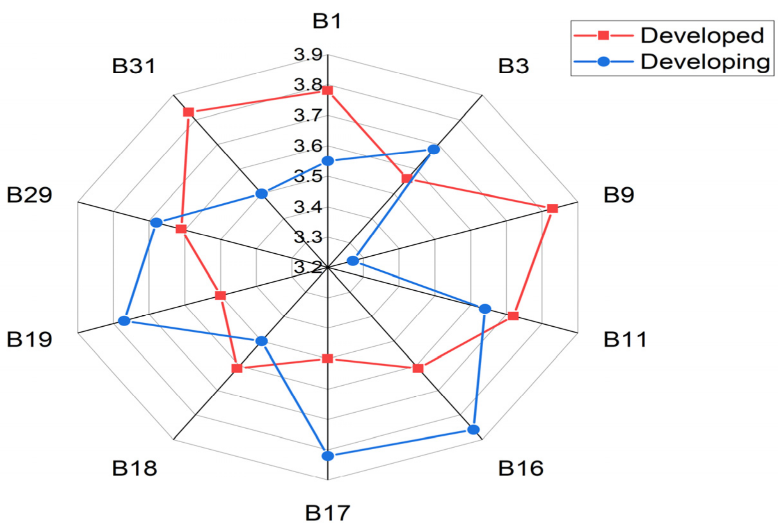

Figure 5. Mean of barriers between developed and developing countries.

4.1.6. Differences Among Company Sizes

A one-way analysis of variance (ANOVA) was performed on the data to determine the disparities in each barrier between small, medium, and large companies. The results are detailed in Table 6. One-way ANOVA assesses whether there are statistically significant differences among the means of three or more independent groups [51]. In this study, SPSS 27 is used to execute a one-way ANOVA to compare the means of three groups (small company, medium company, and large company) and to determine whether the barriers vary by company size.

Table 6. One-way ANOVA of company sizes.

Barriers	Company Sizes	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max	Sig
						Lower	Upper			
B1	small	10	3.5	0.85	0.269	2.89	4.11	2	5	0.219
	medium	5	3	1	0.447	1.76	4.24	2	4	
	large	25	3.84	1.068	0.214	3.4	4.28	1	5	
	Total	40	3.65	1.027	0.162	3.32	3.98	1	5	
B2	small	10	3.4	1.075	0.34	2.63	4.17	2	5	0.775
	medium	5	3	1.414	0.632	1.24	4.76	1	4	
	large	25	3.4	1.155	0.231	2.92	3.88	1	5	
	Total	40	3.35	1.145	0.181	2.98	3.72	1	5	
B3	small	10	3.6	0.843	0.267	3	4.2	3	5	0.931
	medium	5	3.8	1.304	0.583	2.18	5.42	2	5	
	large	25	3.6	1.155	0.231	3.12	4.08	1	5	
	Total	40	3.63	1.079	0.171	3.28	3.97	1	5	
B4	small	10	3.3	0.823	0.26	2.71	3.89	2	5	0.581
	medium	5	3	1.581	0.707	1.04	4.96	1	5	
	large	25	3.52	1.046	0.209	3.09	3.95	2	5	
	Total	40	3.4	1.057	0.167	3.06	3.74	1	5	
B5	small	10	3	1.155	0.365	2.17	3.83	1	5	0.652
	medium	5	3.2	1.483	0.663	1.36	5.04	1	5	
	large	25	2.76	0.97	0.194	2.36	3.16	1	4	
	Total	40	2.88	1.067	0.169	2.53	3.22	1	5	
B6	small	10	2.4	1.35	0.427	1.43	3.37	1	5	0.478
	medium	5	2.4	1.342	0.6	0.73	4.07	1	4	
	large	25	1.96	0.935	0.187	1.57	2.35	1	4	
	Total	40	2.13	1.09	0.172	1.78	2.47	1	5	
B7	small	10	3.7	0.823	0.26	3.11	4.29	2	5	0.584
	medium	5	3.2	1.095	0.49	1.84	4.56	2	4	
	large	25	3.48	0.872	0.174	3.12	3.84	2	5	
	Total	40	3.5	0.877	0.139	3.22	3.78	2	5	

Table 6. *Cont.*

Barriers	Company Sizes	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max	Sig
						Lower	Upper			
B8	small	10	3.5	0.972	0.307	2.8	4.2	2	5	0.171
	medium	5	3.4	1.342	0.6	1.73	5.07	1	4	
	large	25	2.84	0.943	0.189	2.45	3.23	1	4	
	Total	40	3.08	1.023	0.162	2.75	3.4	1	5	
B9	small	10	3.6	0.843	0.267	3	4.2	2	5	0.437
	medium	5	4	0.707	0.316	3.12	4.88	3	5	
	large	25	3.4	1.041	0.208	2.97	3.83	1	5	
	Total	40	3.53	0.96	0.152	3.22	3.83	1	5	
B10	small	10	3.4	1.075	0.34	2.63	4.17	1	5	0.541
	medium	5	3.6	1.14	0.51	2.18	5.02	2	5	
	large	25	3.08	1.115	0.223	2.62	3.54	1	5	
	Total	40	3.23	1.097	0.174	2.87	3.58	1	5	
B11	small	10	3.5	1.269	0.401	2.59	4.41	1	5	0.193
	medium	5	3	0.707	0.316	2.12	3.88	2	4	
	large	25	3.88	0.971	0.194	3.48	4.28	2	5	
	Total	40	3.68	1.047	0.166	3.34	4.01	1	5	
B12	small	10	3.1	1.287	0.407	2.18	4.02	1	5	0.315
	medium	5	4	0.707	0.316	3.12	4.88	3	5	
	large	25	3.08	1.288	0.258	2.55	3.61	1	5	
	Total	40	3.2	1.244	0.197	2.8	3.6	1	5	
B13	small	10	3.7	1.252	0.396	2.8	4.6	1	5	0.219
	medium	5	3	1.581	0.707	1.04	4.96	1	5	
	large	25	2.88	1.166	0.233	2.4	3.36	1	5	
	Total	40	3.1	1.257	0.199	2.7	3.5	1	5	
B14	small	10	3.6	1.075	0.34	2.83	4.37	2	5	0.435
	medium	5	3	1.225	0.548	1.48	4.52	2	5	
	large	25	3.16	0.943	0.189	2.77	3.55	1	5	
	Total	40	3.25	1.006	0.159	2.93	3.57	1	5	
B15	small	10	3.5	1.179	0.373	2.66	4.34	1	5	0.283
	medium	5	2.4	1.342	0.6	0.73	4.07	1	4	
	large	25	3.08	1.256	0.251	2.56	3.6	1	5	
	Total	40	3.1	1.257	0.199	2.7	3.5	1	5	
B16	small	10	3.4	0.966	0.306	2.71	4.09	2	5	0.1
	medium	5	4.6	0.548	0.245	3.92	5.28	4	5	
	large	25	3.72	1.061	0.212	3.28	4.16	1	5	
	Total	40	3.75	1.032	0.163	3.42	4.08	1	5	

Table 6. *Cont.*

Barriers	Company Sizes	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max	Sig
						Lower	Upper			
B17	small	10	3.7	1.337	0.423	2.74	4.66	1	5	0.959
	medium	5	3.8	1.304	0.583	2.18	5.42	2	5	
	large	25	3.64	1.075	0.215	3.2	4.08	1	5	
	Total	40	3.68	1.141	0.18	3.31	4.04	1	5	
B18	small	10	3.6	1.174	0.371	2.76	4.44	1	5	0.473
	medium	5	3	0.707	0.316	2.12	3.88	2	4	
	large	25	3.64	1.075	0.215	3.2	4.08	1	5	
	Total	40	3.55	1.061	0.168	3.21	3.89	1	5	
B19	small	10	3.7	1.059	0.335	2.94	4.46	1	5	0.98
	medium	5	3.6	0.548	0.245	2.92	4.28	3	4	
	large	25	3.64	1.036	0.207	3.21	4.07	2	5	
	Total	40	3.65	0.975	0.154	3.34	3.96	1	5	
B20	small	10	3.5	1.08	0.342	2.73	4.27	1	5	0.26
	medium	5	3	1.414	0.632	1.24	4.76	1	4	
	large	25	2.68	1.376	0.275	2.11	3.25	1	5	
	Total	40	2.93	1.328	0.21	2.5	3.35	1	5	
B21	small	10	3.5	1.179	0.373	2.66	4.34	1	5	0.299
	medium	5	3.4	0.894	0.4	2.29	4.51	2	4	
	large	25	2.84	1.281	0.256	2.31	3.37	1	5	
	Total	40	3.08	1.228	0.194	2.68	3.47	1	5	
B22	small	10	3.4	1.075	0.34	2.63	4.17	1	5	0.6
	medium	5	3.4	1.517	0.678	1.52	5.28	1	5	
	large	25	3	1.19	0.238	2.51	3.49	1	5	
	Total	40	3.15	1.189	0.188	2.77	3.53	1	5	
B23	small	10	3.9	1.197	0.379	3.04	4.76	1	5	0.033
	medium	5	4	1	0.447	2.76	5.24	3	5	
	large	25	2.88	1.201	0.24	2.38	3.38	1	4	
	Total	40	3.28	1.261	0.199	2.87	3.68	1	5	
B24	small	10	3.8	0.919	0.291	3.14	4.46	2	5	0.057
	medium	5	3.6	0.894	0.4	2.49	4.71	3	5	
	large	25	3	0.913	0.183	2.62	3.38	1	4	
	Total	40	3.28	0.96	0.152	2.97	3.58	1	5	
B25	small	10	3.6	1.174	0.371	2.76	4.44	1	5	0.199
	medium	5	3.8	0.837	0.374	2.76	4.84	3	5	
	large	25	3	1.155	0.231	2.52	3.48	1	5	
	Total	40	3.25	1.149	0.182	2.88	3.62	1	5	

Table 6. *Cont.*

Barriers	Company Sizes	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max	Sig
						Lower	Upper			
B26	small	10	3.7	1.059	0.335	2.94	4.46	2	5	0.035
	medium	5	4	0.707	0.316	3.12	4.88	3	5	
	large	25	2.92	1.038	0.208	2.49	3.35	1	5	
	Total	40	3.25	1.08	0.171	2.9	3.6	1	5	
B27	small	10	3.1	1.101	0.348	2.31	3.89	1	5	0.986
	medium	5	3	1.414	0.632	1.24	4.76	1	4	
	large	25	3.08	1.077	0.215	2.64	3.52	1	5	
	Total	40	3.08	1.095	0.173	2.72	3.43	1	5	
B28	small	10	3.3	1.059	0.335	2.54	4.06	1	5	0.669
	medium	5	3.2	1.643	0.735	1.16	5.24	1	5	
	large	25	2.92	1.152	0.23	2.44	3.4	1	5	
	Total	40	3.05	1.176	0.186	2.67	3.43	1	5	
B29	small	10	3.5	1.08	0.342	2.73	4.27	2	5	0.655
	medium	5	4	1.225	0.548	2.48	5.52	2	5	
	large	25	3.64	0.907	0.181	3.27	4.01	2	5	
	Total	40	3.65	0.975	0.154	3.34	3.96	2	5	
B30	small	10	3.7	0.949	0.3	3.02	4.38	2	5	0.09
	medium	5	4	1	0.447	2.76	5.24	3	5	
	large	25	3.04	1.098	0.22	2.59	3.49	1	5	
	Total	40	3.33	1.095	0.173	2.97	3.68	1	5	
B31	small	10	3.6	0.843	0.267	3	4.2	2	5	0.115
	medium	5	2.8	1.643	0.735	0.76	4.84	1	5	
	large	25	3.84	0.898	0.18	3.47	4.21	2	5	
	Total	40	3.65	1.027	0.162	3.32	3.98	1	5	
B32	small	10	3.5	1.08	0.342	2.73	4.27	1	5	0.761
	medium	5	3.8	0.837	0.374	2.76	4.84	3	5	
	large	25	3.4	1.155	0.231	2.92	3.88	1	5	
	Total	40	3.48	1.086	0.172	3.13	3.82	1	5	
B33	small	10	3.5	0.707	0.224	2.99	4.01	3	5	0.045
	medium	5	4.6	0.548	0.245	3.92	5.28	4	5	
	large	25	3.24	1.234	0.247	2.73	3.75	1	5	
	Total	40	3.48	1.132	0.179	3.11	3.84	1	5	

The results demonstrate that the barriers of high acquisition costs, data processing software, and unstructured unmanned aerial vehicle systems have varying effects based on the company's scale. Specifically, the high cost of acquisition and data processing software can impede unmanned aerial vehicle (UAV) use in small and medium-sized businesses, but it has been identified as a medium or low barrier in large businesses. In addition, unstructured unmanned aerial vehicle systems are viewed as a moderately significant barrier by both small and large companies, with mean scores of 3.50 and 3.24, respectively (see Figure 6). However, it is a significant barrier for the average medium-sized business (4.6).

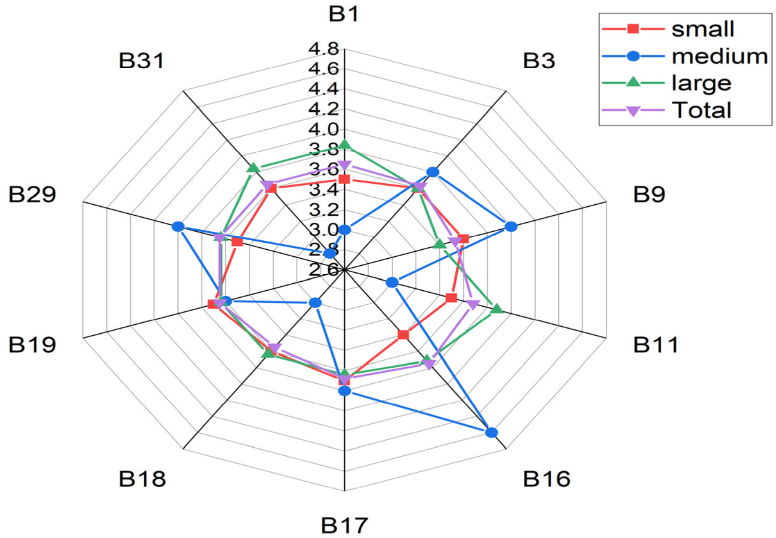

Figure 6. Mean of barriers between company sizes.

4.1.7. Differences in UAV Project Involvement

Using a *t*-test on independent samples, the data were examined to determine whether the significance of barriers yields distinct results based on respondents' involvement. Participation indicates that respondents participated in a project involving UAVs in construction safety management. The results are detailed in Table 7.

Table 7. Independent sample *t*-test of involvement.

Barriers	Independent Samples	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-Tailed)
B1	Yes	20	4	0.973	0.218	2.268	0.029
	No	20	3.3	0.979	0.219		
B2	Yes	20	3.5	1.1	0.246	0.825	0.414
	No	20	3.2	1.196	0.268		
B3	Yes	20	4.05	0.999	0.223	2.683	0.011
	No	20	3.2	1.005	0.225		
B4	Yes	20	3.6	1.188	0.266	1.203	0.236
	No	20	3.2	0.894	0.2		
B5	Yes	20	2.75	1.209	0.27	−0.737	0.466
	No	20	3	0.918	0.205		
B6	Yes	20	1.85	1.089	0.244	−1.628	0.112
	No	20	2.4	1.046	0.234		
B7	Yes	20	3.3	0.923	0.206	−1.463	0.152
	No	20	3.7	0.801	0.179		
B8	Yes	20	3.05	1.05	0.235	−0.153	0.879
	No	20	3.1	1.021	0.228		
B9	Yes	20	3.6	0.94	0.21	0.489	0.628
	No	20	3.45	0.999	0.223		

Table 7. *Cont.*

Barriers	Independent Samples	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-Tailed)
B10	Yes	20	3.2	1.24	0.277	−0.142	0.888
	No	20	3.25	0.967	0.216		
B11	Yes	20	3.8	1.196	0.268	0.751	0.457
	No	20	3.55	0.887	0.198		
B12	Yes	20	3.15	1.387	0.31	−0.251	0.803
	No	20	3.25	1.118	0.25		
B13	Yes	20	3	1.487	0.332	−0.498	0.621
	No	20	3.2	1.005	0.225		
B14	Yes	20	3.35	1.089	0.244	0.623	0.537
	No	20	3.15	0.933	0.209		
B15	Yes	20	2.9	1.447	0.324	−1.007	0.32
	No	20	3.3	1.031	0.231		
B16	Yes	20	3.8	1.24	0.277	0.303	0.764
	No	20	3.7	0.801	0.179		
B17	Yes	20	3.65	1.348	0.302	−0.137	0.892
	No	20	3.7	0.923	0.206		
B18	Yes	20	3.6	1.188	0.266	0.295	0.77
	No	20	3.5	0.946	0.212		
B19	Yes	20	3.65	1.182	0.264	0	1
	No	20	3.65	0.745	0.167		
B20	Yes	20	2.6	1.392	0.311	−1.577	0.123
	No	20	3.25	1.209	0.27		
B21	Yes	20	2.8	1.281	0.287	−1.436	0.159
	No	20	3.35	1.137	0.254		
B22	Yes	20	3.1	1.252	0.28	−0.263	0.794
	No	20	3.2	1.152	0.258		
B23	Yes	20	3.2	1.576	0.352	−0.372	0.712
	No	20	3.35	0.875	0.196		
B24	Yes	20	3.25	1.118	0.25	−0.163	0.872
	No	20	3.3	0.801	0.179		
B25	Yes	20	3.25	1.293	0.289	0	1
	No	20	3.25	1.02	0.228		
B26	Yes	20	3.1	1.071	0.24	−0.876	0.387
	No	20	3.4	1.095	0.245		
B27	Yes	20	2.85	1.348	0.302	−1.311	0.2
	No	20	3.3	0.733	0.164		
B28	Yes	20	3	1.451	0.324	−0.266	0.792
	No	20	3.1	0.852	0.191		
B29	Yes	20	3.6	1.095	0.245	−0.32	0.75
	No	20	3.7	0.865	0.193		
B30	Yes	20	3.25	1.209	0.27	−0.429	0.671
	No	20	3.4	0.995	0.222		
B31	Yes	20	3.55	1.099	0.246	−0.611	0.545
	No	20	3.75	0.967	0.216		
B32	Yes	20	3.45	1.276	0.285	−0.144	0.886
	No	20	3.5	0.889	0.199		
B33	Yes	20	3.65	1.268	0.284	0.977	0.335
	No	20	3.3	0.979	0.219		

The results indicate that respondents who have participated in an actual project involving UAVs in construction safety management tend to view collision and human error as more significant than those who have not. People involved in the UAV initiative believe collisions and human error are significant, with a mean score of 4 and 4.05, respectively (see Figure 7). In contrast, the mean of these obstacles is only 3.3 and 3.2 for respondents who have never participated in an actual UAV initiative.

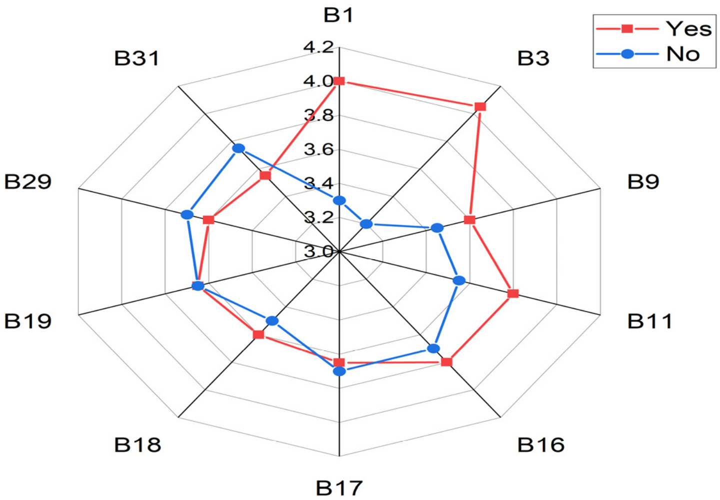

Figure 7. Mean of barriers between involvement or not.

5. Discussion

The restricted area barrier is a critical challenge for UAV adoption in construction due to its direct impact on operational feasibility, safety, and monitoring effectiveness. UAVs often face difficulties in confined spaces, indoor projects, and complex construction sites where maneuverability is limited. For instance, in a project converting an old factory into a modern office space, drones must navigate through intricate structural elements, tight passages, and restricted-access zones, making effective monitoring and hazard detection challenging. Additionally, limited flight areas can compromise UAV efficiency by reducing operational range and increasing the risk of collisions in constrained environments [10]. Similarly, the lack of safety regulations poses significant risks, particularly in high-density construction sites. In the absence of well-defined UAV safety protocols, construction firms may deploy drones for site monitoring without adequate guidelines, increasing the likelihood of accidents. For example, a UAV operating near a high-rise project could collide with cranes, workers, or even pedestrians outside the construction zone, leading to severe safety hazards. The criticality of this barrier is further amplified by the evolving nature of drone legislation, which varies across regions and often lags behind rapid technological advancements in UAV applications [11].

UAVs' short flight duration may challenge resource allocation strategies [12]. For instance, if a company attempts to integrate UAVs into its safety management process to achieve real-time site monitoring, efficient data collection, and rapid identification of potential hazards, it may encounter complications. Due to the flight duration limitation, additional flights are required to monitor the same area, increasing the possibility of waste of resources and complexity of designing resource allocation schedules. Collisions between unmanned aerial vehicles (UAVs) will result in severe problems, including equipment damage, injuries, mortality, financial impact, and reputational harm [13,17]. For example, one of the UAVs may collide with a crane or employees due to operator error, system malfunction, or unanticipated environmental factors such as gusty winds, which could have a significant negative impact. Pilots of unmanned aircraft must be adept and quick to respond to incidents. However, drones may capture data inefficiently or cause accidents. Incompetent pilots cannot navigate complex construction environments effectively, so good piloting skills are essential to ensure safety [14,15].

Many construction employees are oblivious to using unmanned aerial vehicles (UAVs) in construction safety management; however, this ignorance of using drones might impede the performance of certain site inspections caused by natural disasters [15]. Some individuals oppose incorporating new technologies for various reasons, including the cost of integration and the failure of new technologies. However, resisting new technologies may have negative consequences. For instance, the competitive advantage will be lost: construction companies that do not integrate UAVs may lose contracts or proposals to rivals who emphasize their technological advantage in assuring safety and efficiency. Human error has a high likelihood of causing collisions with structures and worker injury. Due to improper navigation, the drone may collide with building materials, equipment, or the structure itself. Depending on the severity of the collision, this may cause damage to the drone, the apparatus, or even the structural integrity. In addition, if a drone, particularly a larger one, is improperly navigated and descends unexpectedly or veers off course, it could pose a direct risk to employees' physical safety [7].

Training is a barrier for construction companies integrating UASs into construction safety management. Training requirements can increase expenses and time commitments. As a result of the novelty of the technology, it is difficult to locate qualified educators, and employees have varying learning curves [37,47]. Specifically, training can be costly due to training fees and the cost of employing trainers. Staff training can delay projects and divert human resources from on-site duties. In addition, it may be challenging to find qualified trainers or training programs covering UAV operations, regulations, and their applicability to construction safety management. Last but not least, not all employees will have the same aptitude or background knowledge regarding drones, resulting in varying learning trajectories that can create consistency issues during training sessions [8,26,52].

UAV laws limit the height and complexity of applications. Limitations imposed by the law, such as height restrictions, will restrict the inspection scope and have legal repercussions. In particular, if there are restrictions on the maximum height to which drones can fly, their ability to survey towering structures, such as skyscrapers or tall cranes, may be limited, diminishing their utility in specific construction environments. In addition, failure to comply with restrictions may result in severe legal consequences, such as fines, litigation, or prohibitions on future UAV operations [12,13,15].

There are differences between developed and developing countries; the mean of critical barriers between different countries is shown in Figure 5. Law restrictions, resistance to new technology, and collision are viewed as much more significant obstacles in developed nations than in developing countries. In developed nations, there are more clearly defined regulations for drone use, including height restrictions, no-fly zones, and user certification [53]. Limitations imposed by law, such as height restrictions and no-fly zones, can make it challenging to inspect tall structures, such as skyscrapers or cranes, diminishing their utility in specific construction projects. Failure to comply with restrictions may result in severe legal consequences, such as fines, lawsuits, or prohibitions on future UAV operations [54,55]. However, developing countries tend to have less detailed regulations about utilizing drones.

The construction industry has already adopted a comprehensive construction safety management system with comprehensive regulations in developed nations. The integration of novel technology may present two difficulties. First, from an economic perspective, the acquisition of drones, their upkeep, the training of personnel, the construction of an interaction platform, and the purchase of data analysis software are typically costly endeavors. Second, high expectations. Since construction companies in developing nations are already endowed with advanced technology and have demonstrated high project efficiency, they tend to have greater expectations for new technologies. Resistance may result if the technology fails to meet or exceed their expectations [56,57].

In contrast, there may be greater adoption of drones in some developing regions due to their role in societal development [58–60]. In developing nations, the barriers of restricted area, limited flight time, and lack of piloting abilities are viewed as significantly more significant than in developed nations. The availability of new drone technology in restricted areas may be restricted in developing nations compared to developed nations. Due to less sophisticated systems for averting collisions and navigation, using drones in confined or interior environments may be challenging. In addition, developing nations may lack expert operators; the dearth of trained operators could make it difficult to use drones in restricted areas [20,61]. In contrast, developed nations can address this issue more effectively with their superior technology.

In developing regions, limited flight time is also considered an essential barrier. Budget constraints in developing nations may prevent construction companies from having fallback drones or additional batteries on hand, which may exacerbate the issue of limited flight durations. Flight duration limitations may result in repeated work in the same area and higher costs due to speedier battery degradation. In contrast, construction companies in developed nations are more likely to use drones with longer battery lives. In developing countries, there are three reasons why piloting skills have become a critical barrier for pilots. First, a paucity of support instruments, such as sophisticated sensors and interaction platforms, necessitates a higher skill requirement for pilots to ensure safety. However, due to economic constraints, companies in developing nations may employ less-skilled drone operators to save money, increasing the safety risk. Even though there is a growing interest in drone technology, specialized training infrastructure may be scarce [22,23]. However, in developing countries, there are typically more training resources or regulatory support (regulations may require drone pilots to undergo specific training), which makes it less important than in developed nations.

The radar chart below (Figure 6) shows the attitude of respondents from different company sizes (small, medium, and large) about UAVs barriers. The barriers show this. There are few disparities between small and large companies regarding the mean of UAV barriers. However, the restricted area average is 4.6. This indicates that most respondents consider restricted areas a significant barrier when implementing UAVs for construction safety management. The inconsistency of resources and output may cause this phenomenon. Compared to small businesses, medium-sized businesses are more likely to undertake complex projects that may encounter restricted areas. However, medium-sized businesses have fewer resources, such as sophisticated technology, budget, and skilled pilots, to manage complex environments. Thus, the restricted area is recognized as a significant obstacle for medium-sized construction firms.

Respondents involved in a real construction project utilizing UAVs for their construction safety show different opinions about barriers. A radar chart below shows the mean of the critical obstacles (Figure 7). Respondents involved in an actual UAV project highlight the importance of collision and human errors; their opinions come from real-world challenges and observations, which are much more valuable. First, the payload capacity of many unmanned aerial vehicles is limited. Their limited payload capacities can limit their ability to transport sophisticated sensors or equipment, diminishing their efficiency in specific construction projects. Second, construction companies typically incur substantial expenses when acquiring network communication infrastructure. In some nations, there are regulations governing the importation of foreign-made goods. According to the American

Security Drone Act, Chinese drones are prohibited in many U.S. states [2]. However, these regulations may increase the price of acquiring drones and limit data analysis.

5.1. Implications

The results of this study have implications for construction safety, both in theoretical and practical aspects.

5.1.1. Theoretical Implications

First, this study employs qualitative and quantitative methods, including a systematic literature review and a questionnaire survey, to identify and rank the obstacles to UAV adoption in construction safety management. However, implementing UAVs in construction safety management has received limited attention in previous studies. This study integrates and evaluates these UAV-related obstacles. This study used the Spearman rank, one-sample t-, and one-way ANOVA tests to analyze the relationship between the identified barriers. Previous research merely enumerated these obstacles with no discussion of their relationship. However, this study examined the correlation between these obstacles. Thirdly, this research compares significant barriers between developed and developing nations. Prior research has focused more on established nations, such as the United States, and few papers have addressed how to utilize UAVs for construction safety management in developing nations. Thus, there is a dearth of attention and data collection regarding the use of UAVs in the administration of construction safety in developing nations. This study filled these knowledge gaps.

5.1.2. Practical Implications

This research ranks the obstacles and analyzes them according to country and company size. For the construction industry, this research can guide construction companies attempting to use UAVs for construction safety management in overcoming potential obstacles. This paper not only listed critical barriers but also provided analysis based on countries and company size, as well as which barriers may be underestimated if construction firms lack relevant experience. This paper demonstrated why and how each critical barrier affects the adoption of unmanned aerial vehicles (UAVs) and the relationship between those barriers. Companies in the construction industry will be able to determine their position based on company size and country, allowing them to identify the most significant obstacles they may face if they wish to implement drones in construction safety management.

This research indicates that to integrate UAVs into an existing construction company, the construction manager must plan for two significant barriers: UAVs operating in restricted areas and drone flight time. The restricted area and limited flight time may result in ineffectiveness and additional expenses. Additionally, a significant correlation exists between restricted areas and limited flight duration. The construction manager should consider both of these obstacles in advance. This research guides project managers on what they should consider when integrating UAVs into their current safety management system. First, the project manager can focus on establishing safety regulations within the organization. Second, UAV piloting abilities are crucial. Third, there may be resistance to new technology; therefore, the project manager must communicate effectively with stakeholders, such as construction employees, supervisors, and clients, and provide continuous feedback to mitigate resistance. Finally, project managers must take training seriously, including training for safety managers and pilots.

6. Conclusions

This study investigates the barriers hampering the adoption of UAVs for construction safety management. Employing an inductive research methodology within a positivist framework, this study integrates both quantitative and qualitative strategies, including a systematic literature review (SLR) and a questionnaire survey, to collect and analyze data. The study addresses three key research questions: (1) The SLR identified 33 potential barriers, of which 12 were classified as critical based on a mean score threshold of 3.51. The most significant barriers include restricted area, lack of safety regulations, and limited flight duration. (2) In developed countries, collision risks, legal restrictions, and resistance to new technologies were the most pressing concerns. In contrast, restricted areas, limited flight time, and piloting expertise were the dominant barriers in developing nations. Medium-sized construction firms encountered pronounced challenges related to UAV usage in restricted areas. (3) The analysis revealed strong interdependencies among barriers. Restricted area was closely linked to limited flight duration and piloting abilities, as spatial constraints directly impact UAV operation time and require skilled pilots for maneuvering. Lack of safety regulations showed strong connections with collision risks, training requirements, piloting abilities, and resistance to new technologies, highlighting regulatory gaps as a fundamental challenge in UAV integration. Limited flight duration was strongly correlated with restricted areas and piloting expertise, further emphasizing the operational constraints of UAVs in construction safety management.

This study contributes to the existing body of knowledge by offering a comprehensive, context-specific analysis of UAV adoption barriers in construction safety management. Unlike previous studies that focus on isolated challenges, this research provides an integrated, regionally comparative perspective, highlighting critical differences between developed and developing nations. Additionally, by examining interdependencies among barriers, this study enhances understanding of the systemic challenges hindering UAV adoption. The primary limitation of this study is the small sample size; although 58 responses were collected, only 40 were deemed valid. Future research should address this limitation by extending data collection periods and increasing sample sizes to enhance generalizability. Additionally, exploring technological and policy-driven solutions could help mitigate the identified barriers, while conducting longitudinal studies would provide insights into how UAV adoption challenges evolve over time. Furthermore, sector-specific adaptations, such as tailored UAV policies for urban versus rural construction projects, should be investigated to ensure context-appropriate implementation. By providing actionable insights for policymakers, industry professionals, and researchers, this study underscores the need for targeted strategies to overcome barriers to UAV adoption, ultimately contributing to safer and more efficient construction practices.

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