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Impediments to Construction Site Digitalisation Using Unmanned Aerial Vehicles (UAVs)

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Abstract: Utilising emerging innovative technologies and systems to improve construction processes in an effort towards digitalisation has been earmarked as critical to delivering resilience and responsive infrastructure. However, successful implementation is hindered by several challenges. Hence, this study evaluates the challenges facing the adoption of unmanned aerial vehicles towards the digitalisation of the built environment. The study adopted a quantitative survey of built environment stakeholders in developed and developing economies. A total of 161 completely filled forms were received after the survey, and the data were analysed using descriptive analysis and inferential statistics. The study's findings show that there are different barriers experienced between developed and developing countries in the adoption of drones towards digitalising construction processes in the built environment. Moreover, economic/cost-related factors were identified as the most critical barriers to the adoption of drones, followed by technical/regulatory factors and education/organisation-related factors. The findings can assist the built environment in reducing the impact of these barriers and could serve as a policy instrument and helpful guidelines for governmental organisations, stakeholders, and others.

Keywords: challenges; impediments; drones; unmanned aerial vehicles (UAVs); digitalisation; digital transformation; construction; built environment; AEC

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1. Introduction

Digitalisation has been highlighted to assist construction firms in establishing and optimising their infrastructure delivery in a sector constrained by resource scarcity, inefficient procedures, material waste, schedule overruns, and cost overruns [1]. Drones (unmanned aerial systems/vehicles (UASs/UAVs)), which were first used for military purposes and increasingly recent civilian applications, have been identified as critical in the digitalisation processes of the built environment. UAVs can fly autonomously or remotely without a pilot aboard. UAVs are becoming frequent tools for data collection, mapping, and visual inspection in architecture, engineering, construction, and facilities management (AEC-FM). High-quality drone imagery can quickly gather large aerial data with GPS points in 2D and 3D, allowing for precise distance measurements and the creation of 3D models that can help analyse important construction-related data in various formats, such as volumes, surfaces, and altitudes [2]. UAVs are being utilised increasingly in various industrial processes, including mining, farming, and surveying. The usage of UAVs in building development has increased at an unparalleled rate [3]. One of the approaches to realising resilient and responsive construction processes at the speed necessary to switch from conventional development strategies to improved and sustainable infrastructure delivery methodologies is digital transformation. Recognising digitalisation as a socio-technical process that uses the possibilities of digital technology to create new organisational practices is imperative to increasing awareness for industry uptake, higher learning, reskilling efforts, and effective government policies. Despite the immense benefits of applied digital technologies to the built environment processes, industry use is limited. This low adoption is attributed to a lack of understanding of technology adoption's socio-technical challenges [4]. Many construction firms understand that they must develop their ability to adapt to digital disruption to ensure business continuity but are inhibited by challenges characterising digital transformation, especially in using drones. Because of this, the enormous prospects presented by digitalisation have not yet been completely realised, which is especially true in the construction industry. Lundberg et al. [5] pointed out that compared to previous times where technological constraints limited upscaling, recent advancements require identifying that digital technology systems are not self-contained entities with set meanings and linkages but rather loosely connected and infrastructure-based, allowing for many value pathways to be exploited. Such value pathway exploitation has seen the use of drones in construction to execute the monitoring of workflows, inspection of infrastructure projects, security of building facilities, photography, maintenance inspections, and safety and progress monitoring, amongst others [6]. Despite opportunities provided by drones to access difficult-to-reach parts of construction sites more quickly than humans and the ability to be fitted with equipment such as cameras, sensors, radar, and communication technology to send real-time data to safety managers, adoption and interest are still low [7]. The low adoption has been attributed to challenges facing drone utilisation in the built environment, little discourse on what these challenges entail, and a lack of practical strategies to overcome the impediments [8].

Consequently, this current study aims to evaluate the challenges facing the adoption of unmanned aerial vehicles in the built environment. Although several other studies have highlighted the challenges to adopting drones, none of the earlier studies examined how drones' drive to digitise the built environment is affected. The contribution of this research is to establish more applicable and efficient solutions to assure the full adoption of drones in built environment practices. In this article, we emphasise practical proposals for increasing the use of drones in the construction industry and the viewpoints of construction industry experts on how to increase the use of drones in construction projects. To ensure that drones can fulfil the full potential of digitalisation strategies in the construction industry, the findings can be utilised as a policy instrument and valuable suggestions for government agencies, stakeholders, and other parties. The study's findings add to the knowledge of concerns related to using unmanned aerial vehicles to adopt digitalisation by providing useful recommendations on overcoming key challenges. The rest of the paper is organised into five sections. Section 2 presents the literature review, Section 3 gives the methodological approach adopted for the study, and the results from the process are presented in Section 4. Section 5 presents the discussion of the study.

2. Literature Review

2.1. Digitalising Construction Processes towards Enhanced Resilience and Sustainable Infrastructure Delivery

The pace of change in the built environment is exponentially accelerating due to the digital revolution, which radically alters our world. The digitalisation of construction sites provides new opportunities for innovative solutions in information management and enhanced and improved construction workflows, processes, and systems to achieve sustainable infrastructure delivery [9]. Despite fast-rising investments in digital technology, the sector is only now considering adopting digitalised systems to drive digital transformation [5]. Recent shock events have brought to the fore the need to deliver resilient and responsive infrastructure, and while digitalisation is critical to achieving this process, leveraging digital innovations to achieve this aim is underwhelming in the AEC sector. Factors such as the cost of investment, awareness, capacity development, fragmented value chains, project-based logic, and monolithic IT systems have been identified as causative elements inhibiting large-scale adoption from leveraging digitalisation in enhancing construction processes [10].

Due to significant obstacles, the sector frequently struggles to envisage, implement, and realise the potential of digital technology at construction sites [5]. While several studies have examined the challenges of emerging digital systems in construction, critical socio-technical challenges in drone adoption have received less attention despite enormous evidence on their role in inhibiting adoption [11].

Lundberg et al. [5] argued that technology has been employed in the building sector for decades with applications ranging from processing data (such as spreadsheeting), basic automatisation (such as process automation), and architectural design (e.g., computer-aided design). However, emerging digital innovations such as building information modelling (BIM), robotics, virtual reality, point-cloud data extraction, sensors, artificial intelligence, drone, semantic web technology or ontology, radio-frequency identification (RFID), blockchain, and augmented reality, amongst others, offer much more [11]. In this study, we use digitalisation to depict the application of drones/UAVs as well as other emerging technologies in construction. Innovative technologies such as UAVs are used to ensure that civil infrastructures remain healthy, and losses of human lives and money are minimised, if not eliminated, to enable effective damage assessment methods [12]. Furthermore, when checking the health of a structure, reliable, quick, and effective crack detection procedures are essential since they determine the structure's durability and safety. The effectiveness of traditional (manual) crack detection techniques depends greatly on the investigators' knowledge and procedures. Such manual inspection is carried out via crack analysis (i.e., crack location and widths), where the outcomes are arbitrary and depend on the inspector's skill set. These restrictions result in incorrect damage assessments for essential infrastructure [13].

In hazard planning and urban development, decision-makers face data shortages for vulnerable projects and high-interest locations due to the difficulty of making reliable measurements and damage assessments at smaller scales due to the availability of large-scale datasets; with the use of UAS, these datasets are captured at a much lower cost and more accurately. Recent developments in drones such as a double closed-loop UAV speed tracking system with quick convergence, high control precision, strong stability, and good resilience serve to implement speed control, target tracking, and trajectory tracking [14]. Jiang et al. [15] employed a sigma-pi neural network (SPNN) as a compensator to lessen model error and enhance system performance in the presence of environmental, payload, and UAV dynamics uncertainty while Cheng et al. [16] developed a neural network-based controller to learn the system dynamics and correct the tracking error between the UAV dynamics and the required dynamic performance. By drawing on the concept of a novel path planner termed the obstacle avoidance beetle antennae search (OABAS) algorithm, Wu et al. [17] resolved the high computing complexity of the bio-heuristic algorithm and real-time path planning of UAVs.

These innovations have enabled the commercialisation of drones, which has expanded substantially. The global drone industry generated over USD 19.5 billion in revenue in 2019, rising to USD 22.5 billion in 2020. Through 2027, it is anticipated to expand by almost 20% annually, reaching USD 55.6 billion in sales [18]. Despite their increasing popularity and versatile use, little is known about drones' adoption in the built environment towards aiding the delivery of enhanced, resilient, and sustainable infrastructure. Digitalisation is the main tool for resilient and responsive infrastructure management in the built environment. With increasing digital culture amongst younger population demographics globally, the use of digital technologies to enhance infrastructure delivery has become inevitable. However, driving drone adoption to leverage its opportunities in aiding resilient infrastructure delivery requires overcoming impediments to widespread adoption.

2.2. Role of Unmanned Aerial Vehicles in Digitalisation of Construction Sites

Digitisation, or the translation of information from physical analogue to digital representations, is necessary to achieve a number of benefits [5]. As a result, construction firms must actively engage in digitalisation—the socio-technical process of utilising digitalised elements to create new organisational procedures, following the successful digitisation of operations [18,19]. Drones in construction offer an integrated and substitutive digital approach that supports lifecycle infrastructure delivery from inception to asset management. The use of UAVs in this process involves improvement in security surveillance, response times, site inspection, progress reporting, and photography by integrating digital data captured from drones into software's analytical capabilities [20]. Data capture and analysis are often the first two essential phases in UASs; the first phase involves the drone taking aerial pictures or videos, and powerful image processing techniques are employed to analyse the visual data obtained in the second phase.

Reality capture and digitalisation through drones can assist organisations in meeting the rising need for future-proof structures, generating immediate financial gains, promoting teamwork, and settling disputes regarding the actual status of construction projects on the ground [21–23]. A UAS can be the perfect partner for safety inspections, giving a safety manager access to videos or photographs in real time from a variety of predetermined paths and locations around the workplace and acting as an audio platform to speak with construction workers [7]. Any construction project's success depends on the decision-making process. Every day, construction workers must make decisions and be able to defend their choices. Making the wrong choice can be expensive in terms of relationships, quality, time, safety, and cost. The use of drones enhances decision-making by providing superior aerial visualised data of the construction site with the ability to integrate such data in building information modelling to ensure better design and implementation. In managing complex information, drones play a huge role in the digitalisation of the provided platform to capture and integrate project insight to support project stakeholders' decision-making [22,24]. This helps to ensure that designs are well implemented with little clashes and data are easily accessible and available.

Pivotal to the drive for the digital transformation of the built environment is the push to ensure transparency and accountability in executing contracts. This is a huge challenge in developing economies. With drones, large and sophisticated datasets may be gathered, processed, analysed, and disclosed to eliminate disputes on site and inform all stakeholders in real time. As stated by Wbcsd [22], organisations can continually monitor their operations, avoid incidents, and focus interventions for performance improvement by using data-driven and science-based approaches to collecting, managing, and reporting sustainability performance information. By detecting items or following resources and employees during building operations, risks can now be found thanks to advancements in data analysis from drone video cameras or vision cameras [7,15].

Furthermore, drones on site are important in the drive for sustainable infrastructure delivery as they can increase safety through surveillance, save construction time by detecting clashes and reporting progress, and more effectively use resources. Resources are better managed as drones can track and trace materials, enabling stakeholders to better understand how resources are used in operations. The reality captured by the drone from the inception to the maintenance of the asset is therefore vital for the lifecycle operations of the buildings and for enhancing the built environment's value to be more efficient in the process. UASs can be used to spot possible fall hazards and vulnerable workers because they can be fitted with various cameras and sensors. Workers exposed to hidden dangers can then receive alerts that help ensure their safety [7,13].

In construction transport, drone research to deliver materials, equipment, or robots in hazardous areas is gaining momentum. However, drones, unlike vehicles, can typically only convey one package at a time due to technical limits [25–27]. However, the opportunities they provide in quick delivery time, reduced labour cost and cost of procuring vehicles, ability to deploy equipment in hazardous areas, autonomous operations, and non-congested travel paths make these applications valuable for construction digitalisation [25,28]. Other applications involve observation and simulation of traffic, observation of structures, bridge examination, safety assessment, checking the exteriors of buildings, surveying, material monitoring, visual inspection of structures, deployment of equipment and building inspection, site observation, and monitoring the progress of the project, amongst other use cases [7,9,17]. In the built environment, the most used cases for drones were found to be building inspection, damage assessment, site surveying and mapping, safety inspections, and progress monitoring, amongst others [8].

Adoption of UAS also brings cost-saving benefits to reduce project costs, as it has been observed that drones' usage in mapping and surveying construction sites can reduce operating costs. This provides the opportunity to create new services, markets, and procedures. Drones have been identified to positively influence how we construct, share information, and make decisions in the building industry [6]. Digitalisation speeds up the sharing and dissemination of information during the construction process, enabling businesses to test concepts, examine vast amounts of data, and resolve complicated issues in a fraction of the time needed by conventional techniques. Despite the obvious advantages, the industry has been slow to seize the new digital prospects. Several important causes can be identified for this resistance, as discussed in the next section.

2.3. Impediments or Challenges to Construction Site Digitalisation Using Unmanned Arial Vehicles (UAVs)

The challenge of digital transformation is made more difficult by workforce and labour issues due to a significant shift in corporate culture. To comprehend systemic change and digitalisation outcomes, the socio-technical study of construction site digitalisation is still lacking and mostly focuses on industry factors and their dynamic effects on digitalisation [5,29]. As argued by Nichols [30], such impediments identified include limited tool development, significant entry cost to utilise and learn some of the tools, lack of comprehensive measurement and metrics demonstrating low process maturity and the absence of an integrated end-to-end process, the requirement for dedication to an overarching strategy and implementation, a few combinations of solutions that did not function well together, and problems with experience, tools, and training. Important issues such as partial or non-existent regulations make it difficult to use drones regularly and safely in the airspace [2]. The difficulties caused by people not understanding the necessary laws and regulations in the usage of the equipment could be misused, leading to accidents or privacy violation.

Areas where it is possible to see and operate drones directly are defined by a visual line of sight (VLOS) and radio line of sight (RLOS), respectively [31]. These circumstances prevent the operation of long-range flights, restricting the uses that drones may have. The legal issue has been added to this, as it is illegal for these devices to fly over restricted locations. If this rule is broken, the UAV owner may face legal repercussions [31]. Previous studies such as Olawumi and Chan [32] noted that it would be challenging to develop and advance without an adequate understanding of the challenges of the implementation of these concepts in the building sector [33–35].

3. Methods

This study identified and evaluated implementation difficulties associated with the digitalisation of the construction site through the adoption of unmanned aerial vehicles (UAVs). The study used empirical questionnaire surveys, a quantitative research approach, to collect the required data. Targeting pertinent respondents for the study involved using a snowball sampling method and convenience and purposive sampling strategy. The study's respondents are construction professionals with a solid understanding of infrastructure delivery. Brief details were given to the respondents on what digitalisation through unmanned aerial vehicles (UAVs) entails. The survey was administered to the respondents via online survey forms. The administered questionnaire consists of four sections, the first section solicits information about the background of the respondents, the second section collected information on state of the art of adoption of drones and use cases, while section three retrieved information on the perception towards adoption and the challenges of adoption. The benefits of adoption and impact of design factors, social factors, legal factors, and financial factors on adoption are examined in section four of the questionnaire survey. A 5-point Likert scale (1 = strongly disagree, 3 = neutral/no comment, 5 = strongly agree) was employed to evaluate the perception of the respondents because it does not overburden the respondents and has been employed in similar studies. To ensure all challenges were fully captured and to identify challenges not captured, the questionnaire also requested options for participating professionals to indicate factors not identified. The participants, however, identified no other challenging factor. Before the main survey distribution, the questionnaire underwent piloting.

Received responses from three targeted countries (Nigeria, South Africa, and the United States) accumulated feedback from 161 surveys, which we analysed and have presented in this study. The selected sample areas were chosen purposively to solicit information based on country comparison between the USA, an area much advanced in drone adoption, and sub-Saharan Africa. The questionnaire return ratio was difficult to calculate because a snowball sampling method was used. However, the total number of 161 responses was deemed suitable, as the focus on the survey was on specific countries and the number of responses was more than the minimum threshold of 30 for the central limit theorem.

Statistical Tools for Data Analysis

Several statistical techniques and tools were used to analyse the data gathered during the investigation: (a) Cronbach's (α) alpha reliability test; (b) mean score ranking and standard deviation (SD); (c) ANOVA—post hoc Tukey tests and correlation analysis were the inferential statistical tests used; (d) factor analysis and groupings were used to categorise the factors. As highlighted by Field [36], a reliability test must be performed before conducting additional analysis on a collection of data. The Cronbach alpha reliability test was used to ascertain if the survey tool rightly uses the associated scale. Cronbach's alpha coefficient, which ranges from 0 to 1, is used to assess a construct's internal consistency and dependability [32]. It signifies that the scale's reliability depends on the α-value [37]. The average values of a group of figures are shown by the arithmetic mean, which is a measure of central tendency (Equation (1)). At the same time, the standard deviation is a numerical indicator of how far each number deviates from the mean and serves as a gauge of variability (see Equation (2)). While a high SD suggests that the data points are dispersed throughout a wide range of values, a low SD suggests that the values are close to the mean. The inferential statistical method ANOVA (analysis of variance) is used to assess whether there are any statistically significant differences between the means of two or more independent datasets. Typically, distributed data points are needed for ANOVA. The post hoc Tukey test is characterised as an a posteriori test because it is only required to validate and identify the locations of group differences after an ANOVA analysis has shown which groups are statistically significant. Section 4.5 explains the full details of the factor analysis conducted.

$$\bar{x} = \frac{\sum \chi}{n} \tag{1}$$

$$SD = \sqrt[n]{\frac{\sum \left(x - \bar{x}\right)^2}{n - 1}} \tag{2}$$

where $\bar{x} = mean\ score$, $\sum x$ = aggregate score of a set of values, x = number of values (that is, the number of respondents in this study), and $SD = Standard\ deviation$.

The α-value for this study was 0.946, which is greater than the 0.70 minimal criterion [32]. This suggests that the data have strong internal consistency and are appropriate for additional statistical investigation. When two or more factors have the same mean value for the mean ranking, the factors are sorted using their SD values; the factor with the lower SD value is given a higher ranking. However, if their mean and standard deviation values are equal, they will be ranked equally [24].

4. Results

4.1. Background Information

The section provides important background details on the 161 respondents who participated in the poll. The respondents, as presented in Figure 1, were from three different countries: South Africa (55%), Nigeria (27%), and the United States (18%). The respondents, as presented in Figure 2, were key built environment professionals: engineers (civil, M&E building services, 30%), project managers (29%), construction project managers (9%), architects (15%), and quantity surveyors (15%). The level of awareness assessment of the participants, as shown in Figure 3, reveals that a significant percentage of the respondents have at least a very high level of awareness (47%), a high level of awareness (37%), average awareness (10%), low awareness (4%), and very low awareness (2%). Meanwhile, the respondent's organisational setup, as shown in Figure 4, reflects construction project consultants (32%), built environment researchers (30%), built environment postgraduate students (16%), private clients (5%), government employees (4%), drone design/technology experts (4%), certified UAV/UAS/RPAS pilots (2%), drone manufacturers (2%), drone design and operations consultants (1%), construction manufacturers/suppliers (1%), drone consultants (1%), and drone usage enthusiasts (1%).

The findings also revealed increasing drone uptake, with 32% of the respondents revealing they use drones for construction site digitalisation purposes. In comparison, 13% indicated they had used drones for research purposes, and 55% indicated no drone usage. To support these findings, the number of drones procured and used was examined, and 79% of the participants revealed that they have used 1–2 drones, 10% indicated they have used 3–4 drones, 6% indicated that their organisations have procured 5–6 drones, and 5% mentioned the procurement of 7–9 drones. In terms of the preferred usage or industry uses of unmanned aerial vehicles for construction site digitalisation, the respondents revealed, as shown in Figure 5, that productivity monitoring is the highest (35%), followed by construction quality/site inspection with 17%, construction safety monitoring with 13%, building surveying with 12%, research design studies with 6%, construction site photography with 3%, site mapping/land surveying with 2%, and security surveillance with 2%. However, the following use cases were ranked low, with 1% each: construction project tour/site planning, damage assessment, material inventory, spatial measurement, thermal imaging, site live streaming, construction consulting, building facility maintenance, and disaster monitoring management. Drones' usage for construction site digitalisation is an emerging applications area, with 80% of the participants only adopting them in the past 1–2 years, 11% in the past 3–4 years, 5% in the past 5–6 years and 4% in the past 7–8 years.

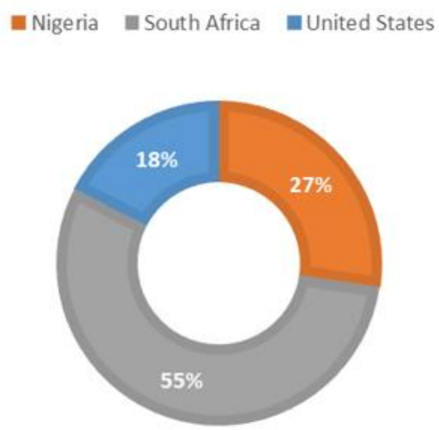


Figure 1. Countries of survey respondents.

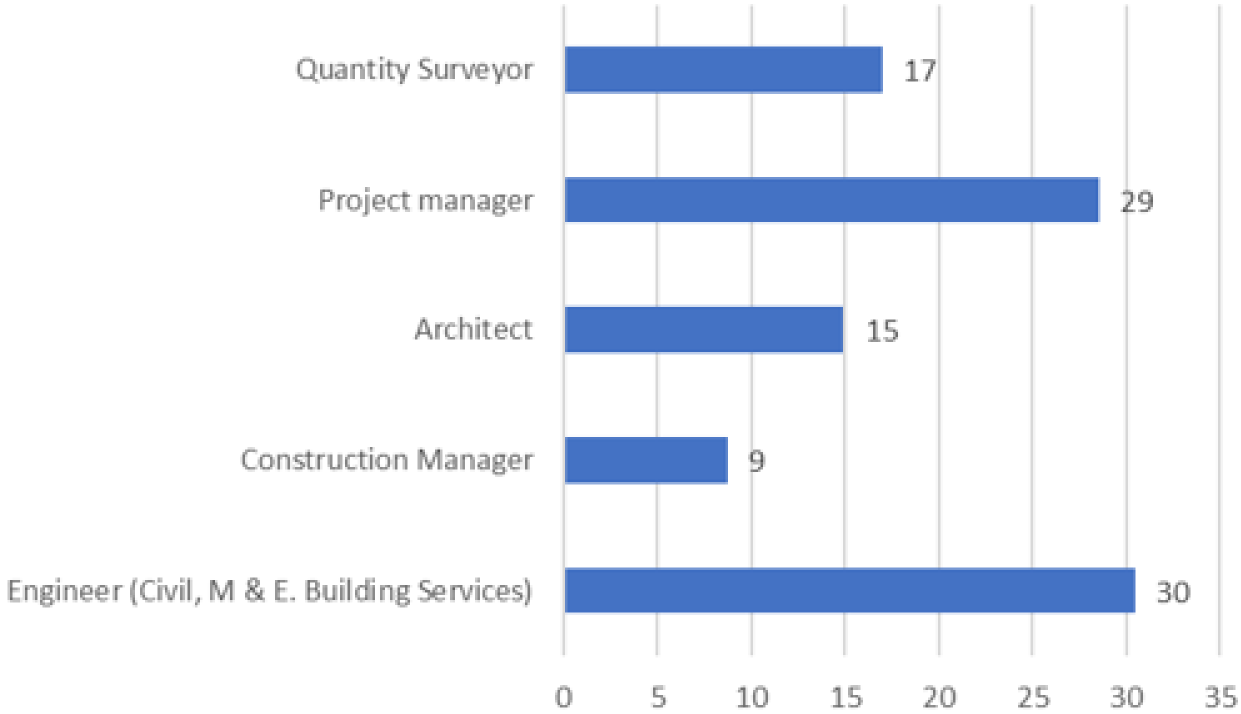


Figure 2. Professional disciplines.

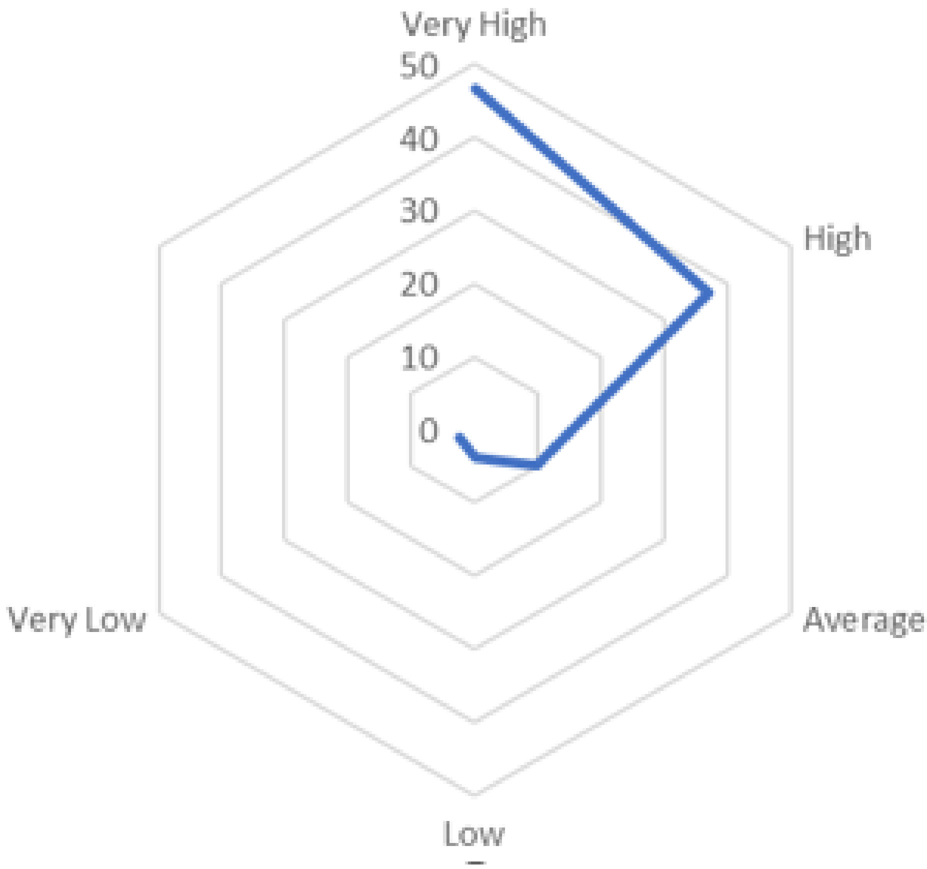


Figure 3. Level of awareness.

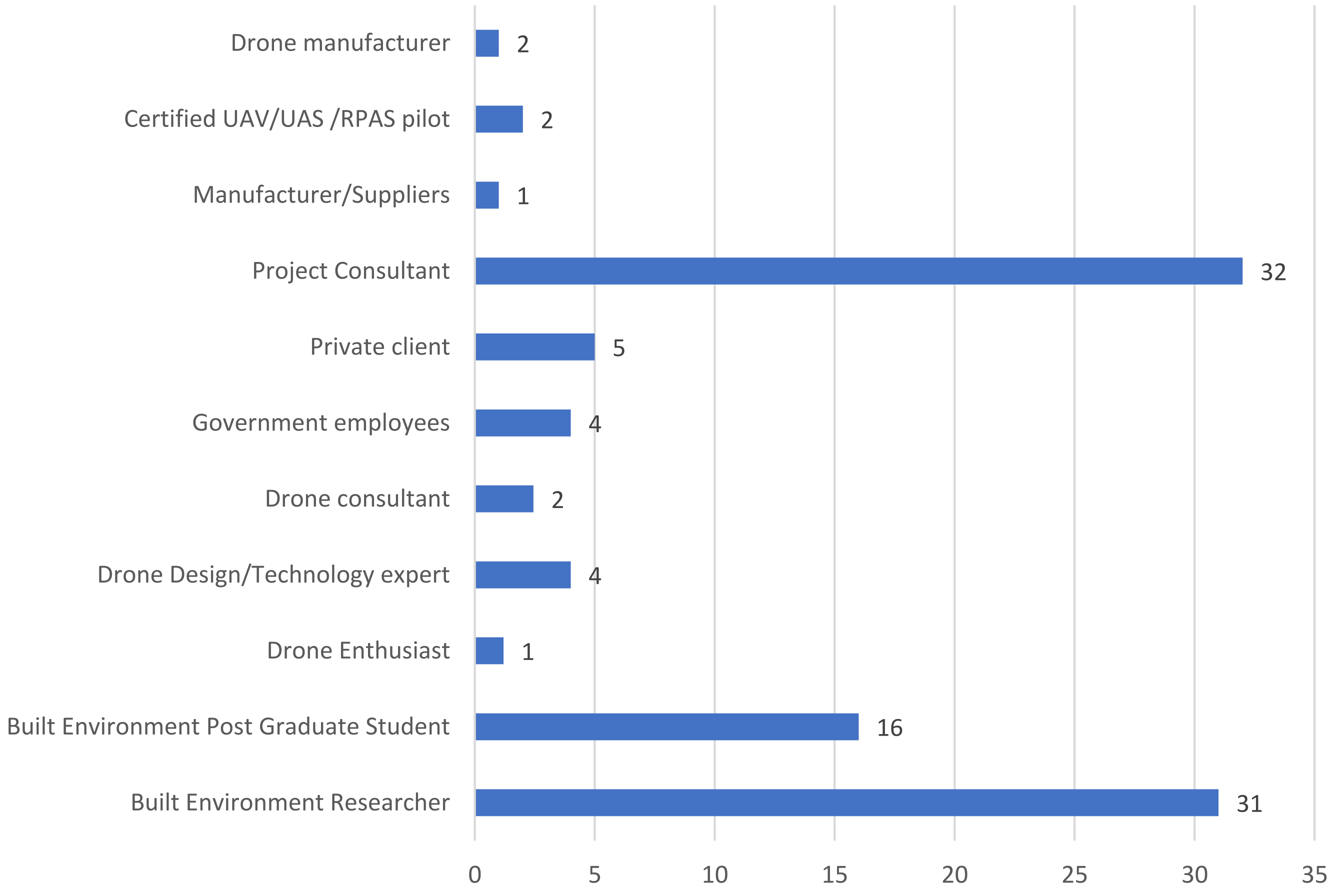


Figure 4. Organisational setup.

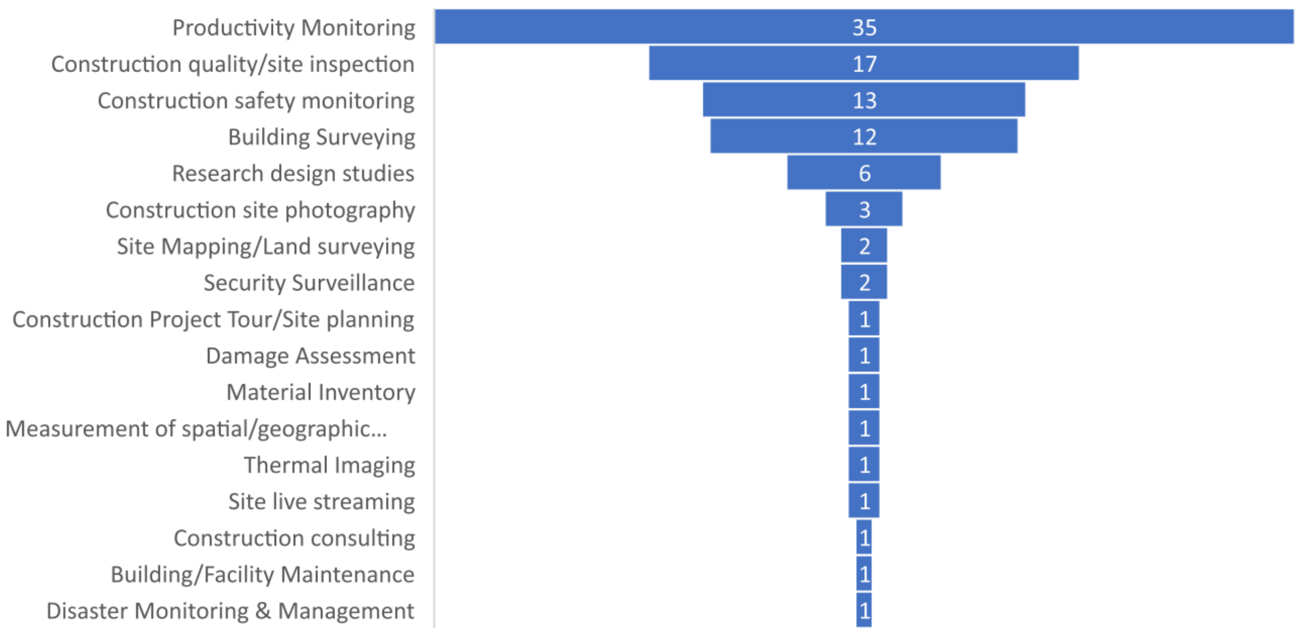


Figure 5. Application of drones in construction process.

4.2. Results of Statistical Analyses

This section explains the findings of the study's statistical techniques and the data obtained from the questionnaire surveys.

Descriptive Statistical Tests

For the twenty challenges (see Table 1) identified, the results are explained and presented using the mean values and standard deviation. The respondents identified as engineers pointed out "C11—High initial capital investment" (M = 3.3365, SD = 1.18) as the most significant challenge to adopting unmanned aerial vehicles in construction site digitalisation. This is supported by project managers, who also identified it as the most significant barrier. However, it was rated as the second most important challenge by quantity surveyors, who rated "C18—Cost of maintenance and software subscription cost" as the most significant challenge. Similarly, architects also identified this as the most significant challenge. Construction managers indicated "high initial capital investment" as the third most significant challenge, while the professionals ranked "C14—Limitations to project types" (M = 2.7143, SD = 0.97) as the most significant challenge. The results from the different professions demonstrate that respondents perceive cost-related factors such as cost of uptake, maintenance, and software subscriptions as significant barriers to unmanned aerial vehicle adoption. This is also more prevalent with respondents from small organisations, indicating cost as a critical challenge amongst small and medium enterprises (SMEs).

"C12—The cost of switching brand/product" is considered the least important challenge by the project managers, architects, and quantity surveyors. This suggests that going by the high initial capital investment in procuring the solutions, most users prefer to maximise the benefits of procured brands/products as against incurring further costs from trying out new products/brands. Engineers consider "C14—Limitations to project types" as the least significant barrier. This could result from various drone solutions for civil engineering projects with external and internal applications in infrastructure development.

Delgado et al. [38] analysed the industry-specific impediments to robotics adoption in the construction industry and identified high capital investment as a critical defining factor.

Table 1. Summary of identified challenges to adopting unmanned aerial vehicles (UAVs) for construction site digitalisation.

Code	Challenges	Related Sources of Data
C1	Regulations limiting operational clearances for flying drones	[31,39,40]
C2	Lack of training in AEC education	[3,41,42]
C3	Legal bottlenecks restricting beyond visual line of sight (BVLOS) operations	[31,43–45]
C4	Training cost	[2,7,46]
C5	Justifying cost–benefit use	[20,47]
C6	Low awareness in the industry	[2,8,47]
C7	Difficulty finding qualified pilots	[31,42,45]
C8	Difficulty getting safety or industry-specific training	[45,47,48]
C9	Public privacy and safety concerns	[7,49–51]
C10	Slow adoption in construction	[7,44,49]
C11	High initial capital investment	[7,44,49]
C12	Cost of switching brand/product	[8,13,45]
C13	Data processing software	[45,52,53]
C14	Limitations to project types	[45,47,52]
C15	Visibility in night operations	[31,45,47]
C16	Extensive training or certification requirements	[45,50,54]
C17	Liability and litigation from damage or injuries	[42,44,53,55]
C18	Cost of maintenance and software subscription cost	[44,50,52]
C19	Disposition of clients and project stakeholders	[8,44,54]
C20	Interoperability with existing systems	[8,44,52]

4.3. Inferential Statistical Tests

To better explore the perceptual variations among the many respondents from various professions (architects, engineers, project managers, quantity surveyors, and construction managers), as highlighted by Olawumi and Chan [32], ANOVA, a parametric statistical technique based on the mean of scores, is advised for this purpose and a post hoc Tukey's test for factors that are significant at $p < 0.05$.

Statistical Tests Based on Professional Disciplines

The data underwent ANOVA analysis, which uncovered a sizable difference in the viewpoints (at significance < 5%) among the group of participants on three factors, which are "C2—Lack of drone training in AEC education" [F(3.128) = 0.80, $p = 0.046$), "C3—Legal bottlenecks restricting beyond visual line of sight (BVLOS) operations" [F(3.785) = 1.24, $p = 0.043$), and "C5—Justifying cost–benefit use" [F(3.205) = 1.12, $p = 0.034$). The finding is consistent with previous studies that have identified a lack of capacity development in training, reskilling, and education as limiting digitalisation efforts of the construction industry [39–41]. Moreover, regulatory policies guiding the use of drones to avoid issues such as privacy and collision with wildlife or aircraft are critical challenges [6,10]. The third most significant impediment identified by the post hoc Tukey tests revealed that depending on project types, professionals are careful to adopt drones as they are not convinced of the cost–benefit of digitalising construction processes through drones. The outcomes of the post hoc Tukey tests for the professional disciplines are shown in Table 2. The findings of the conducted ANOVA analysis revealed some significant differences in respondents' opinions from various organisational setups (at a significant level of 5%).

Table 2. Post hoc Tukey test for professional disciplines.

Factors	Organisational Setups	Significance	Factors	Organisational Setups	Significance
C2	Project Manager vs. Quantity Surveyor	0.046	C5	Engineer (Civil, M&E Building Services) vs. Quantity Surveyor	0.064
C2	Quantity Surveyor vs. Project Manager	0.046	C5	Engineer (Civil, M&E Building Services) vs. Project Manager	0.034
C3	Engineer (Civil, M&E Building Services) vs. Project Manager	0.043	C5	Construction Manager vs. Project Manager	0.043
			C5	Project Manager vs. Construction Manager	0.043
			C5		

4.4. Challenges to Construction Site Digitalisation through Unmanned Aerial Vehicles (UAVs)—Inter-Group Comparisons

The analysis of the inter-group comparisons on the perception of challenges inhibiting UAVs adoption in the built environment revealed significant differences on nineteen factors from the ANOVA conducted. The factors were "C11—Cost of procurement" [M = 3.30, SD = 1.18, $p < 0.001$], "C1—Regulations limiting operational clearances for flying drones" [M = 3.29, SD = 1.17, $p < 0.001$], "C5—Justifying cost–benefit use" [M = 2.80, SD = 1.12, $p < 0.009$], "C18—Cost of maintenance and software subscription cost" [M = 2.65, SD = 1.22, $p = 0.001$], "C3—Legal bottlenecks restricting beyond visual line of sight (BVLOS) operations [M = 2.63, SD = 1.24, $p = 0.003$], "C8—Difficulty getting safety or industry-specific training [M = 2.35, SD = 0.92, $p = 0.021$], "C4—Limited training cost" [M = 2.24, SD = 0.95, $p = 0.017$], "C16—Extensive training or certification requirements" [M = 2.24, SD = 1.00, $p < 0.001$], "C2—Awareness and lack of drone training in AEC education" [M = 1.04, SD = 0.80, $p = 0.010$], "C7—Difficulty finding qualified pilots" [M = 1.91, SD = 0.80, $p < 0.001$], "C15—Visibility in night operations" [M = 1.84, SD = 0.84, $p < 0.001$], "C6—Low awareness in the industry" [M = 1.83, SD = 0.80, $p < 0.001$], "C9—Public privacy and safety concerns" [M = 1.82, SD = 0.89, $p < 0.001$], "C20—Interoperability with existing systems" [M = 1.81, SD = 1.23, $p < 0.001$], "C14—Limitations to project types" [M = 1.58, SD = 0.97, $p < 0.001$], "C13—Data processing software" [M = 1.57, SD = 0.84, $p < 0.001$], "C10—Slow adoption in construction" [M = 1.55, SD = 0.87, $p < 0.001$], "C19—Disposition of clients and project stakeholders" [M = 1.33, SD = 0.81, $p < 0.001$], "C12—Cost of switching brand/product" [M = 1.33, SD = 0.83, $p < 0.001$]. The results are shown in Table 3.

Table 3. Inter-group Comparisons on impediments.

	Engineer (Civil, M&E Building Services)		**Quantity Surveyor**		**Construction Manager**		**Architect**		**Project Manager**		**Overall**				
	Mean	**R**	**Mean**	**R**	**Mean**	**R**	**Mean**	**R**	**Mean**	**R**	**Mean**	**SD**	**R**	**F**	**Sig.**
C13	1.2653	15	2.1250	18	2.2143	17	1.5417	18	1.3043	18	1.57	0.84	17	10.746	<0.001
C7	1.6939	12	2.1667	12	2.5714	8	2.0417	12	1.6304	11	1.91	0.80	11	7.019	<0.001
C2	1.8163	11	2.1667	11	2.0714	20	2.1250	11	1.7391	10	1.94	0.80	10	3.128	0.010
C6	1.6531	13	2.1667	15	2.5714	7	1.7083	15	1.5652	15	1.83	0.80	13	7.928	<0.001
C15	1.8163	10	1.2917	6	2.2857	12	2.4167	6	1.6087	12	1.84	0.84	12	9.111	<0.001
C14	1.0204	20	2.1250	17	2.7143	1	1.6250	17	1.3913	16	1.58	0.97	16	15.724	<0.001
C18	3.2041	5	2.2500	1	2.2857	7	2.8333	1	2.2609	6	2.65	1.22	4	4.291	0.001
C16	1.9388	9	3.9167	8	2.1429	18	2.3333	8	1.5870	13	2.24	1.00	9	43.675	<0.001
C20	1.0204	19	3.8750	16	2.5000	9	1.6250	16	1.3478	17	1.81	1.23	15	56.736	<0.001
C12	1.0204	18	1.2500	20	2.3571	11	1.4583	20	1.1739	20	1.33	0.83	20	12.630	<0.001
C19	1.0204	17	1.2500	19	2.2143	16	1.4583	19	1.2174	19	1.33	0.81	19	11.155	<0.001
C1	3.3265	2	4.8750	3	2.7143	4	2.7500	3	2.8913	2	3.29	1.17	2	17.735	<0.001
C11	3.3265	1	4.8750	2	2.7143	3	2.7500	2	2.9348	1	3.30	1.18	1	16.639	<0.001
C5	3.2449	3	2.2500	5	2.7143	2	2.5417	5	2.7609	3	2.80	1.12	3	3.205	0.009
C17	2.6939	6	2.2083	10	2.6429	6	2.2917	10	2.3913	4	2.48	0.79	6	2.214	0.056
C9	1.4286	14	2.1250	14	2.5000	10	1.7917	14	1.7826	9	1.82	0.89	14	6.401	<0.001
C8	2.6122	7	2.2083	9	2.6429	5	2.2917	9	2.0435	7	2.35	0.92	7	2.749	0.021
C4	2.4898	8	2.2083	7	2.2143	15	2.3750	7	1.8696	8	2.24	0.95	8	2.866	0.017
C10	1.2245	16	1.2500	13	2.0714	19	1.8750	13	1.5870	14	1.55	0.87	18	6.889	<0.001
C3	3.2041	4	2.2500	4	2.2857	13	2.6250	4	2.3043	5	2.63	1.24	5	3.785	0.003

4.5. Comparative Barriers between Countries

Table 4 shows the result of the country comparison. This is essential to understand how socio-economic realities amongst the countries influence adoption and progress. As seen in Table 4, in the Nigerian context, the top-ranked barrier is "high initial capital investment", with a mean of 2.938. This barrier is also ranked as the first by respondents from South Africa, with a mean of 3.1932. However, it is surprising that the barrier is not considered as the most critical barrier by respondents in the United States, who identified regulations surrounding drone usage as an important factor affecting drone adoption, with a mean score of 4.3214. The pattern revealed in the country comparison shows that economic factors are critical for Nigeria and South Africa in adopting drones for construction digitalisation, while technical and regulatory factors are more pronounced as a barrier towards adoption in the United States. The socio-economic situations could be a reason for these disparities, as well as awareness level differences between the countries.

4.6. Classification of the Key Barriers Based on Factor Analysis

We adopted factor analysis to categorise the challenges into key components by examining the correlations between the different variables. The fundamental tenet of factor analysis (FA) is that underlying dimensions or factors can explain complex phenomena. The FA method was applied in this study to determine the underlying challenges to construction site digitalisation through the adoption of unmanned aerial vehicles (UAVs). By calculating the total percentage of variance explained by each factor, the number of factors needed to represent the dataset was established. Because of its simplicity and unique capacity for data reduction for factor extraction, principal component analysis was chosen for this inquiry to identify the underlying factors. Factor extraction with varimax rotation was used to extract major factors for a sharper image using the SPSS FACTOR program. KMO statistics range from 0 to 1. A score near 1 denotes relatively compact patterns of correlations, and FA would produce distinct and trustworthy components. The KMO value must exceed the allowable threshold of 0.5 for a successful FA to continue. Bartlett's test of sphericity was also run to emphasise the presence of correlations among the variables and to support the appropriateness of component analysis.

The idea that the correlation matrix is an identity matrix, indicating that there is no relationship between the items, is tested using this method. Principal component analysis (PCA) and the Promax rotation method are two-factor analysis methods. This study made use of PCA. The PCA was carried out on the 20 identified challenges using the varimax rotation approach (an orthogonal rotation method). Table 5 displays the factor analysis findings; the "factor loading" column shows how much of the overall variance is explained by each component. As highlighted by Lingard and Rawlinson [56] and Xu et al. [57], in the ratio of 1:5 (number of variables: sample size), which the current study satisfied, the sample size must be deemed sufficient. Five samples are needed for each barrier factor, and multiplied by 20 equals 100 samples required to go ahead with the FA.

Table 4. Country comparison.

S/N	Impediments	Nigeria		South Africa		United States of America	
		Mean	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**
1	Regulations limiting operational clearances for flying drones	2.3182	6	2.9205	4	4.3214	1
2	Lack of training in AEC education	2.0682	9	1.9205	10	2.0357	14
3	Legal bottlenecks restricting beyond visual line of sight (BVLOS) operations	2.0000	11	1.2841	17	2.0714	9
4	Training cost	2.4545	5	1.8977	11	2.0357	11
5	Justifying cost–benefit use	2.5682	4	2.4773	7	2.0357	12
6	Low awareness in the industry	1.9773	12	1.2841	18	2.0357	13
7	Difficulty finding qualified pilots	1.5000	18	2.9091	5	4.3214	2
8	Difficulty getting safety or industry-specific training	2.3182	7	2.7045	6	2.0714	7
9	Public privacy and safety concerns	1.5909	17	1.7955	12	2.0714	5
10	Slow adoption in construction	2.0455	10	1.9659	9	2.0357	15
11	High initial capital investment	2.9318	1	3.1932	1	2.0714	6
12	Cost of switching brand/product	1.8864	13	1.7614	13	2.0357	16
13	Data processing software	1.7727	16	3.1818	3	1.2857	20
14	Limitations to project types	2.0909	8	3.1477	2	1.3214	18
15	Visibility in night operations	1.5000	19	1.2614	19	1.2857	19
16	Extensive training or certification requirements	1.8864	14	1.7386	14	3.5357	3
17	Liability and litigation from damage or injuries	1.7955	15	1.6477	15	3.5357	4
18	Cost of maintenance and software subscription cost	2.8636	2	1.4205	16	2.0714	10
19	Disposition of clients and project stakeholders	2.6136	3	1.2500	20	1.3214	17
20	Interoperability with existing systems	1.5000	20	2.3864	8	2.0714	8

Bartlett's test of sphericity (BTS) and Kaiser–Meyer–Olkin (KMO) tests for sampling adequacy were employed to determine whether PCA was a suitable method for factor extraction [58]. The factor analysis for the study's KMO value is 0.689, demonstrating an acceptable level of common variance. A KMO value over 0.5 and a significance level for Bartlett's test below 0.05 suggest a substantial correlation in the data [59,60]. Bartlett's test of sphericity tests the hypothesis that the variables correlation matrix is an identity matrix.

This test statistic follows a Chi-square distribution with k-1 degrees of freedom. According to the BTS analyses, the test statistic value was quite high (Chi-square = 3704.055) and with a small significance value ($p < 0.001$, ds = 117), which, per [32], indicates that the correlation matrix is not the same as the identity matrix. As a result, the PCA can be used in this study for further inquiry and discussion because the numerous prerequisites needed to proceed with a factor analysis have been satisfied. This guarantees that the research can be carried out reliably and confidently. Three underlying factors were identified to account for 89% of the total variance (see Table 5), which is above the minimum threshold of 60% [61–63]. The challenges highlighted are represented in one of the underlying three dynamics. All the factor loadings for each identified barrier factor are close to 0.5 or higher, as explained in previous studies [63]. Xu et al. [57] pointed out that an individual factor's factor loading value, which can be as high as 1.0, indicates how significant the component is to the underlying cluster factor. Invariably, the factor loading values also demonstrate the contribution of each component to its fundamental grouping component [60,64].

Table 5. Factor structure of the key impediments to drones' adoption for construction site digitalisation.

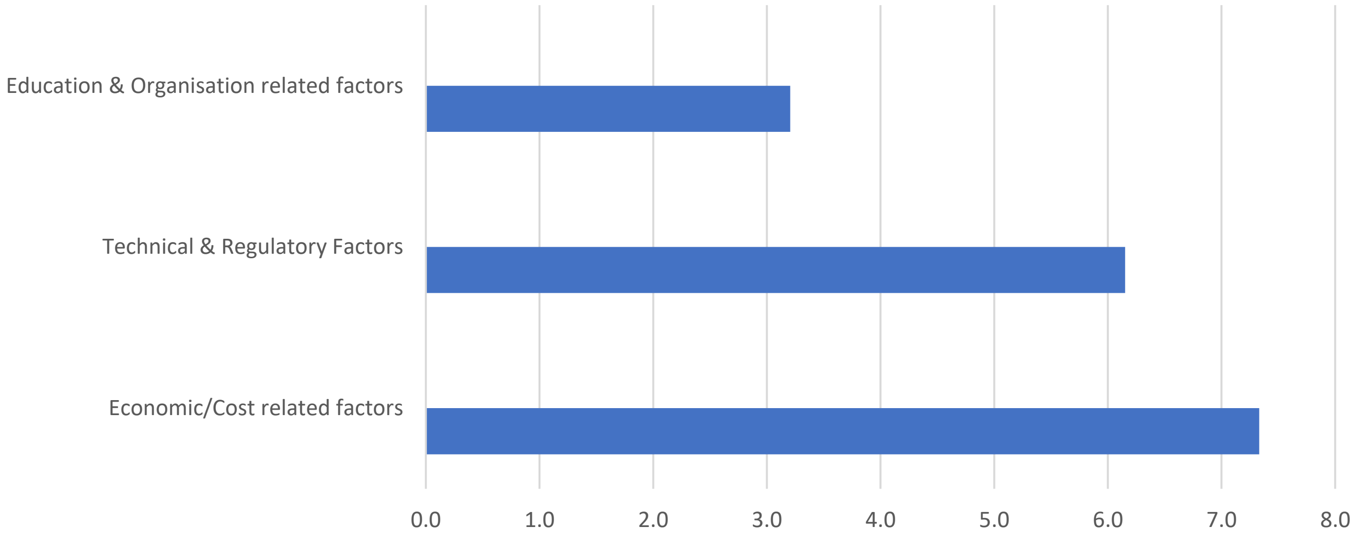
Code	Challenges to Implementing	Factor Loading	Eigenvalue	Percentage of Variance Explained	Cumulative Percentage of Variance Explained
Technical and Regulatory Factors			10.764	36.599	36.599
C1	Regulations limiting operational clearances for flying drones	0.961			
C3	Legal bottlenecks restricting beyond visual line of sight (BVLOS) operations	0.955			
C17	Liability and litigation from damage or injuries	0.952			
C8	Difficulty getting safety or industry-specific training	0.915			
C9	Public privacy and safety concerns	0.868			
C20	Interoperability with existing systems	0.655			
C13	Data processing software	0.634			
C14	Limitations to project types	0.625			
C15	Visibility in night operations	0.619			
C1	Regulations limiting operational clearances for flying drones	0.961			
Economic/Cost-related factors			4.768	35.442	72.041
C11	High initial capital investment	0.923			
C4	Training cost	0.919			
C5	Justifying cost–benefit use	0.893			
C12	Cost of switching brand/product	0.888			
C18	Cost of maintenance and software subscription cost	0.887			
C10	Slow adoption in construction	0.845			
Education and Organisation-related factors			2.279	17.018	89.059
C2	Lack of training in AEC education	0.836			
C6	Low awareness in the industry	0.835			
C7	Difficulty finding qualified pilots	0.794			
C16	Extensive training or certification required	0.741			
C19	Disposition of clients and project stakeholders	0.657			

5. Discussion of Survey Findings

5.1. Discussion of Key Cluster Factors after Factor Analysis

The grouped barriers are analysed as shown in Figure 6 in order of decreasing importance for evaluating the individual aspects connected to them. As recommended by Sato [65], each group of factors with high correlation coefficients, which are themselves a collection of unique factors, has a distinct and collective name. However, Olawumi and

Chan [63] stated that these designations are arbitrary, and different authors may assign various labels. The factor clusters are rated according to [32]. The ratio of the mean of each factor inside a cluster divided by the total number of factors within the cluster is the factor scale rating [66]. The main factor clusters that will be discussed are the three identified factors. This is in line with previous studies that discussed three basic factors [57,63]. The factor scale rating analysis is also used to uncover more relevant cluster factors with relatively low levels of increased rating values for discussion [67].



	Economic/Cost related factors	Technical & Regulatory Factors	Education & Organisation related factors
Ranking	1	2	3
Factor Scale ranking	7.331	6.152	3.206

Figure 6. Factor scale ranking of impediments.

5.1.1. Economic/Cost-Related Factors

Factor 2, comprising six barrier-related factors, is the highest-rated grouped factor, with a factor scale rating of M = 7.331. The cluster is related to high initial capital investment, training cost, justifying cost–benefit use, cost of switching products, cost of maintenance, and slow adoption in the industry. This is supported by Olawumi and Chain [32], who identified market-related factors as highly significant in construction site digitalisation. The high initial capital investment cost is a significant barrier to digitalisation efforts. It entails the cost of procuring the drones and accompanying software, yearly licensing cost, maintenance, and cost of replacement of drones, as they are prone to being lost during flight. As stated by Aiyetan and Das [2], the high cost of procuring drones is seen in commercial products that cost up to USD 100,000 and beyond, with accompanying costs of personnel, training, software, and data interpretation. Onososen et al. [68] affirm this. They noted that the complexity and dynamic nature of the construction sector make the cost of adopting new technologies a risk for most organisations. However, for some organisations yet to explore these solutions, the main obstacle preventing construction companies from adopting cutting-edge technologies is the belief that doing so will be expensive. This is also influenced by stakeholders' scepticism of investment in digitalisation yielding tangible gains for the organisation.

However, while the initial investment is high, it justifies the benefits that drone usage offers, as UASs can carry out similar activities to those carried out by manned vehicles but more rapidly, safely, and affordably [7]. Gheisari and Esmaieli [8] highlighted that employing UASs may result in cost reductions. For instance, if a single person can operate the UAS, the cost of inspecting communication towers may be reduced as tower scaling typically takes a crew of at least two people. Justifying cost–benefit use is an important factor, as unclear benefits of drone adoption for construction enterprises can limit interest and eliminate adoption. The need for comprehensive cost–benefit analyses from academia on implementing drones is crucial as a strategy to overcome this barrier [38]. As shown by the variables influencing the usage of drones in construction, which include budget availability for drone purchases, drone operation, maintenance, and data storage, analysis, and interpretation, government intervention in partnership with the private sector and design companies to subside the costs of investment is important to overcome these challenges [2].

5.1.2. Technical and Regulatory Factors

This group comprises the practical constraints on the application of UAVs towards achieving construction site digitalisation. The next significant clustered factor is factor 1, with ten key factors and a factor scale rating of M = 6.152. The cluster is focused on regulations limiting operational clearances for flying drones, legal bottlenecks restricting beyond visual line of sight (BVLOS) operations, liability and litigation from damage or injuries, difficulty getting safety or industry-specific training, and public privacy and safety concerns. Other key technical and regulatory barrier-related factors also include interoperability with existing systems, data processing software, limitations to project types, visibility in night operations, and regulations limiting operational clearances for flying drones. In a study by Gheisari and Esmaiaeli [8], they indicated legal and liability issues as the most critical barriers. Previous studies have also identified technical factors as the second most important barrier to digitalisation [69]. However, recent technological developments in the design of UAS have made it possible to create new, inexpensive, lightweight aerial systems with improved battery life, GPS navigation capabilities, and control dependability [7]. While over the past ten years, the availability of such affordable and simple-to-fly UASs has greatly increased, their utilisation adoption is still low.

A breach of employee privacy was one of the most often cited obstacles to deploying UASs for safety applications [8]. According to the authors, utilising these devices will reduce employee morale since people would think that the organisation is spying on them, which affects the level of trust on the site. Moreover, due to their recent introduction to the construction industry, UAVs can cause serious worker distractions. Workers may become distracted by the sound or sight of UAVs, which will interfere with their work [3]. Utilising UASs for inspection presents two difficulties: UAS safe flight requirements and post-processing images and data [8]. Stabilisation of the flight platform, anti-collision navigation, and path planning algorithms are required to increase UAS-safe flight requirements.

Since it causes technical issues such as the loss of data collected by the device in one or more instants of time during the flight and even legal misunderstandings when the drone flies over forbidden or private areas, the issue of loss of line of sight when operating drones has become a reality with negative effects for professional and amateur drone operators [31]. Murillo et al. [31] further identified critical challenges in line with technical and regulatory requirements, including the overflight of forbidden areas, the breaching of height restrictions already established under various legislative frameworks, and restrictions on daytime flights, among others which a variety of circumstances has impacted. Another issue is the possibility of the UAV losing control. Interference could happen and prevent the operator from knowing the device's state at those times, which could result in accidents and even the possibility of death. To resolve these challenges, attention must be paid to ensure that drone flight restriction is enforced within a maximum height and spatial range (geofence) [45].

To combat this challenge, several developed nations, including the United States, the United Kingdom, Germany, France, Australia, and Japan, have established policies, rules, and regulations for the use of drones [2]. As mentioned by Aiyetan and Das [2], governments in developing nations have recently passed laws and rules governing airspace and flying credentials expressly for commercial use. This is to ensure that UAVs do not clash with flight movement, wildlife, national security infrastructure and restricted heritage.

Additionally, a pilot's license for using drones for business purposes has become mandatory [15]. While these regulations regarding the usage of drones are not comprehensive, it provides an opportunity for public–private stakeholders' partnership to collaborate on driving safe adoption of UAVs towards construction site digitalisation.

Other technical and social concerns are on misdelivery, fear of drones taking over jobs, less pleasant skies, less human interaction, the noise of drones on construction sites, safety of humans in the site environment, transport safety, the package being stolen, risk of malfunction mid-flight, violation of privacy, transportation of illicit goods, and intentionally injuring people, which are factors critical to address to reduce drone adoption aversion [17].

5.1.3. Education and Organisation-Related Factors

Factor 3 includes five barriers, each with a factor scale rating of M = 3.206, which are connected to lack of training in AEC education, low awareness in the industry, difficulty finding qualified pilots, extensive training or certification required, and disposition of clients and project stakeholders. In developing the capacity of professionals, previous studies have indicated that there has been little to no focus on training construction professionals to increase their knowledge and expertise in the application of unmanned aerial vehicles (UAVs) in construction [32,70,71]. Despite the opportunities unmanned aerial vehicles (UAVs) provide to realising resilient and responsive infrastructure development through construction site digitalisation, the current skills scarcity in the industry has diminished the potentiality of their positive impact on building processes. The population's acceptance and attitude toward drones positively correlate with their knowledge level and technical interest [17]. Users of drones typically have more awareness and acceptance of them and generally support less stringent criteria and identifications for the flights of drones [17]. Rapid technological development has decreased the workforce's ability to adapt, given the variety of systems and digital tools emerging [32]. However, reskilling professionals to acquire this expertise is inevitable for future work in a digitalised construction sector [6,72]. To achieve this, Olawumi and Chan [32] pointed out that professional organisations and construction companies should work together to enhance the capacities and skill sets of their members and staff in developing emerging digitalisation expertise. Moreso, the authors explained that early instruction on these ideas helps pupils understand them better and provides an edge after graduation. For training and reskilling initiatives in education to succeed, the government can help this endeavour by training its employees in parastatals and departments connected to construction and by giving financial assistance to private companies to train their personnel.

Unmanned aerial systems (UASs) are becoming more and more popular across the whole Construction, Engineering, and Management (CEM) domain [73]. Current CEM students are urged to advance their drone flight operating skills as drone-mediated building inspection grows in popularity across inspection disciplines and becomes more standardised in the industry [53]. This is highly important as previous studies such as Albeaino et al. [53] have identified the difficulty of safely navigating the drone in complex environments as emanating from a lack of adequate capacity development approaches and training. Recent developments are looking at virtual reality to train users to undertake drone piloting in complex environments. The use of virtual environments in drone training is critical given that the inclusion of real-world building inspection training using drones in the CEM education curriculum seems promising. Obstacles to such opportunities such as high costs of the UAS hardware components, liability and safety worries related to flying close to buildings and people, as well as the inadequate novice pilot skills require a safer approach to training. In the United States, many educational curricula have begun to incorporate drone training to deal with the rising use of this technology in the CEM realm. However, such efforts are absent in educational institutions in developing countries. Educating the next generation of construction workers is crucial, especially given the current shortage of qualified UAS pilots and safety managers on project sites [73]. Drones are becoming frequent tools for data collection, mapping, and visual inspection in architecture, engineering, construction, and facilities management and can serve various AEC course offerings and training [48]. When institutions drive capacity development in drone expertise, recent concern that exists regarding the ability and capacity of operators and pilots to meet certain requirements will be eliminated as a barrier [68].

Despite claims that technology in the construction industry is being adopted slowly, many businesses are increasingly implementing cutting-edge solutions [2,74]. This indicates that one of the crucial tactics that must be considered for using drones in construction is the development of organisational culture for adapting to technological change. This should make it easier for employees in the construction business to adopt drones gradually and reduce their reluctance to change, thereby improving their use.

5.2. Practical Implications of Research Findings

This study aimed to examine the impediments to construction site digitalisation through the adoption and usage of unmanned aerial vehicles (UAVs) in infrastructure development and delivery. According to our findings, the professionals highlighted the economic-related factors in high initial capital investment in drones. Previous studies have advocated for government incentives to enable affordability and accessibility to construction digitalisation technologies. This includes the provision of subsidies and financial resources for private clients and developers to facilitate adoption [32,74]. Furthermore, the lack of impressive awareness of the cost–benefit use of drones has influenced the ability of stakeholders to buy into adoption. It, therefore, requires the need for pilot projects and project showcases to reiterate its benefits. This will spur interest and collaborative discussions between the public and private sectors on ensuring adoption for all organisation types. The built environment may not be able to implement digitalisation without addressing these challenges. Thus, construction organisations must prioritise capacity development to ensure that workers are knowledgeable of and actively engaged in digitalisation efforts. Moreover, it is critical to restrict organisations in a way that anticipates and proactively plans for businesses to make it simpler to integrate digitalisation into their operations. The role of professional organisations in driving construction digitalisation is vital to the success of adoption efforts; these involve knowledge sessions and capacity development, policy drive, curriculum development in partnership with academia, and partnering with the government to ensure reduced capital investment for technology uptake.

To resolve these impediments, previous studies have identified the development of objective government policy, regulations, and legal provisions; the facilitation of competency development through training and piloting licenses; approval of airspace for the exclusive use of drones in and around construction sites; budgeting for drones and their operation as part of project costs; and the development of organisational cultures for embracing technological change [2,3,21].

6. Conclusions and Recommendations

This study identified and assessed the major impediments to the adoption of digitalisation in improving construction site operations, systems, workflows, and infrastructure delivery approach. The study utilised responses from 161 respondents across three countries on 20 identified barriers to adopting UAVs. The professionals come from various fields and organisational backgrounds, adding credibility to the data gathered. The study compared the perspectives of the study participants based on their professional backgrounds and organisational affiliations to identify patterns of difference. Most of the respondent groups agreed that the high initial capital investment in adopting drones is a significant barrier to implementation, which is an important finding of this study. The architects and quantity surveyors considered the cost of maintaining the technology uptake and software subscription or licensing cost undertaking yearly as a critical impediment. However, this was not considered highly significant by construction managers, who instead indicated the limitation of drone usage to project types as a critical barrier to its uptake. However, this is only temporary, as more use cases for drones are being developed alongside uses in internal and external parts of structures. Another significant research conclusion is the categorisation of the key impediments based on identified 20 challenges using factor analysis into three major factors. After evaluating the opinions of the various survey respondents, several helpful suggestions and successful methods for reducing or removing the barriers are made. These suggestions consist of (1) government intervention through credit facilities and incentives to reduce the high initial capital investment required to adopt UAVs for construction site digitalisation; (2) to develop capacity, professional organisations and construction companies should devote more time to teaching their members and employees through workshops and seminars; (3) incorporating digitalisation technologies and concepts into construction-related institutions' and departments' curricula; (4) the necessity for construction companies and other stakeholders to take the initiative to implement novel technologies.

This study analysed the challenges and limitations to the digitalisation of construction sites both qualitatively and quantitatively. Government agencies and construction stakeholders can establish a practical and informed decision-making process based on ranking the major impediments. The research's findings have added to the knowledge on digital construction sites, drone use to support the delivery of resilient infrastructure, and practical suggestions for adopting digital construction methods. The findings can be used by government organisations, stakeholders, and others as a policy tool and as helpful guidance to guarantee that UAVs can be used to fulfil the potential of digitalising construction operations and practices in the building industry. The results of this study must be put into practice, since doing so will improve the built environment's ability to maximise the benefits of perceived digitalisation in routine construction tasks. Unmanned aerial systems (UAS), which can be employed as a vehicle in various applications, are developing technology that may positively impact conventional safety inspections.

Meanwhile, it is hoped that these difficulties can be overcome or removed if policy makers and other important stakeholders consider these significant hurdles, as discovered and described in this study. Policy makers, municipal officials, practitioners, academics, and other important stakeholders can work together to address these issues. The research findings are expected to spur discussions regarding the underlying issues plaguing UAVs in digitalising construction operations. The primary distinction between this study and other extant studies is that in addition to identifying and ranking obstacles, this study also used factor analysis to specify three categories for the underlying barriers to adoption. This is a pertinent contribution because it makes it easier to comprehend and create appropriate action plans to address the poor adoption levels. Future studies could consider carrying out more research utilising qualitative or mixed-method methodologies. In addition, a comparative analysis of the perceptions held by the primary categories of respondents was carried out, analysed, and afterwards given, along with a discussion of the findings.

7. Limitations of the Study

One of the strengths of this study is that it considered the adoption of unmanned aerial vehicles (UAVs) in the digitalisation of construction site activities in three different countries of different levels of economic and technological development and located on two different continents. However, a major limitation is that involving all the built environment professionals was difficult due to the non-availability of enough builders (who are key member participants in the built environment market) across the countries studied. This could be due to the diverse meaning ascribed to the profession across the world. Some countries see the builder as an entrepreneur or a contractor who engages in building business for profit—that is, not necessarily qualified to practice building, but must engage qualified hands to execute building contracts. Others such as Nigeria regard the builder as a professional who is responsible for the technical and managerial duties of building procurement. Hence, a banker or lawyer in the business of construction may answer to builder somewhere, while only technically and academically qualified personnel who studied building engineering or technology may bear the term elsewhere (e.g., Nigeria). Furthermore, in Nigeria, where the profession is separated from a contractor, it is uncommon to see builders manage construction project sites; rather, most building and civil engineering project sites are managed by civil engineers. Additionally, most professional builders, as they are distinguished in Nigeria, have upskilled by taking additional academic and professional courses to become either construction managers or project managers. Hence, they either identify with a project manager, construction manager, or site engineer.

Although a few responses were received from builders in Nigeria, the data were considered unfit for inclusion in the analysis for two major reasons: (1) the builders seem to be lacking the requisite knowledge on the subject of this study as all the responses provided showed neutrality, which is considered a questionable coincidence; (2) no response was received from builders in either South Africa or the United States of America. Hence, to ensure a balance in comparison between the perception of the professionals on the subject, it was decided that the responses obtained from the few builders in Nigeria be dropped from the final analysis, as the outcome may lead to misrepresentation of the professional builders across the three countries.

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