Journal of Construction Engineering, Management & Innovation
2022 5(4):228-252
DOI 10.31462/jcemi.2022.04228252

RESEARCH ARTICLE

Critical success factors for implementation of Unmanned Aerial Vehicles (UAVs) in construction

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Article History

Received 17 October 2022
Accepted 06 December 2022

Keywords

Drones
Unmanned aerial vehicles
Critical success factors
Construction industry
Developing countries

Abstract

The construction industry is known for its highly fragmented, project-based, and complex nature, which generally underinvests in digitization and innovation, primarily in developing countries. This results in a lack of efficiency and low productivity levels. Integrating drones, also known as unmanned aerial vehicles (UAVs), into construction management tasks can solve this problem. Thus, this study aims to identify the critical success factors (CSFs) leading to the successful integration of UAV technology in developing countries. A total of 28 CSFs were identified based on an extensive literature review, and a questionnaire survey was administered to the public and private companies to evaluate the role of those CSFs in the performance of UAV technology. Statistical analysis results showed that effective leadership and top management support, proven effectiveness of the technology, the organization's innovation culture, and flexibility were the most important factors of success. Research findings are expected to assist drone operators and construction practitioners in effectively implementing UAV technology in construction projects.

1. Introduction

The fragmented nature of the construction industry and its slow adoption of digital technologies have been recently causing low quality, productivity, and efficiency levels. The recent COVID-19 pandemic has accelerated the use of digital tools in construction [1]. Using UAV technology is expected to enhance construction quality and productivity by improving project progress monitoring and reporting, communication and collaboration among stakeholders, and preventing construction errors and reworks [2]. First, a clear definition of UAV technology should be made. Delgado et al. [3] defined UAVs as "terrestrial, aerial or nautical vehicles, which can be piloted remotely, or which are autonomous." Ayemba [4] refers to UAVs as "flying computers carrying an array of sensors to collect data, giving companies the chance to make intelligent and educated decisions about their projects rapidly, safely, and efficiently". This study defines a drone as an unmanned aircraft known for being remotely controlled by a pilot or flying autonomously through specified flight plans.

Initially, especially during World Wars 1 and 2, UAVs were used for military purposes such as reconnaissance, surveillance, and targeted attacks.

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eISSN 2630-5771

In 2010, they started to be used more for civilian applications such as mapping and photography, agriculture, energy, inspections, surveying, and construction [5]. The 2020 Drone Industry Insights report also stated that the UAV market is projected to increase to $42.8B by 2025 at 13.8% CAGR (Compound Annual Growth Rate). Previous studies in the literature examined the opportunities, barriers, and potential applications of different types of UAVs in the construction industry, mostly in developed countries such as the U.S. and Australia [6-8]. A study done by Golizadeh et al. [7] examined the barriers to UAV technology adoption in construction, which are technical difficulties, restrictive regulatory environment, site problems, weather conditions, and organizational barriers, referring to Australian regulations as an example. Another research [9] identified problems in the management of physical progress monitoring with the implementation of UAVs, photogrammetry, and 4D BIM models. They concluded that this combination was effective for monitoring the physical progress and communications of the project stakeholders. A recent study [10] focused on the factors hindering the incorporation of UAVs in India and stated that expensive commercial solutions and high transport energy costs were significant factors for causes hindering the adoption of this technology, while the uncertain cost for maintenance and repair and deficiency of high-level computing were found as crucial factors affecting the UAV adoption.

Most studies are performed in developed countries in this research as studies before in literature [11-13]. For instance, Graham [11] studied the factors influencing the use of UAVs by specialty construction companies in the U.S.. He found that the most important factors are technological factors, followed by legal factors and human factors. Since UAV technology is novel to the construction industry, more studies are needed to understand CSFs better and develop proper strategies for its implementation in developing countries. It is essential to quantify and assess the importance level of these CSFs to achieve successful technology adoption.

Based on this background, the major objectives of the research are to (1) identify the CSFs and quantify their impact on UAV technology implementation, and (2) discover the underlying aspects of those CSFs in Turkiye, where UAV technology is relatively less common in construction. In this regard, first, a thorough literature review was carried out to gather the CSFs of UAV technology implementation. Then, these CSFs were refined to get a proper and complete set of factors. Subsequently, a questionnaire survey was prepared and administered to construction practitioners in a developing country, Turkiye. Gathered data were then analyzed to examine the experience and opinions of construction professionals in terms of UAV implementation. Factor analysis was employed to group the fundamental factors leading to a successful UAV implementation. Research results are expected to guide construction companies regarding the adoption of UAV technology in their projects.

2. UAV technology implementation in construction

Since the last decade, the integration of UAV technology in construction projects worldwide has been increasingly considered. Researchers reported different UAV applications. These applications include land surveying and 3D modeling or photogrammetry [14-16], progress monitoring and reporting [17-20], time management [16], quality inspection [21], post-disaster damage assessment [6,22,23], safety control and inspection [24-26], and promotional photography [15]. Additionally, benefits such as cost and time savings and improved quality and progress tracking were reported when using UAV technology [27].

The uninterrupted advancements in technology, along with the potential of its integration into construction projects, have induced the interest of many researchers to study the CSFs for the implementation of different kinds of innovation and technologies in the construction industry, such as UAVs, robotics, and automation systems, smart devices, information, and communication technology (ICT), etc. Previous studies also examined the barriers and opportunities for UAV technology in construction projects, which can be considered significant indicators for the CSFs for UAVs in this sector. Li and Liu [16] stated the opportunities of UAVs as well as their limitations which, if addressed correctly, may contribute to the successful implementation of UAVs in construction. As opportunities, from the social standpoint, UAVs can resolve work safety issues; from the economic standpoint, UAVs are cost-effective, reducing the costs associated with construction tasks and preventing delays; and from the environmental standpoint, UAVs are environmentally friendly since they are electric motor-driven without using fossil fuels. However, the limitations of UAVs are considered as local regulations, professional training needs, flight reliability against poor weather conditions (strong winds and heavy rains), workers' safety problems, UAV's lack of electricity capacity, and finally, the payload problem. Greenwood et al. [6] referred to the five key domains which should be considered when using UAVs in infrastructure projects. These are flight adaptation (e.g., UAV interaction with wildlife), regulatory conditions, data management, hardware maintenance, and combination with other platforms.

Furthermore, some researchers studied the critical factors affecting the implementation of UAVs in the logistics sector. Raj and Sah [28] found that technological developments, government regulations, and a skilled workforce are the most critical factors for adopting UAVs in the logistics sector. Winkler and Zinsmeister [29] found that communication between team members, data security, training of IT workforce and employees, and user acceptance are the most significant CSFs for the implementation of digitalization, including drones, in intra-logistics. Also, Sah et al. [30] identified the barriers facing the drone technology implementation in the logistics sector in the US; the most critical barriers were "regulations" and "threat to privacy and security," followed by public perception, environmental issues, technical aspects, and economic aspects, in decreasing order of their criticality.

Considering the findings of the previous studies, UAV technology is still at its infancy to understand CSFs better and develop proper strategies for its implementation in developing countries. This study aims to fill the gap in the UAV literature by improving the digitization and innovation of this technology in developing countries by using Turkish construction industry as a case study. Literature needs prominent studies that quantify and assess the importance level of the CSFs that are observed in this study to achieve successful adoption of this emerging technology.

3. Research methodology

The data collection tool used in this research is a questionnaire. The main purpose of the questionnaire survey is to investigate the CSFs for UAV technology applications in the Turkish construction industry from the perspectives of professionals working in the sector (private and public clients, contractors, subcontractors, and consultants). The survey was administered to construction companies involved in digital construction and using innovative technologies such as UAVs in their construction sites as well as information technology and R&D companies; experts and professionals working in such companies, members of the Turkish Contractors Association (TCA), Association of Turkish Consulting Engineers and Architects (ATCEA), and the Turkish Employers' Association of Construction Industries (TEACI), were asked to fill the questionnaire. Ninety-two questionnaires were filled out of 313 sent out, corresponding to a response rate of 29.4%.

The survey is divided into three sections: (1) general information about the respondents and their organizations, (2) CSFs for UAV technology, and (3) project-specific information (if any). Participants were asked to declare the degree of significance for each of the CSFs listed using a five-point Likert scale (1: not significant, 2: fairly significant, 3: significant, 4: very significant, 5:

extremely significant). The questionnaire sample can be found in Appendix S1 (supplemental data).

3.1. General information about the respondents

The age of the 92 respondents was, on average, about 38 years, in line with their intermediate experience level in the construction industry, which was 14.4 years. Most respondents (61.2%) reported that their organizations have USD$100 million (M) or more, 14.3% had between USD$ 10-100M, and 24.5% had USD$ 10M or fewer turnover values (Fig. 1). Most of the organizations (56.5%) had more than 200 employees. Among the respondents, 13% were owners/cofounders, 36% worked at a managerial level, 10% worked at a chief level, and 24% were architects and engineers (Fig. 2).

3.2. UAV technology use in the construction industry

It was found that about 60% of the respondents implemented UAV technology in their projects. Among these, 61.80% were contractors, 18.20% were consultants, 10.90% private clients, 5.50% public clients, and 3.60% are subcontractors. Also, among the respondents implementing UAV technology, 63.6 % (the majority) were companies having > 201 employees, followed by 20% for medium-sized companies having 51-200 employees and 16.3% for small companies (0-50 employees).

Regarding project types, UAV technology was primarily implemented in infrastructure and heavy construction projects (36.4%), followed by industrial construction (27.3%) and institutional and commercial construction (23.6%). Residential projects had the smallest percentage of 12.7%. Concerning the project size, 70.8% of the projects were large-scale projects with a project cost greater than $50 million, 23.7% were medium-scale projects ($100,000 - $50 million), while only 5.5% were small projects (<$100,000) (Fig. 3). Additionally, responses show that UAV technology has been used during the last eight years (2014-2021; 26 responses) and will be used in the coming years (two responses). Considering the project phases during which UAV technology was most

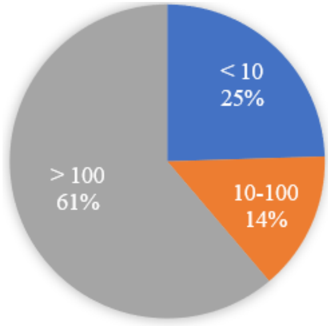

Fig. 1. Distribution of organizations' annual turnovers

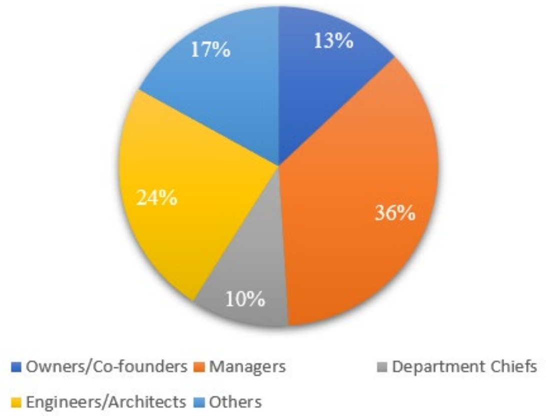

Fig. 2. Distribution of respondents' positions

implemented, the "Construction" phase has got the highest percentage (72.5%), followed by "Feasibility & Preliminary Design" (27.5%), "Detailed Design" (19.6%), and lastly "Operation & Maintenance" (9.8%) (Fig. 4). Also, 77.8% of these respondents indicated that the UAV technology was utilized for photography purposes, followed by progress monitoring and documentation applications (64.8%). Therefore, it can be concluded that UAV technology was used more frequently by contractors in large-scale infrastructure and industrial projects and rarely used in small residential and commercial construction. This might have been because of the complex nature of the infrastructure and industrial projects, which required the use of UAVs to facilitate the visual monitoring and inspection of the existing structures' conditions and communication among the multiple project stakeholders.

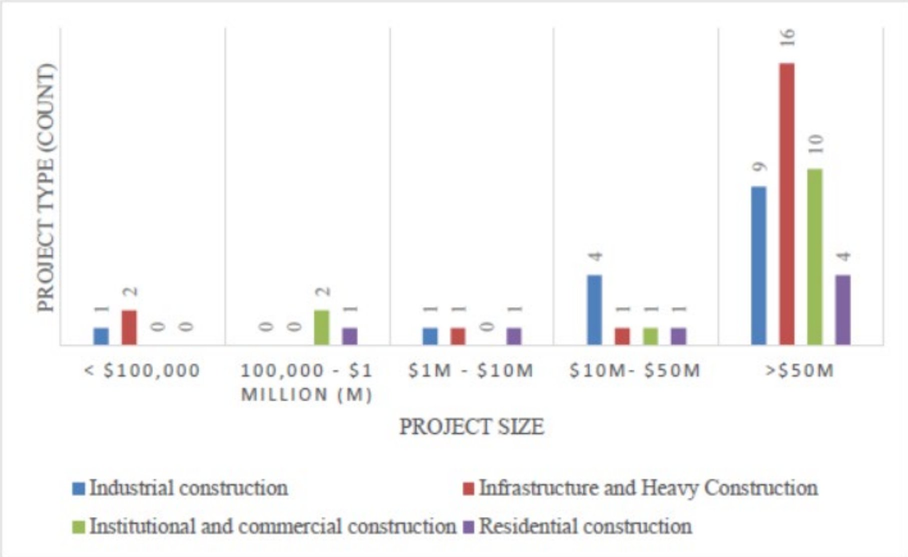

Fig. 3. Distribution of projects by type and size

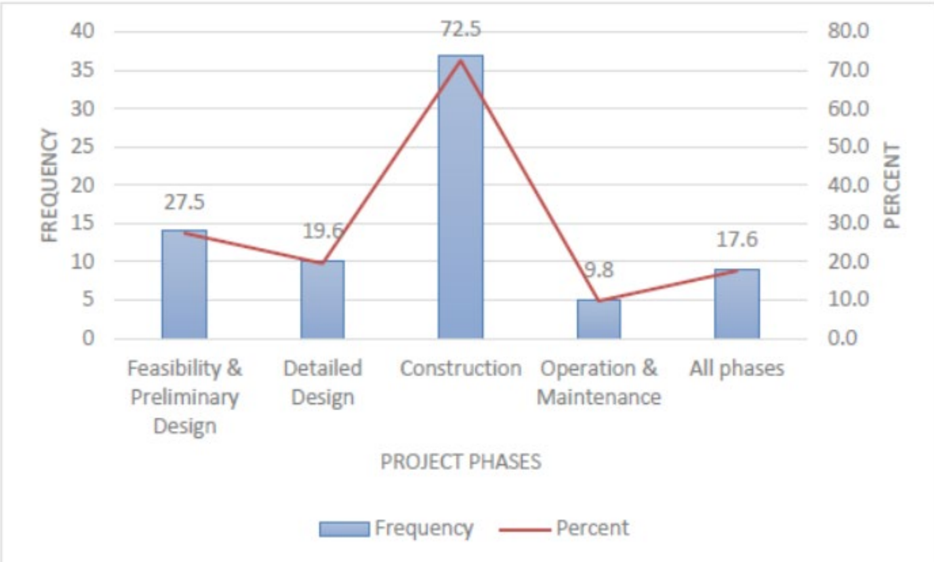

Fig. 4. Rate of UAV Technology Use based on project phase.

Regarding the benefits of UAV technology, “improvement of client satisfaction” got the highest record with 41 responses (80.4%) at the project level (Fig. 5), and “improved company image” got the highest percentage (71.7%) at the company level (Fig. 6). The most frequently mentioned drawbacks were the requirement of flight permits (frequency, 3) and unsuitable weather conditions (3). Additionally, battery problems (2) and unsuitability for use in residential buildings, tall buildings, and covered areas (2) were considered obstacles to the use of UAV technology.

3.3. CSFs for UAV technology implementation

The CSFs evaluated in this study are presented in Table 1. Table 1 shows each factor with its description and literature source. The CSFs list was generated based on an extensive literature review.

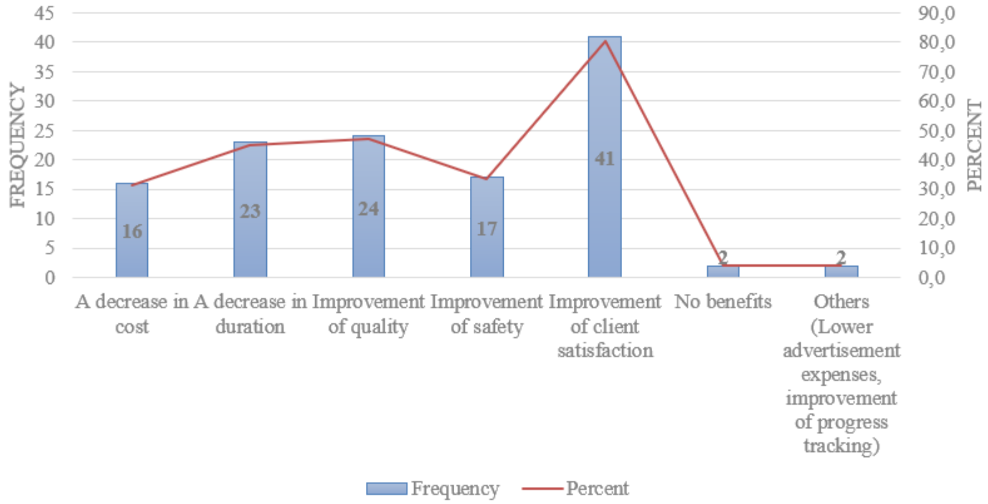

Fig. 5. UAV technology benefits at project level.

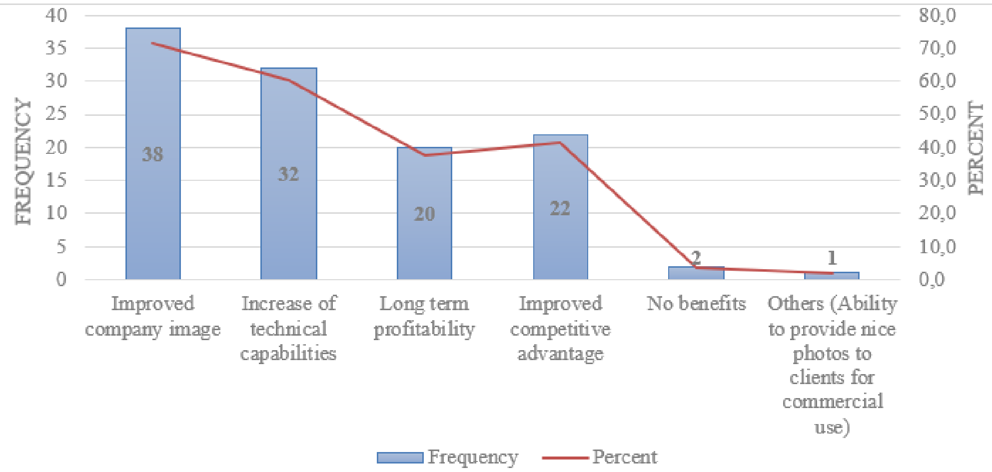

Fig. 6. UAV technology benefits at company level

Table 1. Critical Success Factors (CSFs).

Identifier (V)	List of CSFs	Description	Literature Sources
1	Technology Capital Cost (Availability of financial resources in the Organization)	Sufficient budget allocation to meet drone technology acquisition costs	Graham [11]; Ozorhon and Oral [31]; Nnaji et al. [12]; Golizadeh et al. [7]
2	Effective leadership and top management support	The degree of significance and support for drone technology adoption by top management	Golizadeh et al. [7]; Raj and Sah [28]
3	Organization's innovation culture and flexibility	Organization's willingness to innovate and ability to adapt to new technological changes	Lu et al. [32]; Ozorhon and Oral [31]; Winkler and Zinsmeister [29]

Table 1. Cont'd

4	Availability of ICT infrastructure support	Existence of sufficient support and attention for ICT infrastructure	Lu et al. [32]; Winkler and Zinsmeister [29]
5	Awareness of ethical, privacy and safety issues in the organization	Considering the ethics, privacy and safety of workers and people being near the construction site when flying a drone	Golizadeh et al. [7]
6	Availability of qualified or skilled workforce/ experts	Presence of adept and qualified people within the organization	Graham [11]; Raj and Sah [28]
7	Education and training programs for UAV operators and workers	Providing training sessions in the organization to facilitate Drone technology use and enhance the users' knowledge and skills for the technology	Graham [11]; Winkler and Zinsmeister [29]
8	Project structure and type	Consideration of the project structure and type before investing in UAV technology	Lu et al. [32]
9	Collaboration, communication and coordination among project stakeholders	Existence of a collaborative environment throughout the project to successfully exploit drone technology	Ozorhon and Cinar [33]; Lu et al. [32]
10	Project cost and size	Consideration of the project cost (resources) and size (small or large) before investing in UAV technology	Makdisi and Makadsi [13];
11	Advanced UAV technical characteristics (camera, payload, sensors, battery, autonomy)	Ability to capture high-resolution and interpretable images and videos with its advanced features.	Golizadeh et al. [7]; Albeaino et al. [34]; Sah et al. [30]
12	Easy-to-use, maintainable and controllable systems (fits into operations)	User friendliness; Users' ability to easily use, control and maintain drone outputs and components	Makdisi and Makadsi [13]; Golizadeh et al. [7]
13	Flight reliability and safety (obstacle-avoidance)	Technology's capability to avoid obstacles and collisions with workers and building elements	Dupont et al. [2]; Sah et al. [30]; Raj and Sah [28]
14	UAV technology interoperability	Technology's ability to be integrated with other technologies (BIM, RFID, LIDAR, AR, etc.)	Graham [11]; Dupont et al. [2];
15	Technological advancements (Web, BIM, Wireless technology, AR/VR, LIDAR, RFID)	Continuous development of other technologies and their use in construction	McCabe et al. [35]; Tatum and Liu [15]; Alizadehsalehi et al. [25]; Raj and Sah [28]; Makdisi and Makadsi [13]
16	Technology's cost effectiveness (ROI)	Technology's ability to provide a quick return on investment (costs versus benefits)	Graham [11]; Delgado et al. [3];

Table 1. Cont'd

17	Proved effectiveness of the technology	Level of maturity of drone technology in the industry	Delgado et al. [3]; Nnaji et al. [12]; Makdisi and Makadsi [13]
18	Availability of multiple functional UAV platform types for selection	Continuous production and development of UAVs with different features for specific functions	Graham [11]; Makdisi and Makadsi [13]; Greenwood et al. [6]
19	Availability of required hardware and software	Presence of the necessary components in the market for the efficient operation of UAVs	Golizadeh et al. [7]
20	Attitude towards new technology adoption in the industry	Degree of resistance from construction companies towards drone technology adoption and their general inclination to stick to traditional practices	Makdisi and Makadsi [13]
21	Complexity of construction tasks/ Fragmented nature of the industry	Project-based and complex nature of the industry, difficulty to standardize practices	Ozorhon and Oral [31]; Golizadeh et al. [7];
22	Society or users' awareness of drone technology	Users' perception level and familiarity towards the state of drone technology	Raj and Sah [28]
23	Competition	Companies competing to innovate and adopt drone technology earlier	Ozorhon and Oral [31]; Makdisi and Makadsi [13]
24	Market demand	Sufficient demands for drone technology by construction companies and other businesses	Delgado et al. [3]
25	Weather and site conditions	UAVs' sensitivity to weather conditions	Golizadeh et al. [7]; Raj and Sah [28]; Sah et al. [30]
26	Proper licensure and certification requirement	Necessity to acquire a licence / certification before piloting a drone	Golizadeh et al. [7]
27	Government regulations and support	Existence of adequate government regulations and incentives to promote the use of drones in construction	Dupont et al. [2]; Golizadeh et al. [7]; Raj and Sah [28]
28	R&D investments for UAV technology adoption	Sufficient budget allocation for R&D practices over drone technology and other related technologies in the construction industry	Delgado et al. [3]

The preliminary list included 78 factors related to all industries; it was then refined to 28 CSFs more related to construction. A team of two university professors and three highly experienced UAV consultants was formed to improve the CSF list. Some of the factors with similar meanings were removed, merged, and/or renamed to prevent overlapping. For instance, in the primary list, there were some similar factors such as government support, the presence of a clear regulatory or legal framework, and political and institutional support of the technology. These three factors were merged into a single variable as "government regulations and support" in this study. Similarly, "availability of qualified or skilled workforce/ experts" represents the user's proficiency with drone operation and maintenance, proper usage of UAVs' wireless sensors, and lack of understanding of drones' assets usage and value. Table 2 presents the descriptive statistics of these CSFs based on the 92 responses gathered from construction companies. Findings proposed that effective leadership and top management support, proven effectiveness of the technology, the organization's innovation culture and flexibility, technological advancements, technology's cost-effectiveness, Return on Investment (ROI), and advanced UAV technical characteristics were the most significant factors determining the success of UAV technology. In contrast, proper licensure and certification requirements, availability of multiple functional UAV platform types for selection, and awareness of ethical, privacy, and safety issues in the organization were the least important factors in the Turkish construction industry.

Table 2. Mean ranking of the CSFs.

Variables (CSFs)	Mean	Std. Deviation	Variance	Criticality
(V2) Effective leadership and top management support	3.91	1.116	1.245	Significant
(V17) Proved effectiveness of the technology	3.85	0.937	0.878	Significant
(V3) Organization's innovation culture and flexibility	3.83	1.125	1.266	Significant
(V15) Technological advancements	3.76	0.999	0.997	Significant
(V16) Technology's cost effectiveness (ROI)	3.74	1.057	1.118	Significant
(V11) Advanced UAV technical characteristics	3.73	1.060	1.123	Significant
(V20) Attitude towards new technology adoption in the industry	3.71	1.000	1.001	Significant
(V10) Project cost and size	3.70	1.165	1.357	Significant
(V1) Technology Capital Cost	3.65	1.143	1.306	Significant
(V19) Availability of required hardware and software	3.64	1.023	1.046	Significant
(V12) Easy-to-use, maintainable, and controllable systems (fits into operations)	3.60	1.006	1.012	Significant
(V13) Flight reliability and safety	3.59	1.140	1.300	Significant
(V25) Weather and site conditions	3.58	1.207	1.456	Significant
(V7) Education and training programs for UAV operators and workers	3.58	1.082	1.170	Significant
(V6) Availability of qualified personnel or skilled workforce/ experts	3.57	1.122	1.259	Significant
(V28) R&D investments for UAV technology adoption	3.52	1.053	1.109	Significant
(V8) Project structure and type	3.49	1.200	1.439	Significant
(V14) UAV technology interoperability	3.48	0.955	0.912	Significant
(V21) Complexity of construction tasks	3.46	1.010	1.020	Significant
(V27) Government regulations and support	3.42	1.179	1.390	Significant
(V4) Availability of ICT infrastructure support	3.42	1.040	1.082	Significant
(V22) Society or users' awareness of drone technology	3.38	1.025	1.051	Significant
(V24) Market demand	3.35	0.999	0.999	Significant
(V9) Collaboration, communication and coordination among project stakeholders	3.35	1.104	1.218	Significant
(V23) Competition	3.29	1.011	1.023	Significant
(V26) Proper licensure and certification requirement	3.28	1.103	1.216	Significant
(V18) Availability of multiple functional UAV platform types for selection	3.24	0.942	0.887	Significant
(V5) Awareness of ethical, privacy and safety issues in the organization	3.16	1.051	1.105	Significant

Gathered data were assumed to be normally distributed since t-test and one-way ANOVA test are considered robust against the normality assumption. A T-test was carried out to determine if there is a significant difference between the perspectives of the UAV technology users and nonusers in terms of the significance of CSFs. T-test results showed that only for two variables [(1) organization's innovation culture and (2) project cost and size], the significance was less than 0.05 ($p < 0.05$). This showed that whether the respondent was a user of the UAV technology or not was significant about the perception of these two CSFs. Nonusers of UAV technology (40.2%) found the organization's innovation culture more important than the technology users (respective means, 4.11 versus 3.64). Having a culture in the organization, which fostered the use of innovative technologies in its projects, enhanced the willingness of decision-makers to adopt UAV technology. On the other hand, an absence of such culture and the preference for traditional methods hindered the adoption. This might be the reason behind the importance given by UAV nonusers to this critical factor. Also, this factor was considered more critical by nonusers of UAV technology (4.03 > 3.47) for the project cost and size. Hence, they might not be using UAV technology because their current projects were small and did not require them to invest in innovation. One-way ANOVA results examined whether there were significant differences in the responses of "Contractor, Consultant, Private/Public Client, and Subcontractor" groups on the identified 28 CSFs (5% significance level). The F value and the significance level for each factor indicated no statistically significant difference in the responses of these five groups.

Further analyses were carried out to examine any significant differences among different groups based on the organization size (based on employee number) and participants' professional experience, as shown in Table 3. A homogeneity test of variances was carried out to determine the variables for which group variances are not homogeneous ($p<0.05$). ANOVA test results showed variables with significant differences between groups' responses. Then, a post-hoc test (Tuckey test or Games-Howell test) was carried out to determine which two groups the difference exist. The Tuckey test assumes equal variances, while the Games-Howell test assumes unequal variances.

Table 3. Comparison of responses of different groups.

Category under investigation	Homogeneity of variances test (p-values)	ANOVA test (p-values)	Posthoc test (Tuckey) (Mean values)
Core business (consultant, contractor, private client, public client, subcontractor)	Project structure and type (0.000) Easy-to-use, maintainable, and controllable systems (0.005) Technology's cost effectiveness (0.002) Attitude toward new technology adoption in the industry (0.045)	None	N/A
Size – based on employee number (0-20; 21-50; 51-100; 101-200; >201)	Technology capital cost (0.000) Project cost and size (0.023) Technology's cost effectiveness (0.047)	None	N/A
Level of experience – based on age (0-5; 5-10; 10-15; 15-20; 20-25; 25-30; >30)	Advanced UAV technical characteristics (0.027) Easy-to-use, maintainable, and controllable systems (0.025) Technology's cost effectiveness (0.015) Proved effectiveness of the technology (0.008)	Society or user's awareness of drone technology (0.013) Competition (0.041)	5-10 (2.96); 20-25 (4.33) 5-10 (2.87); 20-25 (3.89)

For example, only for the "age/experience level" category, analysis results showed that there was a significant difference between the two groups (5-10 and 20-25 years) both in terms of two variables which were "Society or user's awareness of drone technology" (0.013) and "Competition" (0.041). Respondents with more experience (20-25 years) gave more importance to these two variables, with respective mean values of 4.33 and 3.89.

In the next stage, factor analysis was conducted to explore the underlying factors for UAV implementation success. Factor Analysis is, as defined by Norusis [30], "a statistical technique used to identify a relatively small number of factors that can represent the relationship among sets of many interrelated variables." Two tests were carried out to check whether factor analysis could be used: the Kaiser-Meyer-Olkin (KMO) adequacy test and Barlett's test of sphericity. KMO adequacy test was performed to measure sampling adequacy and evaluated the correlations and partial correlations to determine if the variables were likely to merge into components. Higher KMO values indicate that more correlations between variables' pairs can be explained by other variables. Factor analysis is suitable only when the KMO value is high. Therefore, KMO values less than 0.5 are not satisfactory; values within a range of 0.5 and 0.7 are average; between 0.7 and 0.8 are good, between 0.8 and 0.9 are great, and more than 0.9 are terrific [31]. Bartlett's test of sphericity is conducted to test the null hypothesis that the correlation matrix is an identity matrix [31]. In this study, the KMO statistic value was acceptable with a value of 0.856. The value of the test statistic for sphericity was large (Bartlett test of sphericity = 1429.90,2), and the associated significance level was small ($p = 0.000$). Therefore, it was suitable to employ factor analysis.

Factor analysis was performed using the Statistical Package for Social Sciences (SPSS). The SPSS program produced output files in the form of a correlation matrix, eigenvalues and total variance explained, scree plot, component matrix, rotated component matrix, and component transformation matrix. However, the examination of the correlation matrix reveals that not all the variables are significantly correlated at the 5% level, and the matrix determinant is 2.08*10-8. The determinant is calculated to test the singularity level of the data. A determinant value greater than 0.00001 indicates the absence of a singularity effect and that no factor should be eliminated. However, 2.08*10-8 is smaller than 0.00001, implying that there is a need to eliminate some of the factors for the principal component analysis. The initial factor analysis performed in SPSS led to seven components; however, eight variables having loadings less than 0.5 and less correlated with other factors were eliminated, considering that a component must have more than two factors. These variables were "Availability of ICT infrastructure support," "Project structure and type," "Project cost and size," "Availability of multiple functional UAV platform types for selection," "Availability of required hardware and software," "Complexity of construction tasks/ Fragmented nature of the industry," "Society or users' awareness of drone technology," and "R&D investments for UAV technology adoption." The correlation matrix of the 20 variables is found in Table 4. After eliminating these factors, the matrix was considered appropriate for analysis.

The rotated component matrix was generated using the varimax rotation method (Table 5). This method attempts to minimize the number of variables that have high loadings on a factor. The purpose of rotation is to get another set of loadings which is more consistent with our expectations and more easily interpreted. The cumulative percentage of variance (65.865%) attained for five components was acceptable as recommended in the literature (Field 2005). Factor 1 accounted for 20.4%, Factor 2 accounted for 12.3%, Factor 3 explained 11.9%, Factor 4 explained 11.3%, and Factor 5 explained 9.9% of the total variance.

Table 4. Correlation matrix of the CSFs

(V1) Technology Capital Cost (Availability of financial resources in the Organization)	1	0.527	0.346	0.112	0.421	0.448	0.201	0.248	0.307	0.378	0.486	0.408	0.497	0.299	0.361	0.213	0.309	0.203	0.323	0.339
(V2) Effective leadership and top management support	0.527	1	0.495	0.153	0.373	0.342	0.292	0.184	0.252	0.403	0.39	0.484	0.437	0.397	0.449	0.296	0.284	0.16	0.217	0.321
(V3) Organization's innovation culture and flexibility	0.346	0.495	1	0.284	0.435	0.444	0.288	0.163	0.258	0.337	0.334	0.266	0.285	0.35	0.462	0.296	0.279	0.156	0.315	0.114
(V5) Awareness of ethical, privacy and safety issues in the organization	0.112	0.153	0.284	1	0.415	0.351	0.329	0.119	0.25	0.213	0.206	0.184	0.128	0.237	0.307	0.409	0.249	0.272	0.301	0.183
(V6) Availability of qualified personnel or skilled workforce/ experts	0.421	0.373	0.435	0.415	1	0.58	0.372	0.186	0.408	0.434	0.535	0.318	0.32	0.323	0.551	0.288	0.264	0.357	0.438	0.265
(V7) Education and training programs for UAV operators and workers	0.448	0.342	0.444	0.351	0.58	1	0.41	0.387	0.377	0.489	0.486	0.485	0.479	0.391	0.463	0.356	0.27	0.4	0.415	0.263
(V9) Collaboration, communication, and coordination among project stakeholders	0.201	0.292	0.288	0.329	0.372	0.41	1	0.392	0.335	0.316	0.445	0.326	0.239	0.296	0.292	0.351	0.238	0.219	0.316	0.164
(V11) Advanced UAV technical characteristics	0.248	0.184	0.163	0.119	0.186	0.387	0.392	1	0.535	0.552	0.401	0.499	0.495	0.301	0.287	0.116	0.215	0.373	0.443	0.181
(V12) Easy-to-use, maintainable, and controllable systems (fits into operations)	0.307	0.252	0.258	0.25	0.408	0.377	0.335	0.535	1	0.725	0.66	0.57	0.551	0.331	0.362	0.182	0.141	0.202	0.421	0.192
(V13) Flight reliability and safety (obstacle-avoidance)	0.378	0.403	0.337	0.213	0.434	0.489	0.316	0.552	0.725	1	0.688	0.549	0.548	0.424	0.442	0.144	0.234	0.263	0.417	0.32
(V14) UAV technology interoperability	0.486	0.39	0.334	0.206	0.535	0.486	0.445	0.401	0.66	0.688	1	0.594	0.56	0.426	0.379	0.149	0.238	0.216	0.476	0.296
(V15) Technological advancements	0.408	0.484	0.266	0.184	0.318	0.485	0.326	0.499	0.57	0.549	0.594	1	0.513	0.442	0.468	0.168	0.249	0.262	0.252	0.283
(V16) Technology's cost effectiveness (ROI)	0.497	0.437	0.285	0.128	0.32	0.479	0.239	0.495	0.551	0.548	0.56	0.513	1	0.559	0.457	0.257	0.274	0.317	0.356	0.231
(V17) Proved effectiveness of the technology	0.299	0.397	0.35	0.237	0.323	0.391	0.296	0.301	0.331	0.424	0.426	0.442	0.559	1	0.55	0.361	0.386	0.283	0.265	0.119
(V20) Attitude towards new technology adoption in the industry	0.361	0.449	0.462	0.307	0.551	0.463	0.292	0.287	0.362	0.442	0.379	0.468	0.457	0.55	1	0.39	0.422	0.369	0.265	0.153
(V23) Competition	0.213	0.296	0.296	0.409	0.288	0.356	0.351	0.116	0.182	0.144	0.149	0.168	0.257	0.361	0.39	1	0.572	0.175	0.053	0.07
(V24) Market demand	0.309	0.284	0.279	0.249	0.264	0.27	0.238	0.215	0.141	0.234	0.238	0.249	0.274	0.386	0.422	0.572	1	0.197	0.109	0.237
(V25) Weather and site conditions	0.203	0.16	0.156	0.272	0.357	0.4	0.219	0.373	0.202	0.263	0.216	0.262	0.317	0.283	0.369	0.175	0.197	1	0.578	0.329
(V26) Proper licensure and certification requirement	0.323	0.217	0.315	0.301	0.438	0.415	0.316	0.443	0.421	0.417	0.476	0.252	0.356	0.265	0.265	0.053	0.109	0.578	1	0.439
(V27) Government regulations and support	0.339	0.321	0.114	0.183	0.265	0.263	0.164	0.181	0.192	0.32	0.296	0.283	0.231	0.119	0.153	0.07	0.237	0.329	0.439	1

Table 5. Rotated Factor Matrix (Loadings) of CSFs.

Common Factors	Variables	Component				
		1	2	3	4	5
UAV & Technology Characteristics	(V12) Easy-to-use, maintainable, and controllable systems (fits into operations)	0.817				
	(V13) Flight reliability and safety (obstacle-avoidance)	0.763				
	(V11) Advanced UAV technical characteristics	0.746				
	(V14) UAV technology interoperability	0.696				
	(V15) Technological advancements	0.686				
	(V16) Technology's cost effectiveness (ROI)	0.663				
Organizational Characteristics	(V2) Effective leadership and top management support		0.749			
	(V1) Technology Capital Cost (Availability of financial resources in the Organization)		0.707			
	(V3) Organization's innovation culture and flexibility		0.543			
Project team characteristics	(V5) Awareness of ethical, privacy and safety issues in the organization			0.725		
	(V6) Availability of qualified personnel or skilled workforce/ experts			0.655		
	(V9) Collaboration, communication, and coordination among project stakeholders			0.554		
	(V7) Education and training programs for UAV operators and workers			0.475		
Market-related Factors	(V24) Market demand				0.777	
	(V23) Competition				0.764	
	(V17) Proved effectiveness of the technology				0.557	
	(V20) Attitude towards new technology adoption in the industry				0.494	
Legal and Environmental Factors	(V25) Weather and site conditions					0.765
	(V27) Government regulations and support					0.703
	(V26) Proper licensure and certification requirement					0.699

Based on the rotated component matrix, easy-to-use, maintainable, and controllable systems (fits into operations), flight reliability and safety (obstacle-avoidance), advanced UAV technical characteristics, UAV technology interoperability, technological advancements, and technology's cost-effectiveness (ROI) constituted Factor 1, named as UAV & Technology characteristics. Effective leadership and top management support, technology capital cost, and the organization's innovation culture and flexibility composed Factor 2, named Organizational characteristics. Awareness of ethical, privacy, and safety issues in the organization, availability of qualified personnel or skilled workforce/ experts, collaboration, communication, coordination among project stakeholders, and education and training programs for UAV operators and workers composed Factor 3, named as Project team characteristics. Factor 4, designated as Market-related factors, included market demand, competition, proven effectiveness of the technology, and attitude towards new technology adoption. Lastly, Factor 5, named as Legal and environmental factors, consisted of weather and site conditions, government regulations and support, and proper licensure and certification requirements.

After the calculation of the average of the variables' mean values to get a mean value for each category, organizational characteristics (mean, 3.8) and UAV and technology characteristics (3.65) were the most indispensable for a successful UAV technology implementation, followed by market-related factors (3.55) and legal and environmental factors (3.43). However, project teams' characteristics (3.41) seemed to have less influence on UAV technology implementation.

4. Discussions

In this study, a comparison between the Turkish regulations and those of the U.S., European Union, and China is made. This comparison showed that Turkiye has more rigid UAV regulations. However, there is still a limited number of studies reporting on the critical success factors of UAV implementation in construction. Analysis of CSFs of UAV technology implementation was performed in two stages: (1) basic statistics (to find out the most significant factors from a list of 28 factors), and (2) factor analysis (to represent the 28 factors in a fewer number of factors and name those depending on their common characteristics). Results of both stages are discussed below, considering the five factors found from factor analysis as described previously.

Factor 1 – UAV & Technology Characteristics: Easy-to-use, maintainable, and controllable systems (fits into operations) are the most significant variables (mean value, 3.6) in this category. To be successfully implemented, UAV systems should not interrupt the existing way of performing construction tasks [13]; they should fit into current operations, considering the project conditions and any possible changes before the implementation. Also, the user-friendliness and the interactivity function of the drone operating interface are crucial for operators when performing inspection tasks and hovering the drone around a specific area; users can easily be familiar with the drone control system [7]. Flight reliability and safety is another significant factor (3.59) for successful UAV implementation. Advanced UAV technical characteristics (3.73) also contribute to better, easier, and more-controlled drone flights. Drones with low weight, high lift, and payload capacities to carry multiple sensors, high-resolution cameras, durable batteries, autonomous flight capabilities, and high wind resistance are being continuously manufactured to leverage drone usage in construction projects [35]. UAV technology interoperability is another critical technology factor (3.48). The easiness of integration and interoperability of UAV technology with other systems, such as GPS systems and other sensors, facilitates the implementation of the technology. UAV data interoperability with other services (e.g., BIM) is essential since shared data are stored only once and kept by the data producer in one specific place to avoid producing redundant versions of data definitions [2,11]. In connection with BIM, Virtual Reality (VR) has had a positive impact on the design and construction phases of buildings [38], which emphasized the need for emerging technologies to work together flawlessly. The UAV technology has been widely used as an expansion of the artificial intelligence (AI) technology, yet the interoperability issues of UAV, BIM, and VR have not been resolved. As a result of the latest improvements in these technologies, new techniques allowing for remote and automated management can be incorporated to get information from the digitalization of the construction [39]. That is why organizations and consultants in Turkiye must consider the currently used software systems and devices when examining UAV technology. Technological advancements (mean, 3.76; rank, 4) are also linked to this category since UAV technology cannot provide its fullest potential when used solely without benefiting from other technologies' advances [34]. The use of advanced technologies such as GPS devices, RFID tags, laser scanning LiDAR, and connected devices with UAV technology enhances the use of UAVs for construction management tasks like material tracking at sites, detecting concrete cracks and leaks, and visual data processing and sharing with stakeholders [2,35]. The last subfactor in this category that adds an essential advantage to UAV technology characteristics is the technology's cost-effectiveness (3.74). In addition to the initial cost of adopting a drone, adapting to new technology and workflow in an organization can cost time and money. However, it is suggested that investment in UAV technology will cover these expenses and provide gains in terms of cost and time to the company. The cost-effectiveness of UAV technology is explained by its ability to cut surveying costs since using traditional techniques (ground-based instruments or renting helicopters) to survey large project areas can take days or weeks; however, using a multirotor drone, for example, reduces the time to few minutes at a low cost [14].

Factor 2 – Organizational Characteristics: According to the basic statistics results, the most critical variable belongs to this factor. Among these, "effective leadership and top management support" was found to be the most significant factor (mean value, 3.91). Consultants and contractors ranked this factor as the most critical factor, with respective mean values of 4.08 and 3.87. An organization with a leadership spirit, focusing on its people and positive change in its construction management practices, creates an internal environment open to innovative practices and staff training. Successful project leaders play an essential role in solving conflicts and communication difficulties between people and departments [33]. Top management is responsible for developing clear and comprehensive strategic plans aligned with the use of drone technology in the organization's current and future construction projects [11]. Allocation of sufficient financial, manpower, and material resources and the project manager's confidence in top management support in case of an undesired situation are significant critical points to consider for successfully implementing UAV technology. Technology capital cost (availability of financial resources in the organization) (3.65) is a factor related to the organization's ability to meet the financial requirements for adopting, operating, and maintaining drone technology as well as training employees. UAVs have gained many advanced functional characteristics with the rapid, continuous technological improvements, but their costs are still decreasing or lower than other alternatives. Depending on the type of camera, the presence of multisensory obstacle avoidance, and GPS add-ons, the new commercial tiny UAVs' costs usually change from less than $50 for a low-resolution camera quadcopter to $50,000 or more for a more sophisticated multi-copter platform [6]. Depending on its financial resources and objectives behind UAV technology adoption, the organization should select the appropriate UAV type to leverage its usage in its current projects. An organization's innovation culture and flexibility (3.83) are the third most important critical success factor. Consultants also ranked this factor as the most critical factor, with a mean value of 4.08. An essential characteristic of an organization aiming to remain in the competition in the construction market is its support for learning, innovation, and change in its business processes, which is also about the top management's support for new technologies [29,31,32,40].

Factor 3 – Project Team Characteristics: Awareness of ethical, privacy, and safety issues in the organization is the most critical factor (3.16) in this category; however, it occupies the last position among the 28 CSFs as found from the basic statistics. It is crucial to consider this factor when developing the characteristics of the project teams (drone operators, contractors, consultants, workers, subcontractors, owners, designers). For instance, a drone operator must consider the regulations (issued by the General Directorate of Civil Aviation, GDCA, in Turkiye) for conducting a safe and reliable drone flight. Invading the privacy of workers or putting workers at risk (injuries, distractions) due to lousy drone operations should be avoided by drone users [7,35]. The availability of qualified personnel or skilled workforce/ experts (3.57) is another significant factor. The presence of an adept and qualified project team within the organization can enhance the chance of success in UAV technology adoption [11,28]. Skilled contractors' and consultants' project teams can apply machine learning and AI technology to get better outcomes from drone data processing [28]. Collaboration, communication, and coordination among project stakeholders (3.35) are also critical for UAV implementation. Coordination meetings between project parties (project managers, consultants, engineers, and clients) during which the UAV-collected data are shown, interpreted, and discussed for project progress tracking against the planned schedule, are necessary for each project. Such regular meetings resolve potential conflicts, delays, and cost overrun issues [33]. The last factor in this category is education and training programs for UAV operators and workers (3.58). These training programs build competent project teams in the organization, which help implement proper drone technology. Hence, the top management must allocate a sufficient budget for training purposes to raise employees' competence and acceptance levels regarding the use of UAV technology [11].

Factor 4 – Market-related Factors: The two most essential aspects of this component are Market demand (3.35) and Competition (3.29). The low costs and availability of w a wide range of functional UAV platforms have been catching the public's interest in the last years. The growing demand for commercial UAVs for civil applications is continuously driving UAV manufacturers (DJI, Parrot, Yuneec, etc.) to offer a wider range of choices at different price levels [6] to the construction market. Additionally, the competition level in the construction industry enforces construction firms to constantly try to remain in the business. This can only be done by following and implementing new technologies such as UAV technologies to outperform their competitors [40]. Moreover, competition among UAV manufacturers to develop advanced UAV platforms is making the drone market highly competitive [41]. The other two factors are Proved effectiveness of the technology (3.85; rank, 2), and Attitude towards new technology adoption in the industry (3.71). It is suggested that the proven effectiveness and maturity of UAV technology in construction projects will increase the demand for it in the construction market [3]. The attitude toward the adoption of drone technology in construction is affected by the level of maturity of drone technology. The more the effectiveness of UAV technology is recognized by construction workers, employees, and clients, in terms of the acquired benefits stated previously, the more it will be accepted in the industry.

Factor 5 – Legal and Environmental Factors: Weather and site conditions (3.58) is an important factor in this category that affect the ability of construction companies to integrate UAV technology into construction tasks. A harsh environment, such as strong winds or rain, would significantly make it difficult to operate a UAV for any construction management task [7,14]. UAVs' sensitivity level to weather conditions should not be ignored by drone pilots. Government regulations and support (3.42) is also an important aspect responsible for a successful drone technology implementation. Turkiye is mostly known for developing and adopting drones for military use. The GDCA is responsible for issuing the regulations related to the use of UAVs. There is a lack of investments and government incentives in Turkiye in the commercial drone market. Providing incentives by the government such as reinvestment loans, allowances, and funds [3] for the use of UAVs in the construction sector will encourage the sector to implement the technology. Regulations concerning airspace restrictions, altitudes, and UAV weights are important to avoid safety- and privacy-related risks [7]. Finally, the last subfactor related to the legal and environment characteristics is the Requirement of a proper licensure and certification by the GDCA in Turkiye as well as in other countries (FAA in the USA, CASA in Australia, for example) [7]. A remote pilot license and UAV registration in the system are required for piloting a UAV over Turkiye's construction sites. This will ensure that the UAV is piloted and controlled by a skilled operator since construction sites are generally complex.

5. Conclusions

Given the productivity problems, rising competitive environment, and altering conditions in the construction sector, all firms have to follow improved project management practices to increase efficiency and improve their competitiveness. A solution to this issue is believed to be by the adoption of digital technologies such as UAV technology at construction sites; UAV technology use can improve the productivity, quality, and safety at construction sites by saving cost and time and improving communication between different project stakeholders. However, integrating UAV technology to construction management tasks may pose a challenge, if not addressed properly. Previous studies focused on the opportunities, challenges, and applications of UAVs in construction. To take full advantage of the benefits of UAV technology, the CSFs of its implementation should be investigated. This study mainly aims to identify the governing factors affecting the successful UAV technology implementation in the construction industry in developing countries, by calculating the importance weight of each CSF, and finally discovering the underlying factors which include correlated variables. Based on an extensive literature review, 28 CSFs were determined, and a questionnaire survey was conducted online to determine the opinions and practices of the construction professionals in Turkiye.

Required data were collected from 92 Turkish construction professionals. Results show that more than half of the respondents (60%) are UAV technology users which indicates that UAV technology has somehow managed to diffuse in the sector. Statistical analysis results show that effective leadership and top management support, proven effectiveness of the technology, the organization's innovation culture and flexibility, technological advancements, technology's cost effectiveness (return on investment - ROI), and advanced UAV technical characteristics are the most important factors determining the success of UAV technology, while proper licensure and certification requirement, availability of multiple functional UAV platform types for selection, and awareness of ethical, privacy and safety issues in the organization are the least important factors in the Turkish construction industry. The findings generally resemble what has been previously stated in the literature. In this regard, it can be derived that the perception of the CSFs for UAV technology implementation is not necessarily related to the market development level; however, the level of experience is expected to affect the implementation performance. ANOVA test results suggest that there are no significant differences in the responses of the five different organization types (contractor, consultant, private/public client, and subcontractor) on the identified 28 CSFs (5% significance level). One of the contributions of this study is that it has determined a set of underlying factors explaining the correlations between the variables. Factor analysis produced five factors namely (1) UAV & technology characteristics, (2) organizational characteristics, (3) project team characteristics, (4) market-related factors, and (5) legal and environmental factors. Among these, it was shown that “organizational characteristics” and “UAV and technology characteristics” are the most essential for a successful UAV technology implementation, followed by “market-related factors”, and “legal and environmental factors”. “Project team characteristics” have the least effect on UAV technology implementation.

It can be stated that the organization plays the most important role in developing successful UAV technology implementation in construction projects. UAV technology characteristics also occupy a significant role in achieving this goal. Unlike the implementation of other innovations (such as BIM, ERP, etc.), in the case of UAV technology-based factors have higher importance weights. Leaders and senior managers should focus on the people working in their organizations as well as on change, on proceeding beyond their comfort zone. They should build an innovative culture among all employees. Also, they should have clear goals and objectives aligned with the use of drone technology in their projects. Also, selecting an appropriate UAV type with advanced characteristics such as high payload, advanced battery, high speed, high wind resistance and good flight time (generally 30 minutes) will lead to a more successful integration of the drone into construction management tasks.

This study emphasizes the factors that would guide the drone pilots, managers, contractors, consultants, and owners in effectively implementing UAV technology in the construction industry. It is the first attempt to provide substantial evidence of the CSFs for the adoption of drones in construction projects. Developed countries such as the USA, the UK, Australia, Germany, etc. have been implementing drone technology in construction more than developing countries, mainly due to their market acceptance, high R&D investments, better technological infrastructure, and policies. These countries have mostly perceived technological factors and government regulations as the most critical factors for success; on the other hand, this study highlights the important role of construction organizations to achieve success. The findings of this study are expected to help stakeholders develop strategies to mitigate the limiting factors of drone adoption. Construction and drone companies in developed countries can also benefit from the research findings to improve corporate performance aligned with the use of drone technology and highlight key industry-specific technological requirements for advanced drone operation. It should be noted that the findings are based on the data collected from Turkish construction professionals; they reflect only the perceptions and experiences of Turkish construction firms. However, researchers may conduct the same study in different regions in the future and compare the CSFs assessment results. This will provide conclusions regarding regional differences that may catch the attention of global construction firms as well as UAV firms.

Finally, future research should focus on UAV technology interoperability with other technologies such as BIM, AI, and AR/VR since drone technology as a data acquisition tool can contribute to data processing and use in construction. Integrated use of those digital technologies will enhance efficiency compared to sole use. Productivity, quality, and thereby cost and schedule problems in construction can only be resolved by the wider adoption of these tools.

Ethics Committee Permission

The authors acquired ethics committee permission for surveys implemented in this paper from the Science and Engineering Fields of Human Research Ethics Committee of Boğaziçi University (Date: 07.06.2021; No:E-84391427-050.01.04-17502).

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Appendix S1: Questionnaire survey for unmanned aerial vehicles

Unmanned Aerial Vehicles (UAVs) in Construction Projects

This questionnaire aims to gather essential information on the Critical Success Factors for Unmanned Aerial Vehicles (UAVs) Implementation in Turkish Construction Industry. Answers provided will be kept strictly confidential and used for academic purposes only. The study is conducted by Malak Al Hajj, MS student in the Department of Civil Engineering, Boğaziçi University, under the supervision of Professor Beliz Ozorhon. In this survey, it is assumed that you are a professional in the construction industry, working in the private or public sector or any other related field and that you are 25 years of age or older. If this does not apply to your situation, please do not participate. This research uses "UAV" and "drone" terms interchangeably. Simply, a drone is an unmanned aircraft. It's a flying robot known for its ability to be remotely controlled by a pilot or fly autonomously through specified flight plans. In other words, drones can be defined as "flying computers carrying an array of sensors to collect data, which enable companies to make intelligent and informed decisions about their projects in a faster, safer and ultimately more efficient way". They are characterized by their ability to access extreme and dangerous environments, to perform surveying, inspection and monitoring tasks as well as automated drilling, excavation and earth moving in construction projects. The purpose of the study is to identify the critical issues that can help in successfully integrating drone technology to construction tasks. The survey comprises three sections: General Information, Critical Success Factors (CSFs) for UAVs, Project Specific Information. Data will be gathered anonymously; results cannot be attributed specifically to you. Collected data are needed to fulfill the requirements of an academic study.In case you need further information about this study, please address your questions to the researcher, Malak Al Hajj: malak.h.elhajj@gmail.com
Your personal information, questions, and comments will be kept confidential.

* Required

1. General Information

1. **What is your company name?**

2. **To which age group do you belong? ***
   - o Less than 25 years' old
   - o 25 to 35 years' old
   - o 36 to 46 years' old
   - o 47 years old or older

3. **What is your main business area in the construction industry? ***
   - o Private Client
   - o Public Client
   - o Subcontractor
   - o Contractor
   - o Consultant

4. **How many years of experience do you have in the construction industry? ***

5. **What is your organization's annual turnover?**USD ($)

6. **How many employees are there in your organization? ***
   - o 0-20
   - o 21-50
   - o 51-100
   - o 101-20
   - o 201

7. **Which of the following best describes your position in the organization? ***
   - o Owner/ Co-founder
   - o General Manager
   - o Manager
   - o Safety Manager
   - o Safety Engineer
   - o Planning Engineer
   - o Project Coordinator
   - o Project Manager
   - o Department Chief
   - o Engineer/ Architect
   - o Surveyor
   - o CAD / BIM Manager or Modeler
   - o IT Manager
   - o Other

8. Which of the following technologies does your company implement? (Check all that apply) *

- o Building Information Modeling (BIM)
- o Synchro Pro Software
- o Auto Cad
- o BIM 360 for Field or other collaborative site software for field management
- o Synchro Field
- o Trimble or Total Station Layout
- o Navisworks Software
- o ContextCapture Software
- o Other

9. Based on your perception, pick one application which you believe would be the best use of an UAV in a construction project related to your Company. *

- o Land surveying and mapping
- o Logistics management
- o Progress monitoring
- o Documentation and reporting
- o Safety control and inspection
- o Quality control and inspection
- o Time management
- o Damage assessment
- o Promotional Photography
- o Decision- making process

10. Based on your perception, pick from the following choices one project phase which you perceive as the most critical phase during which the use of UAVs would be highly beneficial in a construction project. *

- o Feasibility & Preliminary Design
- o Detailed Design
- o Construction
- o Operation & Maintenance

11. Has your organization implemented UAV technology in any of its projects? *

- o Yes
- o No

2. Critical Success Factors (CSFs)

In this study, the critical success factors "CSF"s are considered as "those limited key areas which if defined and measured carefully can guide an organization to achieve better results and successfully adopt and implement the UAV technology in its current and future projects". Hence "success" mainly refers to the ability of the organization to achieve its desired outcomes (i.e., cost saving, improved quality, improved safety, etc.) related to UAV technology implementation process in its construction projects and exploit this technology to its best advantage.

Based on the growing success of UAV technology in the construction industry worldwide and your perception, please state the degree of significance for each of the CSFs listed below for the case of Turkiye by marking your choice as follows:

Scale: 1- not significant; 2- fairly significant; 3- significant; 4- very significant; 5- extremely significant

12. Factors contributing to the success of UAV technology in construction *

CSFs	1	2	3	4	5
Organization Characteristics	○	○	○	○	○
Technology Capital Cost (Availability of financial resources in the Organization)	○	○	○	○	○
Effective leadership and top management support	○	○	○	○	○
Organization's innovation culture and flexibility	○	○	○	○	○
Availability of ICT infrastructure support	○	○	○	○	○
Awareness of ethical, privacy and safety issues in the organization	○	○	○	○	○
Availability of qualified personnel or skilled workforce/ experts	○	○	○	○	○
Education and training programs for UAV operators and workers	○	○	○	○	○
Project Characteristics	○	○	○	○	○
Project structure and type	○	○	○	○	○
Collaboration, communication and coordination among project stakeholders	○	○	○	○	○
Project cost and size	○	○	○	○	○
UAV & Technology Characteristics	○	○	○	○	○
Advanced UAV technical characteristics (camera, payload, sensors, battery, autonomy)	○	○	○	○	○
Easy-to-use, maintainable and controllable systems (fits into operations)	○	○	○	○	○
Flight reliability and safety (obstacle-avoidance)	○	○	○	○	○
UAV technology interoperability	○	○	○	○	○
Technological advancements (Web, BIM, Wireless technology, AR/VR, LIDAR, RFID)	○	○	○	○	○
Technology's cost effectiveness (ROI)	○	○	○	○	○
Proved effectiveness of the technology	○	○	○	○	○
Market-related Factors	○	○	○	○	○
Availability of multiple functional UAV platform types for selection	○	○	○	○	○
Availability of required hardware and software	○	○	○	○	○
Attitude towards new technology adoption in the industry	○	○	○	○	○
Complexity of construction tasks/ Fragmented nature of the industry	○	○	○	○	○
Society or users' awareness of drone technology	○	○	○	○	○
Competition	○	○	○	○	○
Market demand	○	○	○	○	○
Macro-Environment (Legal/Political and environment) - related Factors	○	○	○	○	○
Weather and site conditions	○	○	○	○	○
Proper licensure and certification requirement	○	○	○	○	○
Government regulations and support	○	○	○	○	○
R&D investments for UAV technology adoption	○	○	○	○	○

3. Project-specific information

This section includes questions specific to a project your organization has been involved in and in which UAV technology has been used.

* If your answer to Question 11 is "NO", please ignore this section.

13. What is the project type?

- o Residential construction
- o Industrial construction
- o Institutional and commercial construction
- o Infrastructure and Heavy Construction projects

14. What is the project size?

- o < $100,000
- o 100,000 - $1 Million (M)
- o $1M - $10M
- o $10M- $50M
- o >$50M

15. What is the project duration?

16. During which year have you considered using UAV technology?

17. In which project phase(s) have you implemented UAV technology?

☐Feasibility & Preliminary Design

☐Detailed Design

☐Construction

☐Operation & Maintenance

☐All project phases

18. State the applications for which the UAV technology was used in your projects.

☐Photography

☐Photogrammetry / 3D Modeling

☐Progress Monitoring and Documentation

☐Inspections

☐Equipment/ Materials Tracking

☐Other

19. State the major benefits acquired by your company with UAV technology usage at the project level (Check all that apply)

☐A decrease in cost

☐A decrease in duration

☐Improvement of quality

☐Improvement of safety

☐Improvement of client satisfaction

☐Other

☐No benefits

20. State the major benefits acquired by your company with UAV technology usage at the company level (Check all that apply)

☐Improved company image

☐Increase of technical capabilities

☐Long term profitability

☐Improved competitive advantage

☐Other

☐No benefits

21. If any, state the major drawbacks you have experienced with UAV technology usage.
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