CRITICAL SUCCESS FACTORS FOR UNMANNED AERIAL VEHICLES (UAVS) TECHNOLOGY IMPLEMENTATION IN THE TURKISH CONSTRUCTION INDUSTRY

by

Malak Al Hajj

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ABSTRACT

CRITICAL SUCCESS FACTORS FOR UNMANNED AERIAL VEHICLES (UAVS) TECHNOLOGY IMPLEMENTATION IN THE TURKISH CONSTRUCTION INDUSTRY

The construction sector is known for its highly fragmented, project-based, and complex nature. Besides, resistance to new technology adoption in construction projects worldwide, mainly in developing countries, is considered a main cause behind productivity problems. Hence, integrating drone technology, known as unmanned aerial vehicles (UAVs), to construction management tasks can solve this issue. From this point, this study aims to identify the critical success factors (CSFs) leading to the successful integration of drone technology in the Turkish construction industry. After conducting a comprehensive literature review, a list of 28 CSFs was obtained. A questionnaire survey was prepared and administered to both public and private sectors to collect data using a 1-5 Likert Scale. Ninety-two respondents provided valid responses out of 313 sent questionnaire forms. Then, the relative importance of the 28 CSFs for drone technology implementation was investigated. Statistical analysis results show that the three most important factors are (1) effective leadership and top management support, (2) proved effectiveness of the technology, and (3) organization's innovation culture and flexibility. Also, “Factor analysis” was used to determine the underlying categories for the CSFs. Results indicate that the underlying five factor groups for the 28 CSFs are UAV and technology characteristics, organizational characteristics, project teams characteristics, market-related factors, and legal and environmental factors. Research findings are expected to assist construction practitioners by identifying the focus points for a successful technology adoption. The study provides guidelines helping drone pilots, managers, contractors, consultants, and owners to effectively employ drone technology in construction projects. It constitutes a groundwork for further research.

ÖZET

TÜRK İNŞAAT SEKTÖRÜNDE İNSANSIZ HAVA ARAÇLARI (İHA) TEKNOLOJİSİ UYGULAMASI İÇİN KRİTİK BAŞARI FAKTÖRLERİ

İnşaat sektörü oldukça parçalı, proje bazlı ve karmaşık yapısıyla tanınmaktadır. Ayrıca, dünya çapında, özellikle gelişmekte olan ülkelerde, inşaat projelerinde yeni teknolojilerin benimsenmesine direnç, üretkenlik sorunlarının ana nedeni olarak kabul edilimektedir. Bu nedenle, insansız hava araçları (İHA) olarak da bilinen dron teknolojisinin inşaat yönetimi görevlerine entegre edilmesi bu sorunu çözebilir. Bu noktadan hareketle, bu çalışma, dron teknolojisinin Türk inşaat sektörüne başarılı bir şekilde entegrasyonuna yol açabilecek kritik başarı faktörlerini (KBF'ler) belirlemeyi amaçlamaktadır. Kapsamlı bir literatür taraması yapıldıktan sonra 28 KBF'nin bir listesi elde edildi. 1-5 Likert Ölçeği kullanılarak veri toplamak için hem kamu hem de özel sektöre bir anket çalışması hazırlanmış ve uygulanmıştır. Doksan iki katılımcı, gönderilen 313 anketten geçerli yanıtlar verdi. Sonra, 28 KBF'nin dron teknolojisi uygulaması için göreceli önemi araştırıldı. İstatistiksel analiz sonuçları, en önemli üç faktörün (1) etkili liderlik ve üst yönetim desteği, (2) teknolojinin kanıtlanmış etkinliği ve (3) kuruluşun inovasyon kültürü ve esnekliği olduğunu göstermektedir. Ayrıca, KBF'lerin altında yatan kategorileri belirlemek için “Faktör analizi” kullanıldı. Sonuçlar, 28 KBF'nin altında yatan beş faktör grubunun İHA ve teknoloji özellikleri, organizasyonel özellikler, proje ekipleri özellikleri, pazarla ilgili faktörler ve yasal ve çevresel faktörler olduğunu göstermektedir. Araştırma bulgularının, başarılı bir teknoloji benimsemesi için odak noktalarını belirleyerek inşaat pratisyenlerine yardımcı olması bekleniyor. Çalışma, drone pilotlarının, yöneticilerinin, müteahhitlerin, danışmanların ve sahiplerinin inşaat projelerinde drone teknolojisini etkin bir şekilde kullanmalarına yardımcı olan yönergeler sağlıyor. Daha fazla araştırma için bir zemin oluşturur.

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LIST OF ACRONYMS / ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
ANOVA	Analysis of Variance
AR	Augmented Reality
ATCEA	Association of Turkish Consulting Engineers and Architects
AUVSI	Association for Unmanned Vehicle Systems International
BIM	Building Information Modeling
CAGR	Compound Annual Growth Rate
CASA	Civil Aviation Safety Authority
CC	Cloud Computing
CSF	Critical Success Factor
DSM	Digital Surface Model
ERP	Enterprise Resource Planning
FA	Factor Analysis
FAA	Federal Aviation Administration
GCP	Ground Control Point
GDCA	General Directorate for Civil Aviation
GIS	Geographic Information System
GPS	Global Positioning System
IBS	Industrialized Building System
ICT	Information and Communication Technology
IoT	Internet-of-Things

IT	Information Technology
KMO	Kaiser-Meyer-Olkin Measure
LiDAR	Light Detection and Ranging
OSHA	Occupational Safety and Health Administration
PCA	Principal Component Analysis
PPK	Post-Processing Kinematics
PSO	Particle Swarm Optimization
QA/QC	Quality Assurance/Quality Control
R&D	Research and Development
RC	Remote Control
RFID	Radio-Frequency Identification
RGB	Red, Green and Blue
ROA	Remotely Operated Aircraft
ROI	Return on Investment
RPA	Remotely Piloted Aircraft
RPV	Remotely Piloted Vehicle
RTK	Real-Time Kinematics
SfM	Structure-from-Motion
TCA	Turkish Contractors Association
TEACI	Turkish Employers' Association of Construction Industries
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UB	Ultra-wide Band
UVS	Unmanned Vehicle Systems
VR	Virtual Reality
VTOL	Vertical Takeoff and Landing
WIP	Work-in-Progress

1. INTRODUCTION

1.1. Background

The construction sector is a main contributor to the gross domestic product (GDP) of a country's economy. It, directly or indirectly, impacts the economy of both developing and developed countries. That is why improving the current and future conditions of the construction industry and solving ongoing encountered problems, mainly productivity issues, must be strongly considered by construction companies and authorities.

In other terms, better project management processes should be implemented by construction firms to improve projects' efficiency as well as corporate effectiveness, considering the constantly growing competitive environment and changing conditions in the construction market (Ozorhon and Cinar, 2015).

In addition, we cannot ignore the COVID-19 crisis which has started in early 2020 reaching all the countries in the world. COVID-19 pandemic, with its resulting lockdown periods and strict regulations, has somehow negatively affected the construction sector worldwide. Construction projects were forced to be stopped or postponed, mainly work at construction sites, to ensure the health and safety of workers. Additionally, COVID-19 represents a shock to supply causing the interruption of some building materials supply chains. This prevailing condition is causing construction cost and time overruns as well as productivity problems. As found by a 2016 McKinsey analysis, "construction projects typically take 20 percent longer to finish than scheduled and are up to 80 percent over budget, frequently resulting in litigation". Also, as stated by Wiratunga (2018), 90 percent of infrastructure projects around the world are either late or over budget. These high percentages lead to customer dissatisfaction as well as bad economic condition in the country.

A study done by Gündüz et al. (2013) identified the factors causing delays in construction projects in Turkey, therefore causing productivity loss. Among these factors, the foremost vital ones were inadequate contractor expertise, ineffective project planning and scheduling, poor site management and supervision, design changes by owner or agent during construction; others were late delivery of materials, unreliable subcontractors, delay in performing inspection and testing, unqualified/inexperienced workers, change orders, delay in site delivery, delay in approving design documents, delay in progress payments, slowness in decision-making, poor communication and coordination with different parties, and unexpected surface and subsurface conditions.

For half a century, low efficiency levels in cost, time, and quality, which are the primary performance constraints in the Iron Triangle have been noted. Construction practitioners have been facing several productivity challenges such as labor shortages, inadequate planning and scheduling, lack of communication and collaboration among stakeholders, lack of technology adoption, and the fragmentary nature of the construction industry. All these factors lead to poor productivity levels in construction projects.

A recent report by McKinsey and Co. points out that the construction sector's productivity has been still stuck at the same level for about 80 years while many other U.S. sectors such as agriculture and manufacturing have increased productivity 10 to 15 times since the 1950s. A consistent drop in the construction industry's productivity has been observed since the late 1960s (Jones 2018).

Furthermore, the construction sector's productivity opportunity is summarized by McKinsey and Co. (2017) as follows: "Construction-related spending accounts for 13% of the world's GDP whereas the sector's annual productivity growth has only increased 1% over the past 20 years. $ 1.6 trillion of additional value added could be created through higher productivity meeting half the world's infrastructure need".

Labor shortages, for instance, can considerably lower construction productivity due to the lack of skills and experience of the workforce or due to the presence of companies trying to do more work with fewer workers which will affect labor productivity as well as construction quality. In addition, construction projects are very complex having uncertainty from multiple sources. They represent a cross section of different participants with different project expectations.

The highly fragmented nature of the industry leads also to lack of efficiency and productivity improvement over the years (Ozorhon and Cinar, 2015). In the United States, less than 5% of construction workers work for firms that employ over 10,000 workers. However, in manufacturing and business sector, 25% and 23% of employees work for firms which employ over 10,000 workers, respectively. Hence, the construction industry is four to five times more fragmented than manufacturing and business services. This fragmented structure results in an industry-wide lack of standardization which lowers productivity.

Additionally, due to its project-based nature, construction is one of the less innovative industries (Ozorhon and Oral, 2016). It underinvests in digitization, innovation, and capital. There is a slow adoption of technology in construction projects worldwide, mainly in developing countries. This may be due to project's stakeholders' resistance to change, risk aversion and fear of failure if the investment in the technology to be implemented is not properly evaluated or if the benefits anticipated from its usage are not met throughout the project lifecycle. For instance, as stated in a recent report by Mckinsey and Co. in 2020, "Building information modeling (BIM) adoption rates have reached just 60 to 70 percent in 35 years", which are relatively low compared to other technologies.

However, integrating new technologies such as drones, augmented reality/ virtual reality (AR/VR), building information modeling (BIM), robotics, smart devices, and others, is expected to positively impact the productivity in construction projects. These technologies, especially drones, improve quality and productivity by enhancing communication and collaboration among stakeholders, improving project tracking and reporting, and preventing

construction errors and reworks. Drones can also be used to monitor workers' activities and ensure their safety.

Hence, construction companies, in both developed and developing countries, should consider investing more in such emerging technologies if they seek to save cost and time and deliver their projects safely, with an improved quality. Fortunately, the COVID-19 pandemic is accelerating the integration of digital tools to the construction industry (Mckinsey and Co., 2020).

One of these emerging technologies, drone technology, also known as unmanned aerial vehicle (UAV) and initially used for military purposes, will be explored in detail in this study focusing on its implementation in the construction industry of a developing country: Turkey. From this point, the following research addresses the possibility or opportunity of successfully applying drone technology as a quality-, safety- and productivity-improving tool in Turkish construction industry because improving productivity performance will surely reduce construction delay problems and improve Turkey's economic performance as well as its competitiveness. "UAV" and "drone" terms are used interchangeably in the following research chapters.

1.2. Problem Statement

As stated previously, the construction industry is known for its highly fragmented, changing, and complex nature. Every construction project is unique, having its own scope, site conditions, specifications, and necessary requirements. To ensure a successful project delivery, i.e., meeting the defined scope, agreed-upon budget, specified schedule and quality requirements, focus should exist on three main issues faced in construction projects which are productivity, safety, and quality issues.

Recently, the Covid-19 pandemic has negatively affected the construction sector in Turkey and the world. As stated in a recent report (EPY, 2020/4) in 2021, the Turkish

construction sector decreased by 3.5% by the end of 2020; this decrease was mainly caused by the pandemic which has led to the end of the support packages provided by the government and the increase in loan rates in the last quarter of 2020. Also, this period witnessed a decrease in the construction employment rate.

The share of the construction sector in the country's GDP in the last years is shown in Figure 1.1. As shown, the Turkish construction sector's share was increasing gradually in the first quarters in 2020 reaching a value of 6.6% in the second quarter. However, it declined to a value of 4.8% in the third quarter then started to increase again by the end of 2020 (5.1%).

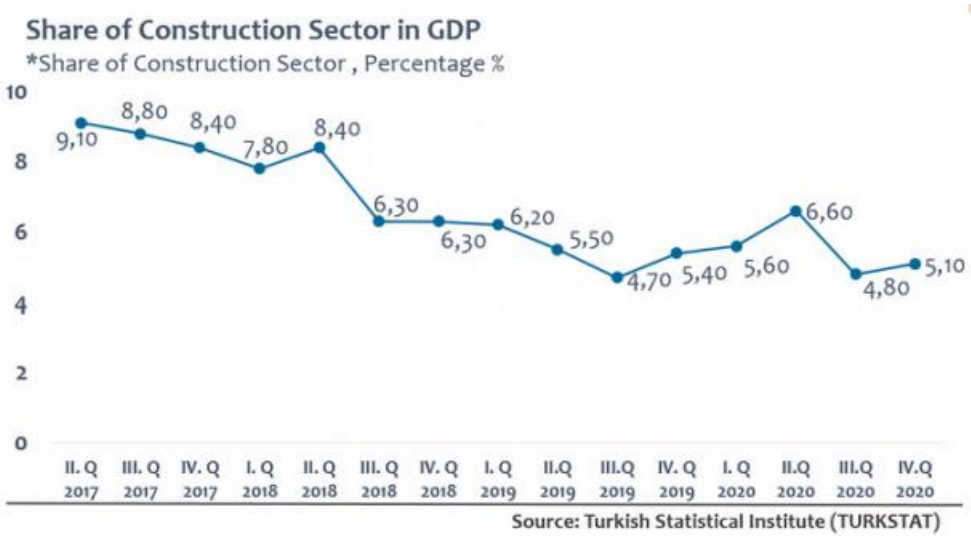


Figure 1.1. Share of construction sector in GDP (2017-2020) (TURKSTAT).

In addition, a productivity gap exists between the construction sector and other sectors such as manufacturing which has increased about 70% in the last decade mainly due to the use of integrated systems by other industries (integrated IT system, intensive sensors usage, etc.).

To fill this productivity gap and improve the construction sector state, the introduction and use of new technologies such as drones in construction projects is becoming a necessity, being one of the recent challenges for construction management (Yildizel and Calis, 2019).

Other technologies to be used are Building Information Model (BIM), Augmented/Virtual Reality (AR/VR), Wireless technology (radio frequency identification technology RFID, personal digital assistants PDAs, and global positioning systems GPS) and others (Lu et al., 2015).

The focus in this research is on drone technology since drones are gaining popularity in Turkey and worldwide among construction projects stakeholders. They are seen as a tool which helps in performing construction management tasks, thus improving productivity, quality, and safety conditions.

Dupont et al. (2017) reported that drones are a mean to answer the needs of productivity improvements due to their growing industry, flexibility, and efficiency. To avoid poor decision-making processes, inadequate communication among stakeholders, poor performance management and site planning, in other words to improve productivity, flexible and adaptive data collection systems (i.e., UAVs) are required. By linking UAVs with BIM, better results can be achieved. As stated by Dupont et al. (2017), a drone can be considered as the “autonomous eyes” of a completely integrated BIM platform; therefore, it can substitute the expensive, inaccurate, and time-consuming manual data collection.

Small (2018) examined the applications of drones (low-cost quadcopters) in construction as well as the research activity in this domain. The benefits of using drones as recognized by the study were cost efficiency, improved productivity and quality and positive schedule impacts. These are the results of aerial imagery captured by UAV’s which allows better documentation, communication and recording of the current site conditions at lower cost. In addition, during the project life cycle, all participants can benefit from drone images. They are useful for planners and designers in conceptual and preliminary design; for construction managers in examining site layouts and monitoring progress; for owners for marketing and business development purposes. However, some accompanied risks that cannot be ignored are risk of drone crashing, risk of property damage, risk of privacy concerns, and risk of personal injuries (employees or civilians).

Current research states that UAVs are “an unprecedented mechanism for inexpensive, easy and quick documentation”, others report their use for seismic risk assessment, transportation, construction management and disaster response, better decision making and risk management.

Also, Irizarry and Costa (2016) performed an exploratory study of potential applications of unmanned aerial systems for construction management tasks which highlights the importance of UAVs in evaluating safety conditions and quality inspections.

Research activity with a focus on the use of drones in construction has been recently studied by Canhete and Machado (2021). A comprehensive review of the literature was performed to determine the percentage of publications per continent and the number of publications per country on sampling 60 articles between 2015 and 2020 as shown in Figures 1.2 and 1.3. respectively. As displayed in Figure 1.2, Europe has the highest percentage of publications (48%). From Figure 1.3, it can be concluded that North America (United States and Canada) has published the highest number of articles (17). Concerning Turkey, Turkey has only provided one publication related to the use of drones in construction during the studied period (2015-2020). Hence there is a need for more research in this field in Turkey.

Canhete and Machado (2021) concluded that the use of drones in the construction field has been lately catching the interest of researchers; an increase in the number of publications in this area has been recorded.

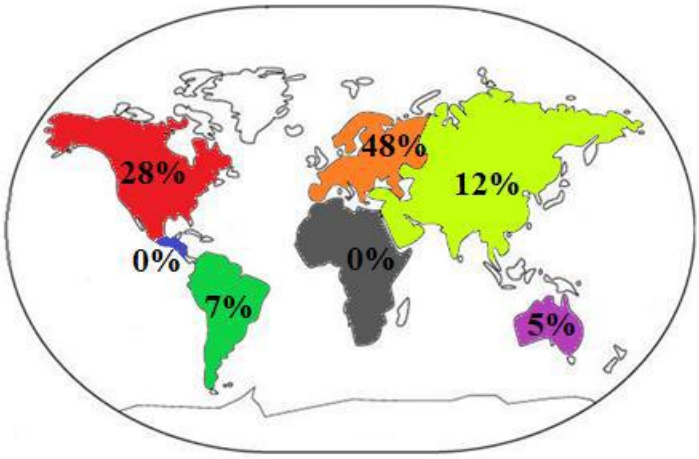


Figure 1.2. Percentage of publications by continents (Canhete and Machado, 2020).

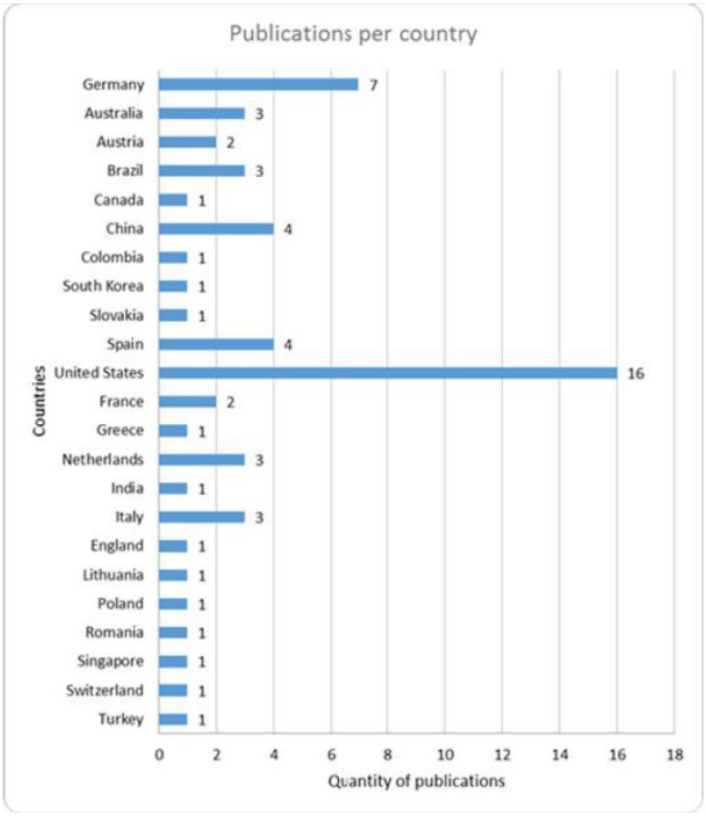


Figure 1.3. Number of publications per country (Canhete and Machado, 2020).

However, despite the increase in research on UAV implementation in construction, there is still a limited research on the critical factors that enable the successful integration of UAVs in construction projects to achieve better productivity, quality, and safety measures. From this point, a research focusing on identifying the critical success factors of UAV technology implementation is needed.

1.3. Aim and Objectives

The research aims to identify the critical factors which can lead to the successful integration of drone technology in the construction industry. To achieve this aim, several objectives were to be addressed. The main objective of the study is to identify the Critical Success Factors (CSFs) for UAV technology implementation in Turkish Construction Industry. Other objectives are:

1) Explore UAVs' potential applications in construction projects through an extensive review of relevant literature.
2) Give an overview on the benefits and challenges accompanying the use of drones in the construction industry especially in construction management field.
3) Help project stakeholders (project managers, engineers, designers, consultants, clients…) and anyone interested in starting or taking part in a drone business to have a better understanding of this relatively new emerging technology regarding its development and usage requirements, types, features, opportunities, and challenges.
4) Contribute to the body of knowledge by introducing practical ways and strategies, based on the research findings, which can be useful to different project parties to ensure the successful implementation of UAVs in construction management practices, improving thereby the productivity in the construction industry in developing countries, mainly in Turkey.

To achieve the above aim and objectives, the following research steps are followed:

1- Explain UAV technology development and current implementation in construction projects worldwide.
2- Explain the current state or position of UAV technology in the Turkish construction industry.
3- Conduct a literature search to examine the critical success factors for UAV technology.
4- Create a list of the identified CSFs for the application of drone technology in construction to be ranked based on their importance level using a questionnaire survey.

1.4. Research Methodology

1.4.1. Research Procedure

The research procedure used in this study comprises five main steps as shown in Figure 1.4. As a first phase, a review of the literature was conducted to identify the problem to be addressed in the research. Subsequently, after identifying the subject, a comprehensive literature review about the application of UAVs in the construction sector was carried out. Literature sources were journal papers, internet papers and conference papers. Literature search was performed using mainly the Google Scholar database which is a freely accessible web-based search engine capable of identifying full text and multi-disciplinary publications (Albeaino et al., 2019).

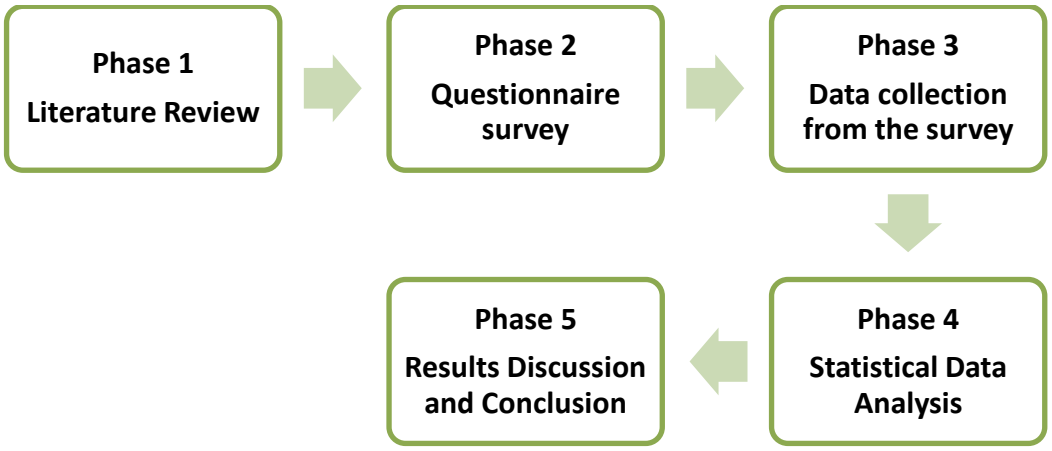


Figure 1.4. Research phases.

Phase 2 consists of the questionnaire survey preparation based on the results of the literature review conducted in Phase 1. The Critical Success Factors (CSFs) extracted from Phase 1 were included in the questionnaire survey to assess their level of importance and identify the main CSFs for UAV technology in Turkish construction industry. This research tool, the questionnaire survey, was developed using Google Form.

The following phases consist of collecting and gathering the data generated from the respondents to the questionnaire survey (Phase 3), analyzing the collected data using suitable statistical methods (Phase 4) and finally discussing analysis results and providing relevant conclusions dealing with UAV technology characteristics and its critical success factors (Phase 5). Phase 3 and Phase 4 are presented and illustrated in detail in Chapter 4 while the results are presented and discussed in Chapter 5 and Chapter 6.

1.4.2. Research Methods

As previously stated, the main research tool used is a questionnaire survey which was prepared in a way to ensure that it includes all necessary questions related to the research topic (UAVs in construction) and thus ensure getting useful related responses.

This tool allows identifying and comparing the different opinions of the participants (clients, contractors, consultants ….) using mean ranking scale, F ratio and significance. The statistical analysis method used was the “Factor analysis” technique which mainly consists of grouping the identified CSFs into components using SPSS Software.

1.4.3. Research Questions

The purpose of a research study is best defined or illustrated using research questions. That is why it is important to identify these questions at the beginning of research and ensure that answering these questions will successfully convey the purpose of the study. The research questions proposed by this study are:

- What are the critical factors leading to the successful implementation of UAV technology in construction projects?
- How can the most critical success factors be identified for the case of Turkish construction industry?
- How are the identified factors interrelated with one another?
- How can these CSFs be evaluated and used effectively by different parties in the Turkish construction industry?

1.5. Study Significance

The findings of the carried study can provide a guideline which can be adopted by project stakeholders when considering the adoption and usage of drone technology in their construction projects. The identification of the CSFs will lead to the successful integration of UAVs in construction management tasks by giving insight to different project parties and widening their understanding of the topic so they will be able to exploit this technology to its best advantage. In other words, the results of this study may support the body of knowledge of the Architecture, Engineering and Construction (AEC) sector in:

- Assessing the feasibility of applying UAV technology in their construction projects,
- Making right decisions and following adequate steps when starting to implement UAV technology,
- Taking corrective actions when needed to deal with risks and problems accompanying the use of UAVs and their limitations,
- Avoiding unsuccessful construction management practices throughout the project life cycle.

1.6. Definitions of Terms

Unmanned Aerial Vehicle (UAV) technology, mostly known by “drone”, is an unmanned aircraft, a flying robot known for its ability to be remotely controlled by a pilot or fly autonomously through specified flight plans (Newcome, 2004). Drone flight plans are controlled by a software in their embedded systems, operating in conjunction with onboard sensors and GPS.

Critical success factors (CSFs) are defined by Boynton and Zmund (1984) as "those few things that must go well to ensure success for a manager or an organization; they are issues vital to an organization’s current operating activities and to its future success” which require special and continuous attention.

Innovation is defined by the Organization for Economic Cooperation and Development (OECD) (2005) as “the implementation of a new or significantly improved product, or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations”. It leads to nationwide economic development and competitiveness as well as better living standards (Ozorhon, 2013).

Information and Communication Technologies (ICT), such as web, wireless, augmented or virtual reality (AR/VR) and BIM, are used in the construction sector to create innovation and improve communication and construction processes' effectiveness (Lu et al., 2015).

Industry Foundation Class (IFC) is a neutral and open file format specification used as a collaboration format in Building Information Modeling (BIM) to enable interoperability in the architecture, engineering and construction (AEC) sector (Wikipedia, 2021).

Interoperability is defined as the ability to integrate systems, software or new technologies used in an organization to operate together (Graham, 2016).

Building Information Modeling (BIM) is a technology becoming commonly used in the AEC sector to represent the physical and functional aspects of a facility. According to the International Standards Organization (ISO) 19650 series, BIM is an important platform for storing and delivering the appropriate amount of information related to the design, construction, operation and maintenance of facilities, using suitable tools.

Virtual and Augmented Reality (VR/AR) are immersive technologies providing innovative and powerful ways for people to generate, use and interact with digital information, by using photographic images, video, or computer-generated graphics. Microsoft HoloLens and VR headsets are examples of the wearable VR/AR tools.

Artificial Intelligence (AI) is the intelligence demonstrated by machines or software (Graham, 2016). It is a human intelligence simulation in machines which are designed to think like humans and imitate their actions. AI is mainly applied for learning and reasoning (Investopedia, 2021).

1.7. Thesis Structure

This first part of the research was an introduction giving an overview of the research main aims and objectives as well as the methodology followed for data collection and analysis. The following five chapters describe the rest of the research. Chapter 2 provides a general overview on UAVs. Chapter 3 examines the literature related to UAVs' definitions, potential applications, and case studies in the construction sector as well as the critical success factors. Chapter 4 presents the research methodology and explains it in detail. Chapter 5 introduces the research results and discusses UAV technology in Turkish construction industry, referring to the data collected from the questionnaire survey. Chapter 6, the final chapter, provides the research summary, implications, conclusion, and recommendations for future research.

2. GENERAL OVERVIEW ON UNMANNED AERIAL VEHICLES

2.1. Introduction

Nowadays, drones or UAVs are being considered a very popular tool used in many fields, especially in the construction field. Understanding the types and characteristics of UAVs is important to successfully apply them depending on the aim behind their use. This chapter provides a general overview on UAVs, referring to their history and development in the first section, to their international market trends and commercial use and regulations in Turkey in the second and third sections respectively, and to their different types and characteristics presented in the fourth section of this chapter.

2.2. Brief Overview on UAVs' History and Development

Drone technology was first known for its use in the military as an unmanned aircraft. Britain and USA were the first countries which started to use this technology by developing their first unmanned vehicles during the First World War. The British's first small radio-controlled aircraft was called "Aerial Target" (Figure 2.1). It was tested in March 1917. The American aerial torpedo, however, also known as the "Kettering Bug" (Figure 2.2), was first tested in October 1918. Despite the promising results observed in the performed flight tests, there was not a real operational use of them during war.

After these initial testing practices, the testing and manufacturing of other pilotless radio-controlled aircrafts persisted in both countries, mainly for target practice and training purposes. During this period, the term "drone" emerged. It began to be used in 1935 when the British called one of these aircrafts by the name of DH.82B Queen Bee.

Figure 2.1. Aerial target (source: IWM Q 67991).

Figure 2.2. Kettering bug (Wikipedia).

The Vietnam War was the starting point where UAVs witnessed widespread use as reconnaissance and field surveillance tools. Drones have also been given new roles, such as acting as traps in war, launching missiles at fixed targets, and throwing leaflets for psychological operations.

Other countries started to search and explore the drone technology after the Vietnam War. New, more sophisticated drone models were developed. These models were characterized by their better endurance capabilities, their ability to fly at higher altitudes, and their ability to use solar energy for greater durability.

During this period, many other functions such as climate change monitoring, assistance in search operations after natural disasters, photography, filming, agriculture and forestry applications, and goods delivery were performed by drones. However, their main use was for military purposes such as reconnaissance, surveillance, and targeted attacks. They were also used as weapons, killed suspected militants, and sometimes caused civilian deaths that raise questions about the ethics of this type of technology.

In 2010, drones started to be used for civilian applications (Lin, 2018). They were considered as funny, radio-controlled toys piloted with a tablet or smartphone. They included many interesting features like a fixed front facing camera able to follow objects by producing image-based 3D environment. Drones were even able to communicate with each other through built-in Wi-Fi hotspots. Examples of these drones are the Parrot AR.Drones (Figure 2.3). However, there were some concerns regarding flight durations and connectivity range since as an example the Parrot AR.Drone was capable of flying for only 12 minutes within a 150 feet radius. This was considered a problem since it would increase drone crashing possibility due to connection losses.

Figure 2.3. Parrot AR.Drone 2.0 (Lin, 2018).

Figure 2.4 illustrates how the drone industry emerged with time for military and civilian applications (Giones and Brem, 2017). Hence, it can be said that the commercial market for unmanned aerial vehicles in various applications has only been formed during the last ten years, while military drones have been used much longer.

The global commercial drone market was worth about $ 3.45 billion in 2018 and is expected to grow to $ 7.13 billion at a 19.9% CAGR by 2022 (Business Research Company, 2020).

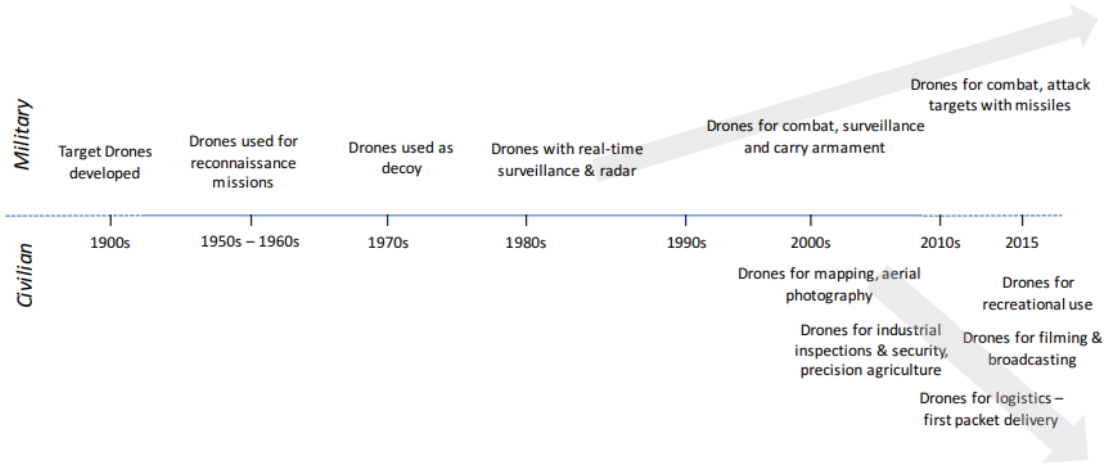


Figure 2.4. Timeline of drone industry development (Giones and Brem, 2017).

Drone technology has been developing and maturing in the last decade. In 2014, it managed to attract the attention of the construction industry. Since 2014, construction companies have started to consider integrating drone technology into their projects due to the popularity and advances drones have gained.

Figure 2.5 better illustrates how the drone market is growing with the advances of the related technologies. Drones, initially seen as toys, are now considered professional tools (Giones and Brem, 2017) by many sectors such as agriculture, industry, surveillance and security, logistics and construction.

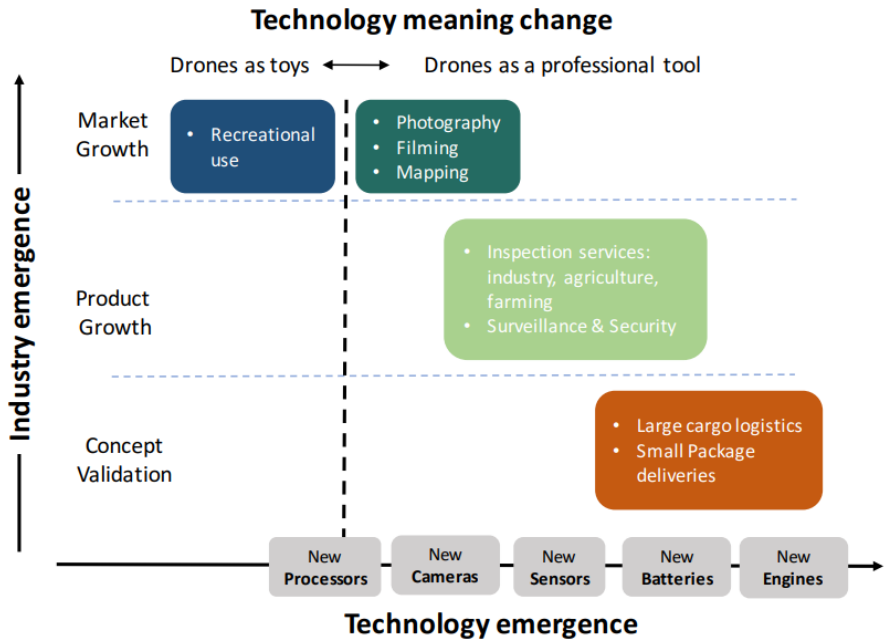


Figure 2.5. Changes in drone applications with technology emergence (Giones and Brem, 2017).

High-quality cameras were mounted on the drones, allowing for 120-degree angle adjustment and 360-degree camera rotation. GPS tracking to provide precise locations, improved battery life and connectivity range were new features that drone companies such as DJI, GoPro and Yuneec have integrated into their drones. These advanced features make the drone a very useful and important tool which therefore increases its chance to be successfully used in construction projects.

It was also observed in the results of a survey conducted in 2016, as shown in Figure 2.6, that around 12% of the construction industry was using drone technology at the end of 2015, given that the drone industry was worth over 2 billion dollars at that time.

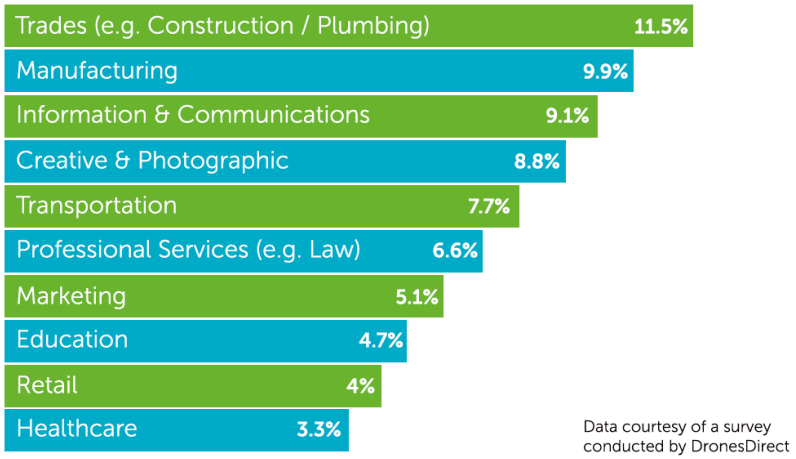


Figure 2.6. Professional drone usage in various industries (Lin, 2018).

2.3. Commercial UAVs' International Market Trends

Source: Mordor Intelligence

A recent report which covers the international drone market analysis was published on *Mordor Intelligence* platform in 2020. The study period was 2018-2026 over which the drone market is expected to record a CAGR of 15.37% to reach US $ 47.76 billion by 2025, as shown in Figure 2.7. Similarly, as stated by Drone Industry Insights (DroneII.com, 2020) in the recent "Drone Market Report 2020-2025", the global commercial drone market is expected to grow to $42.8B by 2025 at 13.8% CAGR. This growth is better demonstrated in Figure 2.8; it is projected that the drone market size will grow nearly twice by 2025 (from $22B to $43B). Furthermore, another more recent article (Rose Morrison, 2021) stated that the construction drone market accounted for $4.8 billion in 2019 and it is projected that it will continue growing to $11.9 billion by 2027.

Figure 2.7. Drone market summary (Mordor Intelligence, 2020).

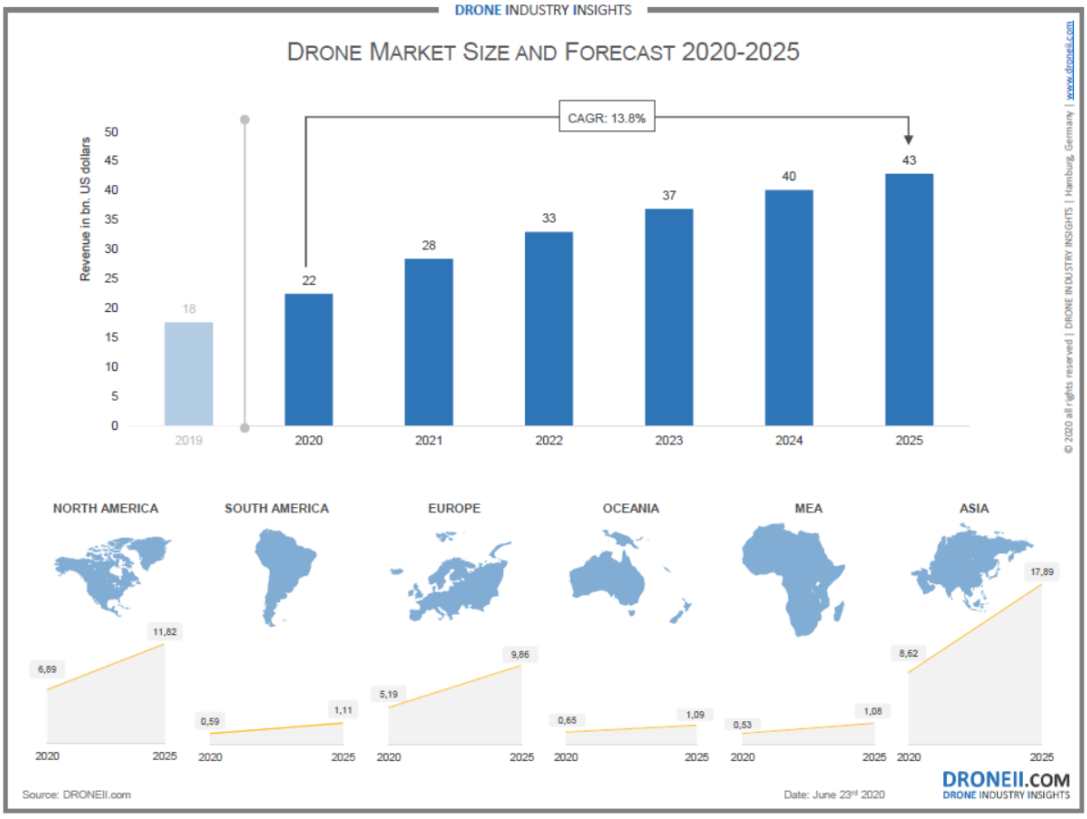


Figure 2.8. Commercial drone market size and forecast, 2020-2025 (DroneII, 2020).

Based on Mordor Intelligence report (2020), the market is divided by drone application, into construction, agriculture, energy (e.g., oil and gas sector), entertainment, law enforcement (e.g., surveillance, search, and rescue), delivery, and other applications (firefighting, mining, aerial mapping).

2.3.1. Key Market Trends by Application

The market analysis shows that the construction industry had the largest market share in 2019 as illustrated in Figure 2.9. This is due to the various applications and benefits which drones can bring to the construction segment. Drones are being used for site surveying and mapping, progress monitoring, visual inspection, and other applications. Additionally, they may lead to more efficient on-site communication and management, costs and time saving as well as better decision-making aspects. Examples on potential applications and benefits of UAVs are presented in the following sections.

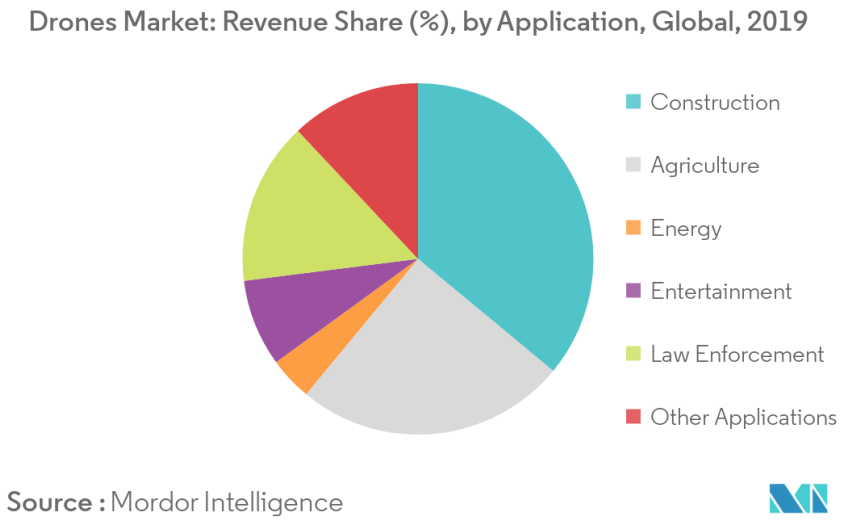
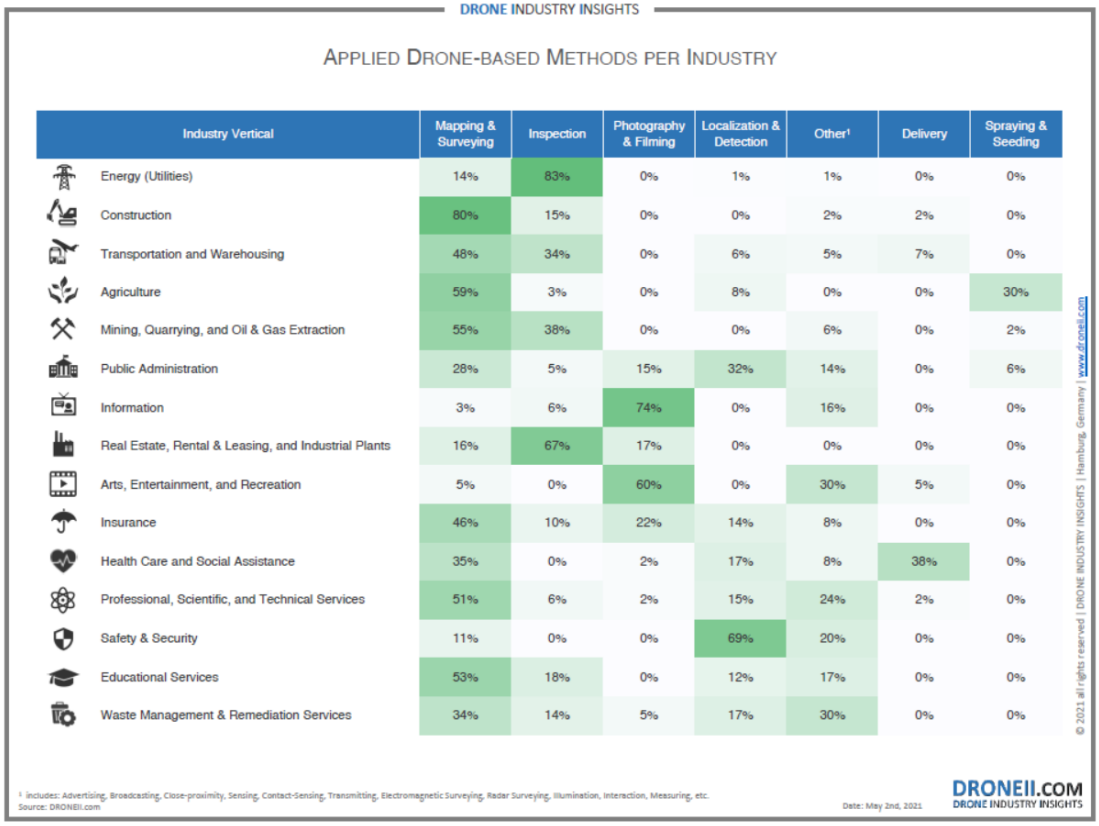


Figure 2.9. Drone market share (%) by application, 2019 (Mordor Intelligence).

Figure 2.10 shows the drone applications per industry as presented by DroneII (2021). The energy sector uses drone technology primarily for inspection purposes (83%) while the construction industry mostly uses drone technology for mapping and surveying purposes. (80%). A quick look at Figure 2.10 shows that mapping and surveying tasks constitute the main drone technology application for most of the examined sectors.



DRONE INDUSTRY INSIGHTS

APPLIED DRONE-BASED METHODS PER INDUSTRY

Industry Vertical	Mapping & Surveying	Inspection	Photography & Filming	Localization & Detection	Other[1]	Delivery	Spraying & Seeding
Energy (Utilities)	14%	83%	0%	1%	1%	0%	0%
Construction	80%	15%	0%	0%	2%	2%	0%
Transportation and Warehousing	48%	34%	0%	6%	5%	7%	0%
Agriculture	59%	3%	0%	8%	0%	0%	30%
Mining, Quarrying, and Oil & Gas Extraction	55%	38%	0%	0%	6%	0%	2%
Public Administration	28%	5%	15%	32%	14%	0%	6%
Information	3%	6%	74%	0%	16%	0%	0%
Real Estate, Rental & Leasing, and Industrial Plants	16%	67%	17%	0%	0%	0%	0%
Arts, Entertainment, and Recreation	5%	0%	60%	0%	30%	5%	0%
Insurance	46%	10%	22%	14%	8%	0%	0%
Health Care and Social Assistance	35%	0%	2%	17%	8%	38%	0%
Professional, Scientific, and Technical Services	51%	6%	2%	15%	24%	2%	0%
Safety & Security	11%	0%	0%	69%	20%	0%	0%
Educational Services	53%	18%	0%	12%	17%	0%	0%
Waste Management & Remediation Services	34%	14%	5%	17%	30%	0%	0%

[1] Includes: Advertising, Broadcasting, Close-proximity, Sensing, Contact-Sensing, Transmitting, Electromagnetic Surveying, Radar Surveying, Illumination, Interaction, Measuring, etc.
Source: DRONEII.com

Date: May 2nd, 2021

DRONEII.COM
DRONE INDUSTRY INSIGHTS

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Figure 2.10. Drone applications per industry (DroneII, 2021).

The recognition of the importance of drones' use in construction projects has led to the increasing demand which has also encouraged drone manufacturers to produce more drones, especially for the construction industry. For example, at the European Drone Summit in Frankfurt, Germany, in October 2018, DJI launched its Phantom 4 RTK drone, designed for surveying and mapping applications. Additionally, in April 2018, a new construction solution, "DroneDeploy App", was launched by DroneDeploy Inc. It allows users to intuitively plan photographic flights, automatically capture corner views, and instantly generate a visual

timeline of a construction site as well as a repeatable weekly progress report. This solution was used by many construction companies such as presented in the “Case studies” section. Such developments helped the market to see an increase in demand from the construction industry.

2.3.2. Key Market Trends by Region

The drone market growth trends were studied in all regions which are North America, Latin America, Asia-Pacific, Europe, Middle East, and Africa as shown in Figure 2.11. As a result of the analysis, the fastest growing market was seen in Asia-Pacific while the largest drone market was in North America.

Several countries across Asia-Pacific region such as China, Japan, and Australia, are expected to witness rapid drone market growth rates. This is mainly due to the positive changes in drone regulations in these countries. For example, in China, which has been the global center for drone manufacturing during the past six years, the government issued favorable schemes and policies for drone purchases, encouraging by that several industries (construction, mining, telecommunication, agriculture…) to increase their adoption of drones. China supports about 70% of the global civilian drone market; it had around 1,200 drone manufacturers at the beginning of 2019 (up from 130 in 2013). Furthermore, in Japan, the government has taken initiatives to develop the country's commercial drone industry and ensure drone delivery in Tokyo by 2020. The government launched its plans to set up a modern drone registry system by 2022 to offer more opportunities for drones. In Australia, a major drone industry hub in the region, more than 1,200 drone operators existed by July 2019. In addition to the supportive regulations issued by the Civil Aviation Safety Authority (CASA) in Australia, new technologies and services are being developed by drone operators to facilitate drones’ integration into several applications.

Figure 2.11. Drone market growth by region (2020-2025) (Mordor Intelligence).

Similar results were provided by DroneII.com stating that the biggest drone market is Asia, mainly in Japan and China, while India is expected to become the third-largest drone market by 2025. As stated by DroneII, the top ten drone market are Australia, Canada, China, France, Germany, India, Italy, Japan, UK and USA.

2.3.3. Market Concentration - Competition

Companies, such as SZ DJI Technology Co. Ltd (DJI), The Boeing Company (Insitu), Terra Drone Corporation, Intel Corporation, BirdsEyeView Aerobotics, Parrot Drones SAS, Yuneec, and Delair SAS, are in continuous state of competition aiming to gain market shares by developing advanced technology-integrated drone hardware and software solutions. Companies, like The Boeing Company, Alphabet, and Intel, are entering into the commercial sector of drones. The ongoing entry of companies to the drone market is expected to make the market fragmented in the near future as shown in Figure 2.12.

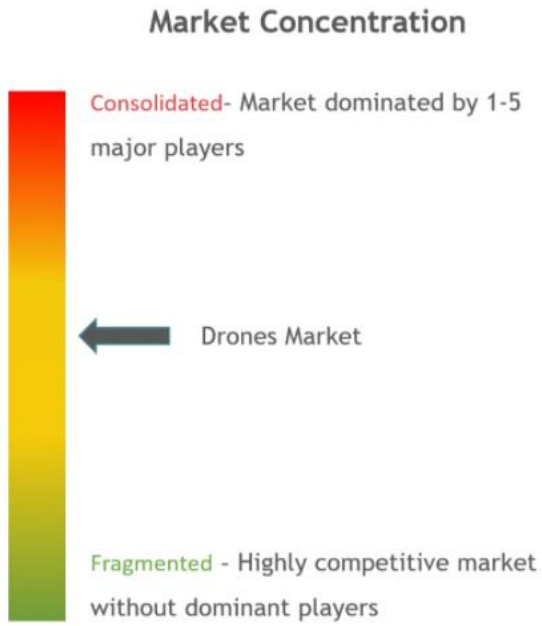

Figure 2.12. Drone market concentration (Mordor Intelligence, 2020).

2.4. Commercial UAV Use and Regulations in Turkey

Turkey became interested in UAVs in 1990s, starting with the direct procurement projects, to respond to the needs of the "Turkish Armed Forces" (TAF). However, 2004 is known as the milestone year for UAV studies in Turkey. Starting from this year, many Turkish UAVs, such as Anka (MALE), Çaldıran (Tactical), Bayraktar (fixed-wing Mini), and Malazgirt (rotary-wing mini), were produced for military purposes. In 2004, yearly UAV expenses was $75 million but it has increased to reach $250 million in 2010 with more than $1 billion expended for R&D, production, and direct procurement of UAVs between the years 2004 and 2010 (Kahvecioglu and Oktal, 2014).

As noticed, Turkey completely focused in its UAV studies on the military requirements. However, UAVs are now being used for different purposes in many fields in Turkey like agricultural surveillance and control, cartography and digital mapping, aerial photography, earthquake tracking, search and rescue etc. (Kahvecioglu and Oktal, 2014).

As stated by the General Directorate of Civil Aviation (GCDA), there were 33,602 registered drones and 51,673 designated drone operators in Turkey (Daily Sabah, 2019) using most commonly the Chinese DJI drone, with over 80% market share (Aviation Turkey, 2019)

Furthermore, unlike the United States, the United Kingdom (UK), and Canada, Turkey has a small number of private businesses operating drones for commercial purposes. This is mainly caused by the regulations set by the General Directorate of Civil Aviation (GDCA). Main regulations are stated below:

- Drone pilot license requirement for drone operators
- Consideration of airspace restrictions
- Flying an UAS that weighs 500 gr or more on Turkish airspace requires pilots to be registered to the system and receive approval from the General Directorate of Civil Aviation
- Any drone heavier than 0.5 kg cannot be flown within 9 km of airports or in closed spaces and cannot hover above 120 m.
- Maximum drone weight is 4 kilograms (8.8 pounds) for private/personal flights.

Hence, there is lack of investments and incentives in Turkey in the commercial drone market since the total amount of investments and incentives in Turkey was less than US$100 million in 2018 compared to more than US$100 million investment in a single start-up company in the US (Uyanık, 2019).

2.5. UAV Types and Characteristics

There are many types of UAVs in the market supporting different uses but also subject to different regulations (Accenture, 2016). These UAVs exist in different forms, depending on their functions, having different selling points such as controlling range and flight time, weight, speed, carrying capacity and videography or photographic capabilities.

Generally, a drone can hover up to 60 minutes, with a maximum speed of 65 km/h; it also can be monitored from a few kilometers away (Makdisi and Makadsi, 2019).

UAVs are constructed with intelligent stabilization systems to keep them flying and can carry multiple sensors, depending on their lift capacity and payload specifications, to execute assigned functions. These sensors support UAVs to obtain a wide range of information which will increase their possible applications and the business value of their results. For example, there are sensors for light intensity, gas vapor, pressure, sound to electric, frequency, radiation (UV), direction and acceleration (Figure 2.13). Drones also can have high-resolution cameras providing high-resolution pictures and videos, as well as thermal or multispectral cameras. A camera mounted on gimbals is one of the most used devices to obtain high-quality video and still photography since gimbals allow the camera to remain in stable position and to some extent isolated from the rotation of the drone (Accenture, 2016; Small, 2018).

The main components of a UAV system (quadcopter) are shown in Figure 2.14. There are two types of propellers in drones which are “standard propellers”, placed in the front part to direct the drone, and “pusher propellers”, placed in the back part to provide forward and backward thrust to the quadcopter. The main body of the drone (quadcopter) is called “chassis”. It constitutes the house for all other components while the “flight controller” represents the drone brain controlling the power supply to the electronic speed controller as well as the motors to ensure the drone stability in the air and detect possible orientation changes. For the electric speed controller, just as its name implies, its main function is to control the speed of the DC motors which are preferred to be high-torque motors to enable speed changes and long flight times. Considering the transmitter and receiver components, these two components work together. The transmitter transmits or sends the signals received from the drone controller to the receiver to generate instruction of direction and thrust to the flight controller. Finally, the GPS module is very important since it is the source of navigational data (longitude, latitude, and elevation) to the Controller, helping thereby the

controller in identifying the taken path and safely returning to the initial location in case of lost connection.

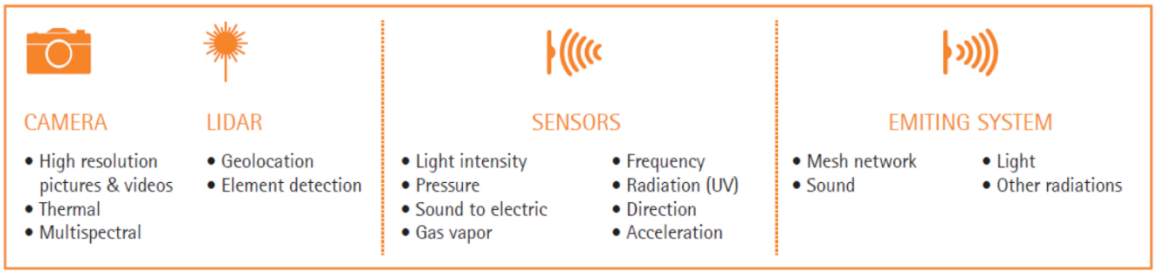

Figure 2.13. UAV general characteristics (Accenture, 2016).

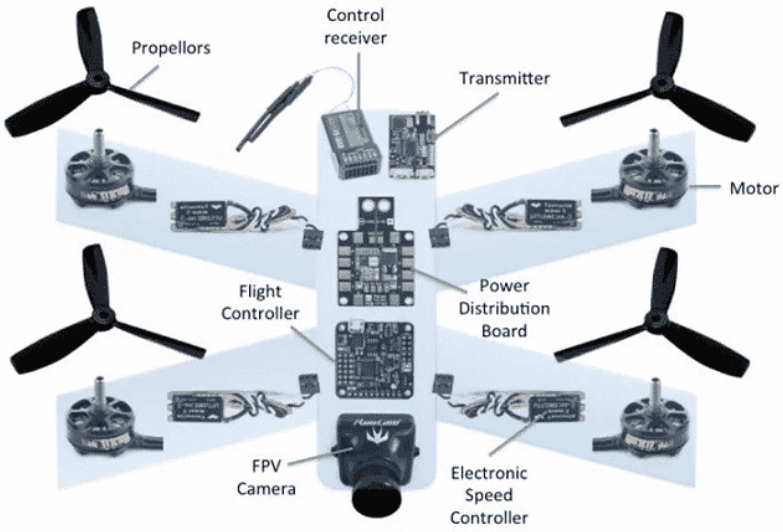

Figure 2.14. Components of a UAV system (Electricalfundablog).

DJI is a leading drone manufacture company which provides a wide range of low-cost consumer drones (Small, 2018). These drones, as shown in Figure 2.15 (starting from the front left to the right, the Spark, Mavic Air, Mavic/Mavic Pro, the Phantom 4 Series, and the DJI Goggles), have different camera resolutions, flight durations, weights, gimbal capabilities and lifting capacities. Larger quadcopters have higher lifting capacities allowing them to carry significant payloads such as an aerial mounted LIDAR which permits the quadcopter to acquire 3D laser scanning data and create digital terrain models and digital elevation models. Figure 2.16 shows an example of an aerial mounted LIDAR unit (Small, 2018).

Figure 2.15. DJI consumer drones (Small, 2018).

Figure 2.16. Commercial drone with aerial mounted LIDAR (Small, 2018).

There are mainly four types of UAVs listed below. Each type of UAV presents strengths and weaknesses which depending on their application may be serious. These types are multi-rotor drones, fixed-wing drones, fixed-wing hybrids, and single rotor helicopter.

In general, fixed-wing UAVs are used when there is a need to cover large distances rapidly. They are more useful than any other type in covering large areas and are perfect for mapping applications or kilometer scale measurements. On the other hand, multi-rotor UAVs

are more flexible. They can hold their position in the air and rotate. They are best used for applications requiring precise vehicle placement and mapping of complex three-dimensional (3D) features (Greenwood et al., 2019). Below more characteristics are presented for each UAV type.

2.5.1. Multi-Rotor Drones

Multi-rotor drones are most used since they can be easily manufactured and are the cheapest choice available in the market (Makdisi and Makadsi, 2019). They are characterized by their easy take-off, precise control, and wind resistibility. These drones can be easily operated and maintained and have high flexibility and stability. The latest drone models provide a payload of up to 5 kg with an ability to hold complex and heavy surveying systems, such as a single-lens reflex (SLR) camera. Quadcopters, having four rotors, are the commonly used multi-copters (Siebert and Teizer, 2014). The multi-rotor drone can be used for aerial photography, aerial video surveillance etc. However, the multi-rotor drone has some disadvantages such as limited flying time, durability, and speed, which does not make them the best choice for large-scale projects (Makdisi and Makadsi, 2019). Figure 2.17 shows an example of a multi-rotor drone.

Figure 2.17. Phantom 4 Pro (source: DJI).

2.5.2. Fixed-Wing Drones

Fixed-wing drones have different design and functions. This type of drones has wings similar to normal airplanes' wings and does not make use of energy to stay floating in the air; unlike multi-rotors, they lack the ability to hover in the air which makes them inefficient for aerial photography. Furthermore, they require higher expenses and training (Makdisi and Makadsi, 2019). However, as mentioned previously, fixed wing drones are ideal for long distance operations, they have long range and endurance which allow them to survey large areas at fairly low building and operating cost (Siebert and Teizer, 2014). That is why they are particularly used for highway planning and programming (Small, 2018). Figure 2.18 shows an example of a fixed wing drone.

Figure 2.18. Fixed wing drone (source: delair.aero).

2.5.3. Fixed-Wing Hybrid VTOL (Vertical Take-off and Landing)

Fixed wing hybrids VTOL (Vertical Take-off and Landing) are a combination of both multi-rotor drones and fixed wing drones which leads to longer flying times and hovering ability (Makdisi and Makadsi, 2019). However, VTOLs are still under development. These drones use the propellers to lift off and the wings for gliding (Greenwood et al., 2019). Figure 2.19 shows an example of a fixed wing hybrid drone.

Figure 2.19. VTOL UAV (source: droneassemble).

2.5.4. Single Rotor Helicopter

Single rotor drones highly resemble to actual helicopters in their design and structure. A single rotor drone has only one rotor and a small tail to control its direction. This drone type is very energy efficient and has higher flight time than other types (Makdisi and Makadsi, 2019). Figure 2.20 shows an example of a single rotor helicopter drone.

Figure 2.20. Single rotor drone (source: prodrone).

Greenwood et al. (2019) has further provided a more detailed breakdown of UAV platform types based on their wing or rotor geometries as shown in Figure 2.21.

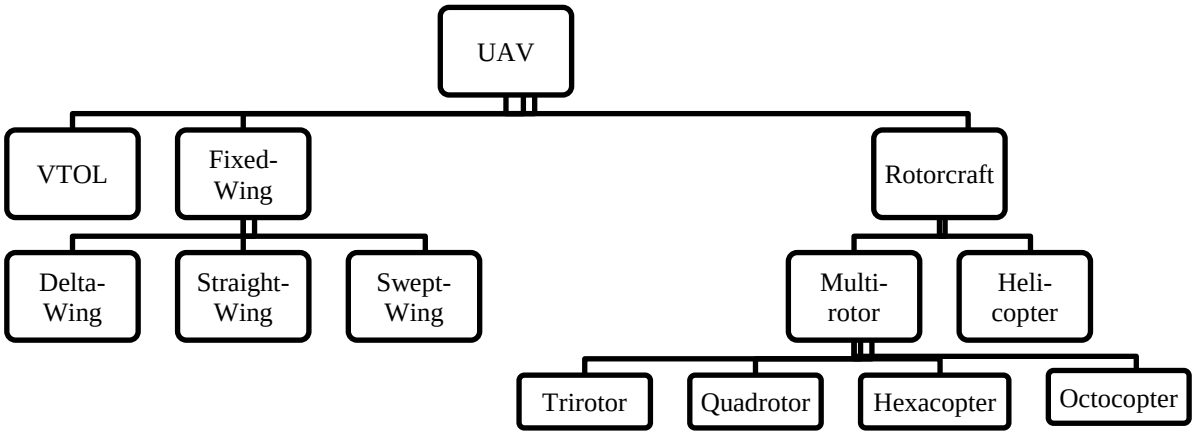

Figure 2.21. UAV types breakdown (adapted from Greenwood et al., 2019).

Furthermore, UAVs may function at different levels of autonomy. Table 2.1 illustrates the different drone levels of autonomy with respect to the degree of human control over these machines. These are no autonomy (human operation), autonomous (function specific), semi-autonomous, and fully autonomous (DeYoung, 2018).

Table 2.1. Levels of drone autonomy (DeYoung, 2018).

Autonomy level	Concept	Definition
0	Human operation	The drone is always controlled by an operator
1	Autonomous (function specific)	The operator has overall control of the drone and oversees its safe operation. However, limited operation can be transferred over a specific drone function such as flying from a point to another
2	Semi-autonomous	The drone performs a subset of the specified tasks without operator intervention
3	Autonomous (fully)	The drone completes all its defined tasks without human interaction

3. UAV(S) IN CONSTRUCTION

This chapter which consists of a comprehensive literature review tends to answer the questions found below.

i. What do we mean by Unmanned Aerial Vehicles (UAVs)?
ii. What are the potential applications of these emerging technologies in the construction sector? (Real case studies are also presented in Turkey and abroad)
iii. What do we mean by Critical Success Factors (CSFs)?
iv. Which Critical Success Factors (CSFs) have been identified by previous researchers for implementing new technologies (UAVs and other similar technologies) mainly in construction projects?

3.1. Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles or Drones are becoming very popular in the construction industry due to the several important benefits they provide mainly for construction management tasks. Their benefits and applications are discussed in the following sections. This section is mainly concerned with understanding the meaning of “drones” as defined by many researchers in the literature relevant to this study.

Simply, a drone is an unmanned aircraft. It is a flying robot known for its ability to be remotely controlled by a pilot or fly autonomously through specified flight plans. These flight plans are controlled by software in their embedded systems, operating in conjunction with onboard sensors and GPS.

In the past, especially in World Wars I and II, UAVs were most often used for military purposes, where they were used initially by pilots for anti-aircraft target practice, intelligence gathering and as weapons platforms to attack the enemy territories.

However, with the continuing advances in technology, drones are now being used for civilian and commercial purposes as well. Their importance has been recognized in many areas ranging from search and rescue, surveillance, traffic monitoring, weather monitoring and firefighting, to personal drones and business drone-based photography, as well as videography, agriculture and even delivery services.

As stated by Alizadehsalehi et al. (2018), many terms other than Unmanned Aerial Vehicles (UAV) are being used interchangeably in the literature to address this type of technology. Among these terms are unmanned aerial systems (UAS), remotely piloted vehicle (RPV), remotely operated aircraft (ROA), remote controlled (RC) helicopter, unmanned vehicle systems (UVS), model helicopter, and drone. In this research, "UAV" and "drone" terms will be used interchangeably. These systems, equipped with a camera and sensors including GPS, can be controlled by a smartphone or tablet to collect high-resolution images from several angles in a precise and efficient way.

Delgado et al. (2019) referred to drones as "terrestrial, aerial or nautical vehicles which can be piloted remotely, or which are autonomous". 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.

Irizarry and Costa (2016) referred to "unmanned aerial systems (UAS)", as adopted by the Federal Aviation Administration (FAA) which is the national aviation authority of the United States. As mentioned in this study, according to a report by the "Association for Unmanned Vehicle Systems International (AUVSI)" in 2013, the market of UASs is in constant growth expected to reach $140 billion in the US alone in the next 10 years.

UASs are defined as unmanned aerial hardware platforms which include a portable control station for the human operator and one or more unmanned aerial vehicles (UAVs) which are equipped with various sensors (cameras, videos, far and near infrared, radar or laser-based range finders and specialized communication devices) to perform data collection

and processing. They can function with or without direct human involvement. In addition, UASs' have high potential to outperform manned vehicles as they are safer, faster, and offered at a lower cost.

Newcome (2004) described the UAS as "a powered aerial vehicle" without a human operator; it utilizes aerodynamic forces to lift the vehicle, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can hold a lethal or nonlethal payload.

Similarly, Greenwood et al. (2019) referred to UAVs as "aeronautical platforms that operate without the use of onboard human operators". They differentiated between UAVs and UAS by stating that an UAS consists of the UAV platform in addition to communication, piloting, sensing, flight planning, and other critical components needed for UAV operation (i.e., control station).

Finally, as defined by Ayemba (2020), in simple and concise terms, drones are "flying computers carrying an array of sensors to collect data, which gives companies the opportunity to make intelligent and educated decisions about their projects rapidly, safely and efficiently".

3.2. UAVs Applications in Construction Projects

Since last decade, the integration of drone technology in construction projects worldwide has been increasingly considered. A good number of researchers have performed studies on the potential applications of UAVs in the construction industry. This section presents some of these studies under the different UAV applications which were extracted from the literature as follows: "Land surveying and 3D Modeling/ Photogrammetry", "Progress monitoring and reporting", "Quality inspection", "Time management", "Post-disaster assessment or Damage assessment", "Safety control and inspection", and "Promotional photography".

3.2.1. Land Surveying and 3D Modeling / Photogrammetry

Land surveying is an essential procedure in all land development projects and at the beginning of the construction process (Li and Liu, 2018). Traditional land surveying methods require bulky tools, such as tripods, total stations and GPS equipment and are lengthy in time making the surveying procedure lasts for weeks. However, with the introduction of drones as surveying tools to construction projects, the surveying process may take only few hours to be completed.

Accurate and quick cut and fill volume calculations as well as other survey analytics necessary for planning and progress tracking can be done using drone-captured data. Earthworks at the construction site are also being simplified by referring to the 3D drone-data surveys which allow tracking earth-moving operations safely and more economically than with traditional walkthroughs.

Photogrammetry is a surveying technique which transforms 2D images to 3D models by using triangulation with high quality photographs. Hence, by combining photogrammetry with LiDAR (Light Detection and Ranging) technology, 3D building models, contour maps, volumetric surveys can be produced from the images previously captured during a UAV flight over the construction site (Tatum and Liu, 2017). Figure 3.1 shows how drones are being used for photogrammetry.

Siebert and Teizer (2014) evaluated the performance of a UAV system with an RGB camera mounted for surveying applications as a measurement tool that can quickly and autonomously collect data for mobile 3D mapping of earthmoving projects. A new flight planning methodology was presented to facilitate the work of pilots for automated surveying tasks by minimizing the manual effort needed. This methodology is comprised of 4 main steps which are preparation (flight planning with the MikroKopter Flight Planning tool), recording, post-flight data processing, and data generation. Siebert and Teizer (2014) compared UAV-based photogrammetry with conventional surveying procedures such as ground truth.

In addition, the possible sources of error in UAV surveying were discussed in this study. The differences between UAV-based photogrammetry and other surveying techniques in terms of total coverage area and survey error are better illustrated in Figure 3.2. The performance of the UAV was evaluated in a test bed environment and showed better results than previous studies.

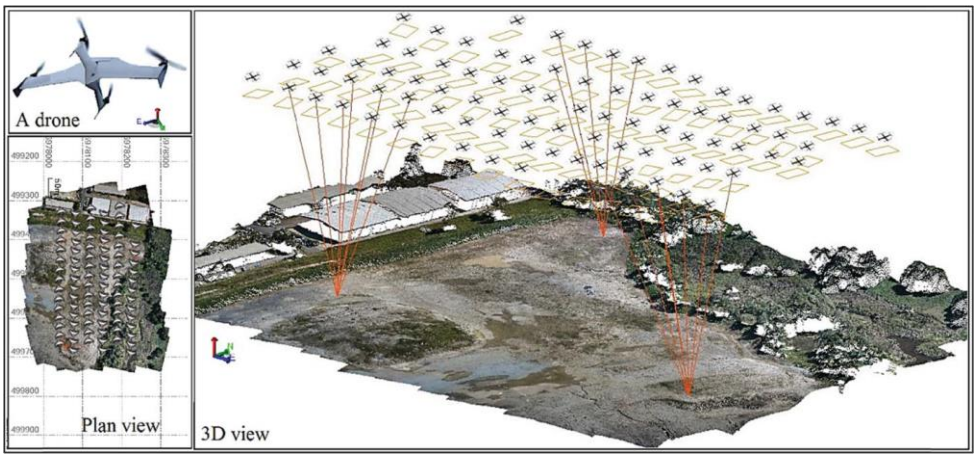

Figure 3.1. Drone-based photogrammetry (Li and Liu, 2018).

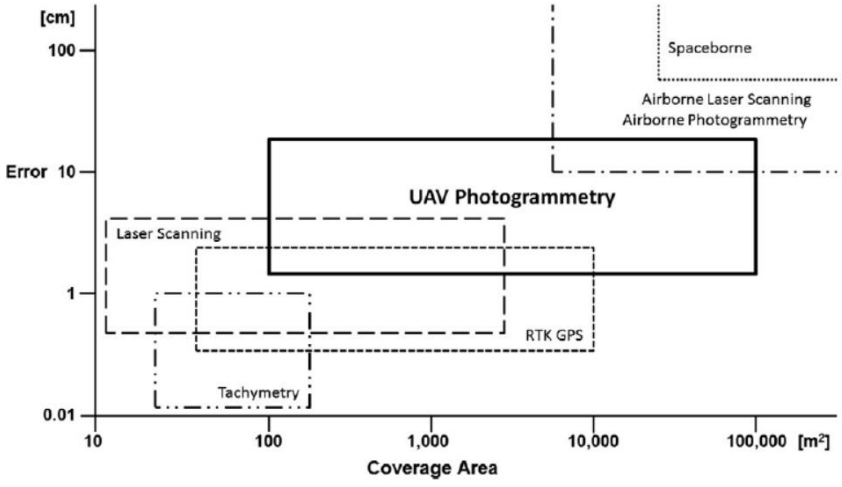

Figure 3.2. UAV applications for surveying tasks (Siebert and Teizer, 2014).

3.2.2. Progress Monitoring and Reporting

Visual assets captured by drones are very important to visualize the construction site transformation as the project progresses. They may be helpful to ensure that the project is still within budget and on schedule by efficiently monitoring the contractor's work at site; in addition, the visual data collected using drones facilitate sharing of information on work progress and collaboration with remote stakeholders. They simplify reporting by providing up-to-date information to project stakeholders and contractors. Traditionally, monthly progress reports are prepared by site engineers so stakeholders can see how everything is progressing. With the recent integration of drones into construction sites, the preparation of reports will be completed and shared faster, as drones can fly over a building and along its sides, providing an aerial view of how development is progressing. Moreover, using online platforms to process drone data can reduce the time and costs associated with site visits.

Additionally, any disputes with contractors can be solved by referring to survey data, timeline features, and reports delivered by drones since they show the physical state of the site at every survey. Delays are considered a major cause of disputes in construction projects. However, these disputes can be avoided if there is a clear illustration of the cause and effect of the delay event so that each party will accept its share of responsibility. The use of UAV and BIM technologies (especially 4D BIM i.e., integrating the time with the 3D model) can resolve the occurring disputes by providing a clear visualization of the work in progress and accurate and detailed record keeping (Vacanas et al., 2016).

Lin et al. (2015) proposed a model-driven approach for visual data acquisition and analysis using UAVs to achieve better automated construction progress monitoring. This study investigated the use of UAVs for more efficient and frequent collection of field images compared to traditional manual acquisition procedures, along with 4D BIM, which is important to drive autonomous data collection. The proposed model has the potential to ensure the accuracy and integrity of 3D as-built models, and to provide the level of detail required to

monitor the Work-in-Progress (WIP) based on both the field images collected by the UAV and BIM.

Ham et al. (2016), in a review of the literature related to visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles (UAVs), stated that the objective behind such monitoring procedure is to:

1. Collect visual data (images or videos) from the most informative views (canonical or top-down view) on a construction site

2. Analyze them with or without a priori BIM to examine performance deviations during construction (e.g., progress and quality)

3. Monitor continuing operations for productivity and safety

4. Describe the current conditions of existing civil infrastructure systems

5. Visualize and communicate the most up-to-date status of work in progress quickly and regularly with on-site and off-site project participants.

A visualization for the next generation construction site using camera-equipped UAVs as a tool to autonomously monitor work-in-progress for improving safety, quality, and productivity was provided by Ham et al. (2016) as shown in Figure 3.3.

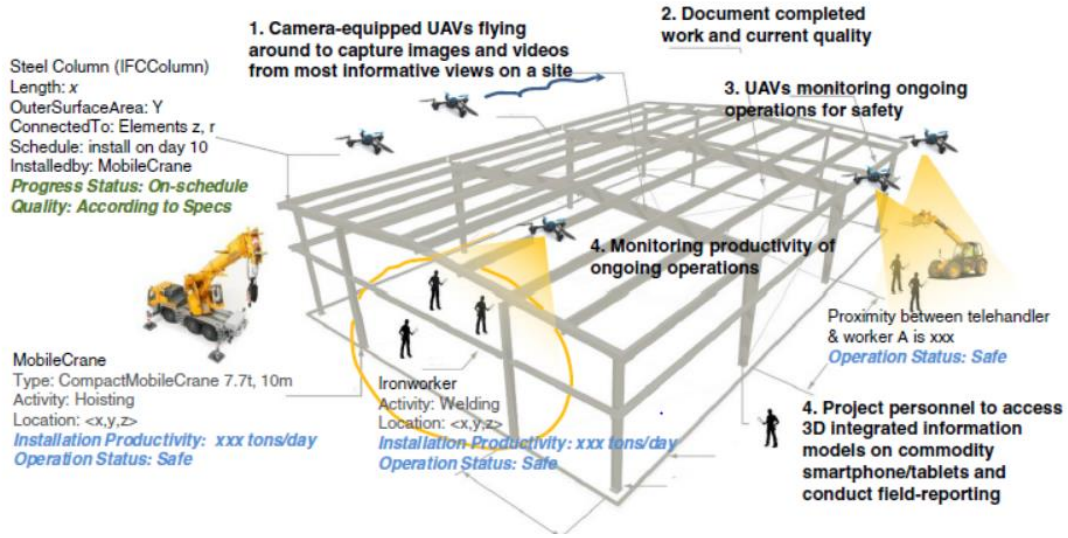

Figure 3.3. A vision for the next generation construction site where camera-equipped UAVs autonomously monitor work-in-progress for improving safety, quality, and productivity (Ham et al., 2016).

In addition, the importance of UAVs for progress monitoring at construction sites can be highly related to their ability to improve logistics management, i.e., equipment and material tracking. Logistics, by definition, is the movement of materials and services from the origin point to the destination where they are needed by the workforce. In construction projects, the materials and services needed are mainly bought from suppliers and subcontractors. The use of drones can help logistics managers to perform better supply chain management since drones can transport materials from suppliers and move them on construction sites. UAVs also can detect and track the location of tagged materials with the help of a real-time location system such as GPS, radio frequency identification (RFID) and ultra-wide band (UB) radio (Li and Liu 2018).

Hubbard et al. (2015) performed several functional tests in an indoor environment with an aim to study the feasibility of combining RFID technology and UAV technology to enhance supply chain management in construction projects. The developed system to be tested consisted of a RFID reader mounted on a UAV considering the frequency interaction between the UAV telemetry and RFID scanning frequencies. Figure 3.4 shows the RFID handheld unit

used in this study. The flight path of the UAV was predetermined according to the spacing and arrangement of RFID tags. After setting the tags, the selected quadcopter was flown manually along the route (within 1 meter over the tags) to determine whether it can detect the tags or not. Figure 3.5 illustrates the setting of the system. Three tags were placed and spaced five meters from each other. During the first test, only one tag was detected while in the second test two tags were detected by the system. No test resulted in the identification of the three tags together. In general, tests showed that a RFID reader mounted on a UAV can track the location of tagged materials and provide information on tagged components which can be then represented visually in 3D BIM models. Also, the combination of these two technologies can facilitate project control and management in supply chain management systems. However, to ensure the successful implementation of the developed system, the reading range of the RFID unit as well as the UAV battery life should be taken into consideration.

Figure 3.4. Trimble June T41S for RFID Tag Reading (Hubbard et al., 2015).

Figure 3.5. IRIS Quadcopter from 3D Robotics with Trimble Juno Handheld Unit (Hubbard et al., 2015).

Daily acquisition of UAV images allows better planning of the placement of stored materials and the flow of workers and vehicles within and around the construction site. It can also help detect potential problems with established construction or the constructability of planned installations. (Tatum and Liu, 2017)

Irizarry and Costa (2016) studied the potential applications of UASs for construction management tasks including progress monitoring and site job logistics as well as other applications such as safety conditions' evaluation and quality inspections. After conducting UAS flights in two construction projects, where one was in the United States while the other one was in Brazil, Irizarry and Costa (2016) developed a database of the UAS visual assets (images and videos) which were collected during flights. Then, semi-structured interviews with construction project professionals and personnel were conducted to determine the potential application of UASs for progress monitoring. These interviews showed that project personnel are more interested in UAS application for training, marketing and more importantly for project documentation, extraction of different viewpoints and information about their jobsite, equipment, building process and the adjacent region; and finally, they mention that visual documentation allows them to have more control over their needs.

Another study was done by Fang et al. (2016) to show the importance of UAVs in tracking materials and equipment locations at jobsites. A point cloud–vision hybrid approach was developed to track 3D location information for mobile construction resources. Structure from Motion (SfM) technique was used to process the 2D aerial images captured by drones. SfM photogrammetry is a technique allowing for automatic computation of camera orientations and scene geometries by using a dense point cloud with many 3D coordination points and colored data. In this study, the tracking of two vehicles, a concrete mixer truck and a minivan, used in the case study proposed, was examined. 169 images with high resolutions (4912 × 3264) were produced by a digital camera (without a mirror) mounted on the multirotor drone used. After that, the generation and processing of the 3D point cloud was performed. Results emphasized the capability of drone technology to dynamically follow the 3D movement of construction project assets in supply management.

Kaamin et al. (2017) showed the difference between construction site's images collected from a traditional digital camera and others captured by a micro-UAV for construction monitoring purposes. Consequently, micro-UAVs proved to provide better angle views of the building whereas common digital cameras have limited angle views, as shown in Figures 3.6 and 3.7. Thus, it is highly preferable to replace the traditional technique of capturing images at construction sites by using UAVs which can offer an overall visualization of the construction works being in progress at site and allow for better construction monitoring and documentation.

Figure 3.6. Construction site image captured by a common digital camera (Kaamin et al, 2017).

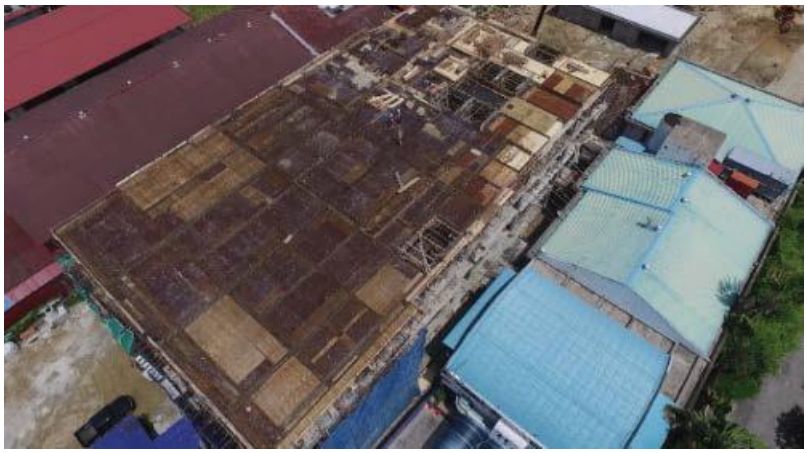

Figure 3.7. Construction site image captured by a Micro UAV (Kaamin et al., 2017).

3.2.3. Time Management

Integrating drone technology with BIM can lead to a better time management in construction projects through helping project managers in identifying possible delay causes and making appropriate decisions to avoid such delay events (Vacanas et al., 2016). Combining these two emerging technologies provides project planners and BIM engineers with a better visualization of the ongoing construction works and the current project state. A 3D BIM model combined with the project schedule is known as a 4D BIM model. There is many software allowing for 4D planning (3D model + schedule) such as Synchro Pro, Navisworks, etc. which is a very important step in construction management. 4D planning links project schedule activities with the 3D BIM model resources; all the information related to project schedule, resources and 3D objects can be found in the generated model. This enables project managers, planning engineers, BIM engineers, BIM coordinators as well as other stakeholders to collaborate, to efficiently track the work progress at any stage of the project, from its start till its completion, to visually recognize the progress of a certain activity at a certain time using 4D animation, and to compare the planned progress with the actual progress. Adding UAV technology to 4D BIM can provide more efficient and easier collection of data compared to other progress data collection tools used at site by contractor's site engineers such as photographs, the site's diary, progress meetings minutes and correspondence (Vacanas et al., 2016).

The framework presented in Figure 3.8 (Li and Liu, 2018) illustrates how 4D BIM and drones can be combined to provide better time management. First, the project schedule, which is mostly prepared using Primavera P6 or Microsoft Project software, should be integrated to the 3D BIM Model (generally designed in Revit software). This integration results in the production of the as-planned BIM Model which will be used, updated, or modified as required during the project lifecycle. On the other hand, a drone is used and flown over the construction site with a predetermined flight path and at project stages to collect visual data (photos and videos) of the construction works being in progress. The collected data will then be imported into photogrammetry software, such as Pix4D, to generate 3D as-built point cloud models with

calibration of camera positions, orientations, and specifications. These as-built point cloud models are then overlaid manually over the as-planned BIM models so that project deviations can be easily detected, and the performance analyzed. After this analysis, the project schedule can be successfully updated and, consequently, new critical schedule information can be produced such as critical activities, current situations, and expected completion data.

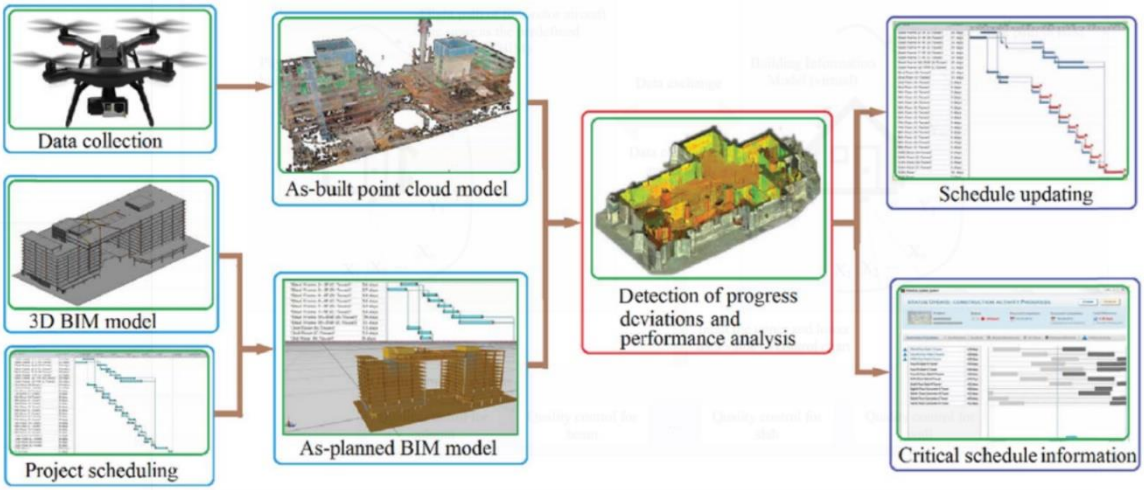

Figure 3.8. Flowchart combining 4D BIM with drone technology (Li and Liu, 2018).

Anwar et al. (2018) developed a drone-based fully automated smart construction monitoring and reporting system and evaluated its importance in facilitation construction management practices by referring to a case study construction project. The project consisted of a single-story residential apartment building. Construction activities were monitored using drones scheduled to operate at several construction stages, with different heights (20, 30 and 50 meters) and camera angle settings (0, 30, 45, and 80 degrees) to finally get four different visual data (images) sets. Then the collected data was analyzed using "3DF Zephyr" software and a 3D model was generated. After its development, the drone-based 3D model was imported to Revit and overlaid over 3D BIM models for progress comparison purposes. Three types of comparison were carried using the developed framework over the selected case study.

The first type was a volumetric comparison between construction plan/schedule and on-site progress for accurate progress monitoring as illustrated in Figure 3.9. The second was a quantity comparison for the placement of toilets which showed that all toilets are placed on schedule. However, the third comparison which was a schedule comparison for the placement of windows showed that there is a delay by schedule for windows' placement. The accuracy of the smart construction monitoring model developed by Anwar et al. (2018) was further proved by applying the model to other five case studies with a mean error in the control point measurements of only less than 0.12 meters. Finally, this model can enhance site supervision and management practices, operations, planning, and on-site adjustments resulting in cost savings, schedule compression and better project quality.

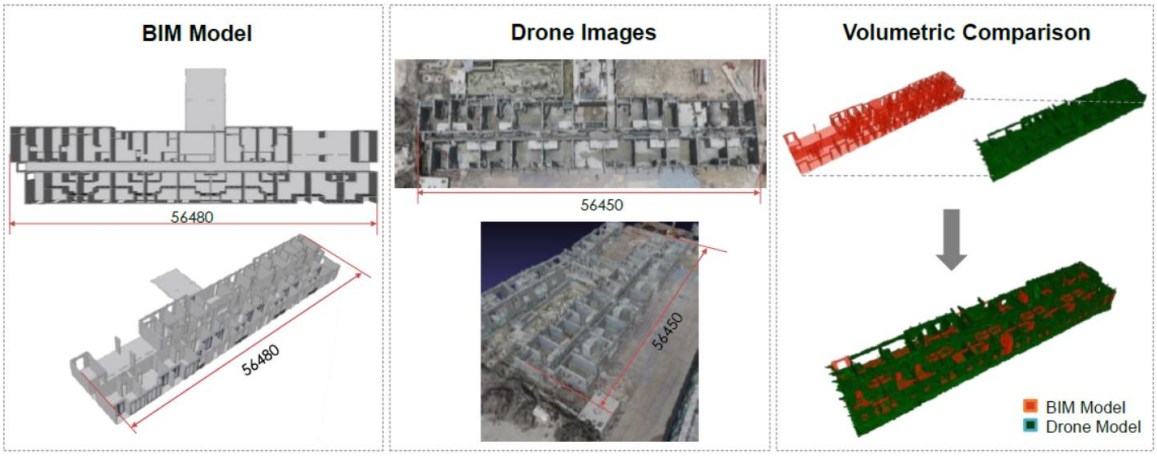

Figure 3.9. Volumetric comparison between construction plan and on-site progress (Anwar et al., 2018).

3.2.4. Quality Inspection

Quality management has been gaining considerable importance in the construction sector since proper quality monitoring can highly increase the chance of avoiding low productivity, high costs and delay problems. Hence, quality inspection and control techniques should be improved so that construction defects can be detected and corrected easily, at lower costs and shorter duration.

Wang et al. (2015) developed a BIM and LiDAR-based construction quality control system to allow quality managers to collect real-time onsite quality data and process them for construction quality control. The system was composed of five parts which are LiDAR-based real-time tracking system, BIM-based real-time checking system, quality control system, point cloud coordinate transformation system, and data processing system. LiDAR-based real-time tracking system was mainly for real-time onsite data collection and comprises three subsystems: quadrotor system (a multi-copter), flight path control system and LiDAR system (used to scan the as-built model). BIM-based real-time checking system was designed to extract the as planned 3D data and visualize quality deviations using Navisworks software. In this part, the predefined flight path parameters were transformed into a Quadrotor flight path control system in such a way that a Quadrotor, in the real environment, will be able to fly the same path as the predefined flight path in the virtual 3D environment. The Proposed BIM-LiDAR construction quality control system and the framework for the entire system are illustrated in Figure 3.10 and Figure 3.11, respectively. Three case studies were used to test the effectiveness and validity of the developed quality control system. The function of Flight Path Control, the synchronization between virtual scene and real scene and the function of construction defect detection and analysis were tested in these case studies. Results revealed an improvement to traditional construction quality inspection since the proposed system proved to detect efficiently construction defects and support real-time quality control; it can also provide some benefits related to safety, accessibility, and efficiency.

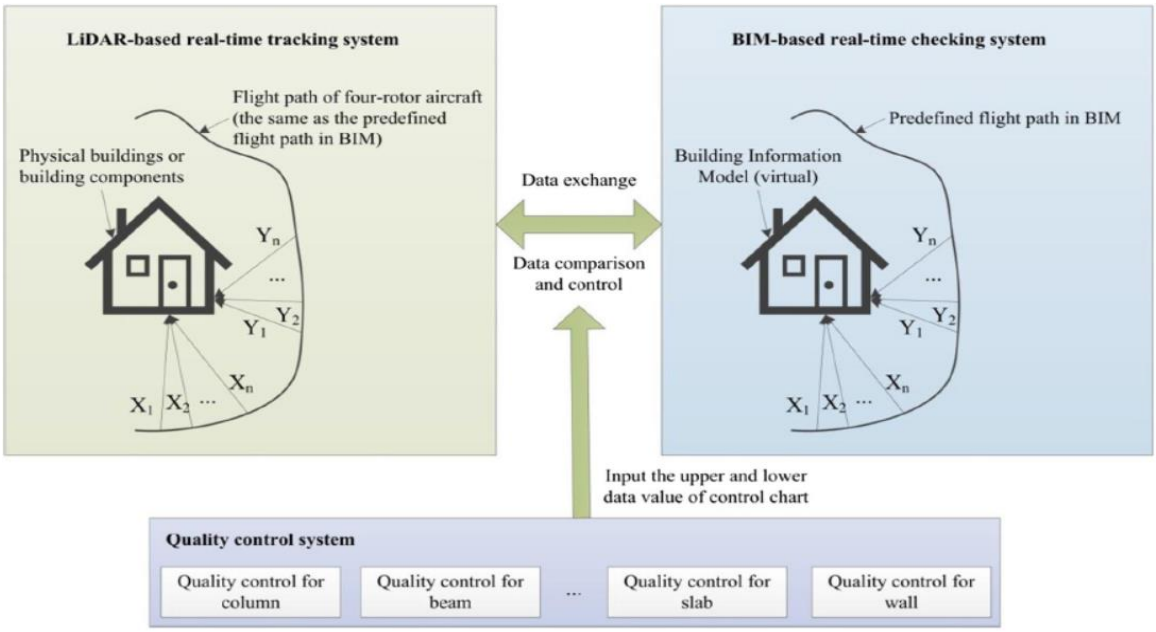

Figure 3.10. BIM-LiDAR construction quality control system (Wang et al., 2015).

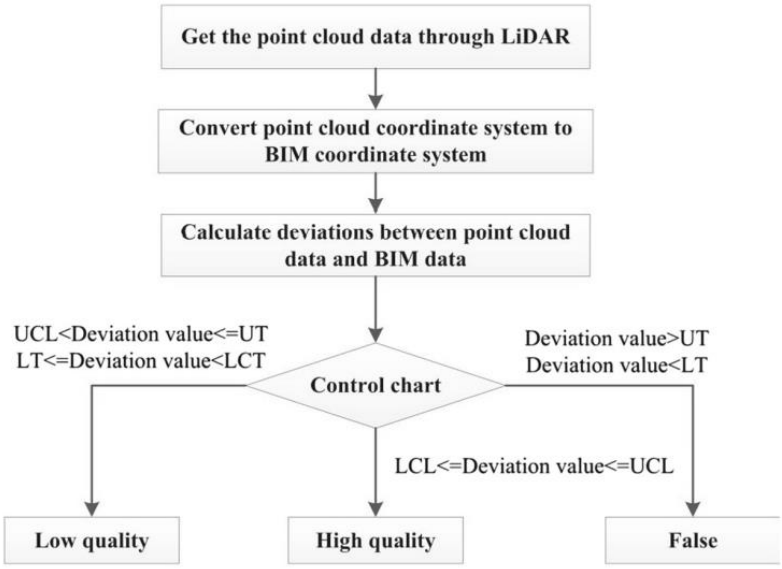

Figure 3.11. Framework integrating BIM and LiDAR for construction quality control (Wang et al., 2015).

In addition, site engineers and supervisors can benefit from the images collected by Micro UAVs from close range of the building to inspect the quality of concrete or monitor the quality of laborers' work. For example, concrete honeycombing and concrete pouring activity in progress, as shown in Figure 3.12 (a) and 3.12 (b) respectively, can be well observed from UAV images (Kaamin et al., 2017).

(a) (b)

Figure 3.12. (a) Concrete honeycombing (b) Concrete pouring in progress (Kaamin et al., 2017).

3.2.5. Post-Disaster Damage Assessment

Drones, due to their ability to access dangerous areas, their promptness of dispatch and their capacity to collect high-resolution images with their optical remote sensors, are also being used as a damage assessment tool for buildings affected by natural disasters such as earthquakes, tsunamis, floods, high winds etc. When such disasters occur, the conditions of the operational environments tend to be difficult presenting many hurdles such as ensuring personnel safety, perishable nature of field data, inaccessibility of many sites, and other challenges associated with acquiring physical measurements. However, the use of UAVs has proven to be an effective measure in mitigating these obstacles.

While conducting terrestrial LIDAR surveys to detect relative displacement measurements after disasters' occurrence is popular, it is still preferable to use UAVs together with these LIDAR scans since they can survey difficult-to-reach sites such as building roofs (Greenwood et al., 2019).

Hence, these technologies can considerably lead to a better and comprehensive damage assessment (Li and Liu, 2018). Different levels of damage evidence, ranging from the complete structure collapse to cracks on buildings and bridges can be identified with drone-based technologies by choosing images at appropriate scales. Concrete cracks, for example, can be detected by drones with high precision, at the decimeter to the centimeter scale (Figure 3.13).

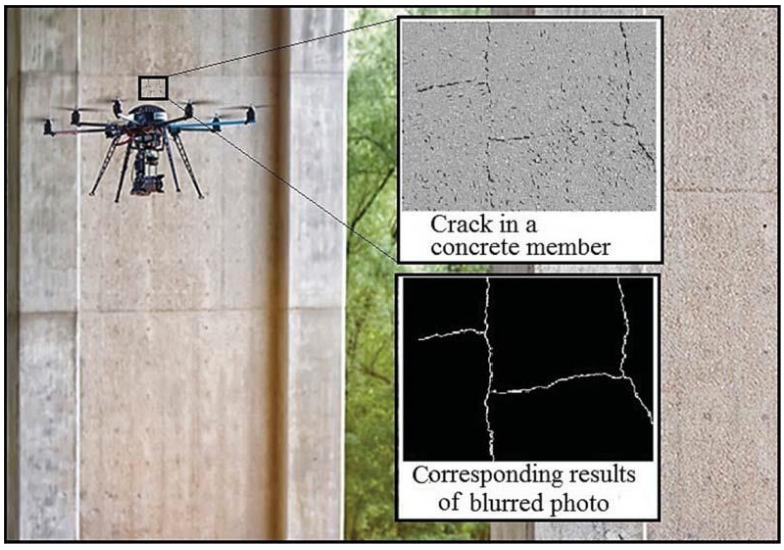

Figure 3.13. Detecting concrete cracks using drones (Li and Liu, 2018).

In a study done by Ellenberg et al. (2014), it was shown that with the use of a UAV equipped with a high-resolution camera, cracks having a thickness of 0.75 mm can be detected at 3 meters from the structure. Ellenberg et al. (2016) demonstrated the effectiveness of UAVs in quantifying bridge-related damage by conducting several experiments (crack identification, deflection measurement, corrosion test) in a simulated environment.

Test results showed that UAVs and their associated imagery are very useful for inspecting bridge damages. Post-processing of UAV images allows for taking different geometrical measurements accurately such as crack thickness and length, elements sizes and span deflections over the time on bridge or beams, due to increasing loads or long-term effects. The use of high-resolution cameras, high-accuracy GPS and gimbals can improve the accuracy of measurements.

Additionally, damages in buildings and bridges can be rapidly investigated, even without any contact with the building, using a non-destructive method which is the drone-supported infrared thermography. This technique is very helpful for determining the types of materials used in different structures (e.g., masonry, concrete), detecting the location of steel reinforcement bars, water leakages or humidity, or the thermal patterns within the building envelope and the movement through and across different construction materials (Ciampa et al., 2019)

Ezequiel et al. (2014) reported on the importance of UAVs in detecting damages in buildings and infrastructure after the occurrence of hurricanes (e.g., Typhoon Haiyan in Philippines). Furthermore, Ezequiel et al. (2014) referred to other applications of UAVs such as fault line detection after an earthquake, lake resource management, and river monitoring. In conclusion, aerial imagery captured by UAVs after the occurrence of any disaster can help experts and decision-makers in acquiring informative data which allows them to analyze the data efficiently and take effective action.

Yamazaki et al. (2015) used a small multirotor drone, called “DJI Phantom 2 vision +”, to collect digital images from air and ground for a turned-down and washed-away building in Onagawa Town in Japan because of the 2011 Tohoku earthquake and tsunami. After collecting images, 3D models are developed using Structure-from-Motion technique with the Agisoft’s *PhotoScan* software. First, a 3D model was developed based on the aerial images collected by the UAV at a vertical camera position. Then another 3D Model was developed using the 45 ground images.

Finally, using aerial (top) and ground (building sides) photos, the best 3D model of the damaged building was generated since all the building (top and sides) appeared clearly, as shown in Figure 3.14.

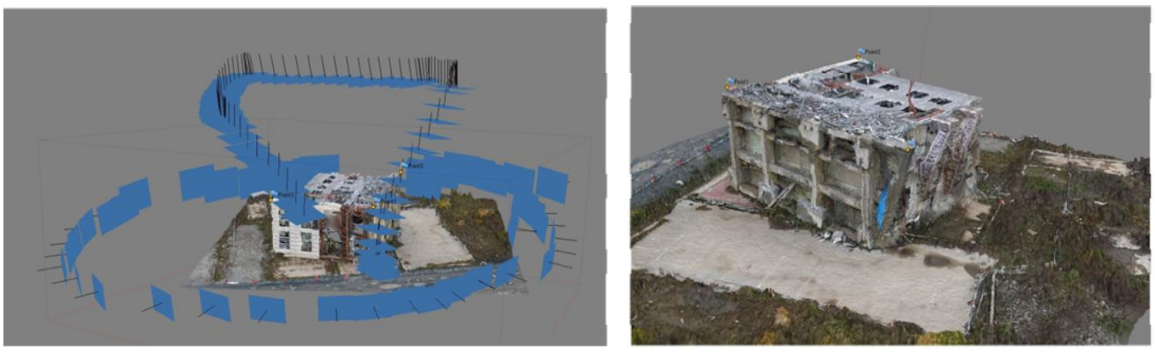

Figure 3.14. Estimated camera positions (left) and generated 3D model from both aerial and ground photos (right) (Yamazaki et al., 2015).

Additionally, Yamazaki et al. (2015) used aerial videos obtained from UAVs for the 3D modeling of other affected areas which are districts in Kathmandu, Nepal, affected by the Mw7.8 Gorkha earthquake on April 25, 2015. The aerial videos of the district were taken by the Canadian humanitarian organization. The details of the damage condition in these districts can be clearly seen in the developed 3D models. Hence, UAVs prove to be useful for post-disaster building assessment by gathering the necessary visual information for detailed 3D modeling based on SfM technique.

Moreover, UAV-collected images were used by researchers for landslide mapping. For example, El Mohtar et al. (2016) gathered 363 images collected from a drone to develop a model for the landslide that occurred at Kfarnabrakh in Lebanon in 2015. These images were geometrically rectified or geo-referenced and a Digital Surface Model (DSM) was generated with a 10 cm resolution. Then, the DSM was compared to the pre-failure geometry of the surface obtained from satellite images. This comparison resulted in estimating the ground surface retreat and failure mass volume where the volume of the failed material was of approximately 15,000 m^3.

Nevertheless, some issues must be considered when integrating UAVs in post-disaster reconnaissance events such as coordination with search-and-rescue teams, and data archiving to appropriately disseminate real time data to stakeholders and decision-makers (Greenwood et al., 2019).

3.2.6. Safety Control and Inspection

The construction sector is one of the most hazardous sectors in the world. Despite its importance in contributing to the country's economy, it still struggles with high rates of injuries and fatalities at construction sites. To address safety concerns, many measures were taken such as personal protective equipment, safety conscious design, focused safety training, and others. However, these measures remain insufficient to prevent construction accidents and fatalities. In 2015, in the US for example, 20% (937) of the total amount of fatal work incidents (4,836) were attributed to construction, more than any other industry. These fatal work incidents were mainly due to: (1) falls, slips and trips (364), (2) transportation incidents (226), and (3) contact with objects and equipment (159) (Moud et al., 2019). Safety managers and employers such as contractors are responsible for safety inspections i.e., for providing workers a safe place at which to work, as required by the Occupational Safety and Health Administration (OSHA). Using drones as a safety inspection tool at construction sites can help safety managers achieve their goals, as reported by several researchers. According to a recent national survey, one-third of US construction general contractors use drones to execute safety- as well as non-safety inspections (SmartMarket Report, 2017).

For example, Martinez et al. (2020) investigated UAV technology to determine its effect on the current safety planning and monitoring processes in high-rise building construction projects in Chile, where it is difficult to inspect hard to reach, inaccessible or unsafe locations due to the limited number of safety managers. Phantom 4 Pro was used due to its very high-resolution camera, sufficient battery life and sensors that allow safe flights in the proximity of objects such as cranes, trucks, scaffolds, and guardrails.

Drone Deploy app was also used due to its ability to conduct flight plans, capture photos automatically, and upload captured content to the cloud, its capability to add plugins, its cloud-based photogrammetry feature, and its software popularity in the construction field. In this study, a UAV- based safety planning and monitoring process was created then the UAV integration effects on the process were assessed. Review of project document and visual content, interviews and site visits were made. Results show that UAV integration enhances hazard identification and assessment, especially in outdoor at-height acts and conditions. This also facilitates the work of safety managers in creating safety checklists and reports and communicating safety issues with others. Higher rating of severity assessment, probability of occurrence and risk level were noted by the safety managers. Also, a reduction in the total amount of time required for site visits was recorded. In addition, aerial videos were found to be the most useful data type followed by photos and 3D models.

Melo et al. (2017) evaluated the effect of UAVs on the safety inspection process on construction sites, based on two case studies in Brazil and focusing on the visualization of the safety requirement to be inspected and the non-compliances with the safety regulations. The study presents an approach comprised of three steps which are target planning, data collection and processing with UAV and data analysis. Results show that the visual assets obtained from UAVs are very useful as they allow a clear detection of unsafe conditions at construction sites.

In more recent work, Alizadehsalehi et al. (2019) proposed a model which combines 4D BIM (3D model + schedule) and UAV-collected data for safety management on construction sites. IDEF0 diagrams were used (IDEF0 is a methodology allowing for the development, analysis and integration of systems such as BIM and UAVs). The developed framework mainly goes through three steps. First, based on safety specialists' expertise and the BIM model developed during the design phase, potential hazards are identified. Then the UAV flies over the construction site to monitor the location of these identified hazards and can detect other dangers as well. Examples of these hazards are the absence of safety barriers, absence of danger signage or adequate scaffolding, and the existence of hazardous openings, workers without hard hats and/or harnesses, or dangerous waste and debris.

As a third step, the real-time data captured by the UAV will be integrated with the 4D BIM-based model to be then analyzed and interpreted so that adequate measures will be taken by site safety staff to prevent such dangerous conditions. Hence, the model presented in this study is very important in that it focuses on the ability of linking the design (using BIM) and construction (using UAVs) phases when managing safety in construction projects. The use of this model can reduce the number of fatal, non-fatal and property damage-causing accidents on jobsites throughout the project life cycle.

Irizarry et al. (2012) assessed the usability of drones as safety inspection tools in construction projects. Similarly, Gheisari et al. (2014) proposed that a drone can be used as a safety inspection tool at construction sites, assisting thereby safety managers in detecting safety conditions on the jobsites. Tasks required from safety managers for safety inspection purposes are mainly frequent walks around the jobsite, direct observation at construction activities' locations, and direct interaction with workers. However, as proposed in this study, the use of drones can assist safety managers by providing them with real time data on what is going on the jobsite and allowing them to interact directly with workers with the help of video and voice transmitters (communication tools) present in the drone system. The drone used as the testing platform was an AR.Drone, the first quadricopter that can be controlled by an iPhone/ iPodTouch/ iPad device through its onboard Wi-Fi system. A user participation study was conducted by asking users to count the number of hardhats in jobsite images via plain view, iPad, and iPhone in the controlled environment of a lab. The study also intended to test whether the accuracy of the results depends on the screen size of used devices or not by designing a survey consisting of subject questions to be answered by the users after each experiment stage. The results of the experiment showed that drones are very practical for safety inspection providing more accurate hardhat detection results under plain view and iPad visualization conditions than when using iPhone. In addition, the survey results revealed that participants were more comfortable in detecting the number of hardhats under plain view iPad conditions due to the larger screen provided.

3.2.7. Promotional photography

Aerial photography has been used by the construction sector as an advertising tool to future business. UAVs allow the capture of a high number of images for the construction site from different camera angles and perspectives. Visual data can be taken from low altitudes, i.e., from ground level to various heights and viewpoints, in only few minutes and at a lower cost compared to the cost of using other aircrafts such as an airplane or a helicopter (Tatum and Liu, 2017).

Thus, projects' photos and videos captured by drones can help construction companies in promoting their projects and catching the interest and attention of their customers as well as other people.

3.3. Case Studies: Drone Application in Construction Projects

Many case studies exist in the construction industry where drones have been increasingly used throughout the different project phases due to their various benefits. In this section, two case studies in the United States and another one in Turkey are presented to illustrate the benefits acquired from the use of UAVs in construction projects. The first case study consists of a manufacturing plant construction project by Choate Construction Company in the US while the second one is another building construction project by McCarthy Building Company in California, US. The third case study consists of a rail corridor mapping project in Turkey.

3.3.1. Case Study One: Choate Construction

Source: DroneDeploy eBook (2018)

Choate Construction is a commercial construction company based in the US. It uses "Drone Mapping" on a 550,000 square-foot bottling plant project as well as on all its other large projects. The project engineer used a Phantom 3 Advanced drone to map the construction site on a weekly basis.

After the drone was flown over the site to get site images, the collected images were uploaded to the DroneDeploy application, a drone mapping software, which allows to produce a high-resolution orthomosaic map. Then, the map was exported in JPEG format to send it to the project team. Additionally, the images were added to a time-lapse GIF of the whole project. Each week, the project engineer repeated this easy process which took him only about fifty minutes.

Using drone mapping in such a large project has proved to have many benefits, such as saving cost and time as well as enhancing progress tracking and communication between project stakeholders.

As stated by the project engineer, Matthew Forster, with the help of drone images, they managed to keep off-site stakeholders informed about the current state of the project, and to provide project managers and site engineers with real-time data which allow them to make adequate decisions.

Moreover, tracking the site progress of such a complex project without using drone images would be relatively difficult since traditional on ground photography does not allow taking a bird's eye view of the site. Besides, considering the cost, Choate Construction managed to save about $1,100 per month, or $7,700 over the entire project by adopting an in-house drone mapping program, instead of hiring an aerial photographer.

Another benefit recognized was the ability to measure stockpile volumes using DroneDeploy's volume measurement tools quickly and easily instead of manually measuring the perimeter of the stockpile and guessing its height. This was recognized when a client from an adjacent construction project piled all their excess dirt onto the Choate site, so the project team hired a subcontractor to move the earth and used the drone map to accurately measure the stockpile volume and inform the subcontractor about it so that the subcontractor would be able to tell the cost to move. Figure 3.15 shows the construction site of the manufacturing plant as captured by a drone.

Figure 3.15. Manufacturing plant construction site: drone mapping
(Drones for Construction Project Management eBook, 2017).

Finally, Matthew Forster summarized his successful drone mapping experience using DroneDeploy software with the following few words:

"I'm trying to get my virtual construction manager to teach everybody else about it, because I think it is a very useful and helpful tool — it illustrates everything very nicely."

Hence, drones facilitate the tracking of the construction of manufacturing plant throughout project lifecycle.

3.3.2. Case Study Two: McCarthy Building

Source: DroneDeploy eBook (2018)

McCarthy Building Company is one of the largest construction companies in California, US, being in business for 152 years and specialized in large, complex construction projects for the healthcare and education sectors, renewable energy, and more.

The company launched an enterprise drone program based on standardized training, building protocols and safety. The program was tested and expanded to more than 20 pilots within a year with the help of the Drone Champion task force.

This task force launched a set of operations policies, safety protocols and staff training program helping to leverage expertise from all company levels. Helping staff in selecting the appropriate drone to use (e.g., Phantom 4) and offering them continuous training over drone hardware and software as well as assessing safety concerns at site have contributed to the maximization of the effectiveness of projects drone data and job site safety.

McCarthy Building Company, in all its construction projects, uses job site live maps, on a weekly basis, after conducting three drone flights, in less than twenty minutes. These flights are the standard mapping flight, another manual flight to detect the additional orbitals necessary for 3D models, and a video capturing flight for marketing purposes.

Drone data are then integrated to DroneDeploy software for data analysis such as area and volume measurement. They allow better job site progress monitoring by keeping track of earthwork, equipment, subcontractors, and structures using real time data. Day-to day

workflows on complex job sites are being improved considerably. Figure 3.16 shows how progress tracking can be done using drone live maps.

Figure 3.16. Job site progress tracking using drone live maps (Drones for Construction Project Management eBook, 2017).

Ryan Moret, Field Solutions Manager at *McCarthy Building Companies*, explains the importance of drone live maps by stating that these maps helped him to finish the day confidently knowing the project state and percentage of tasks completed by the subcontractors. In this way, they were able to offer the best product to their clients.

For example, *McCarthy Building* used drone maps and models in their $65M hospital project in north Dallas. As shown in Figure 3.17, DroneDeploy's tools were used to analyze and share the data extracted from the generated drone maps and models. As a result, enhancements in project efficiency, communication and data management were observed.

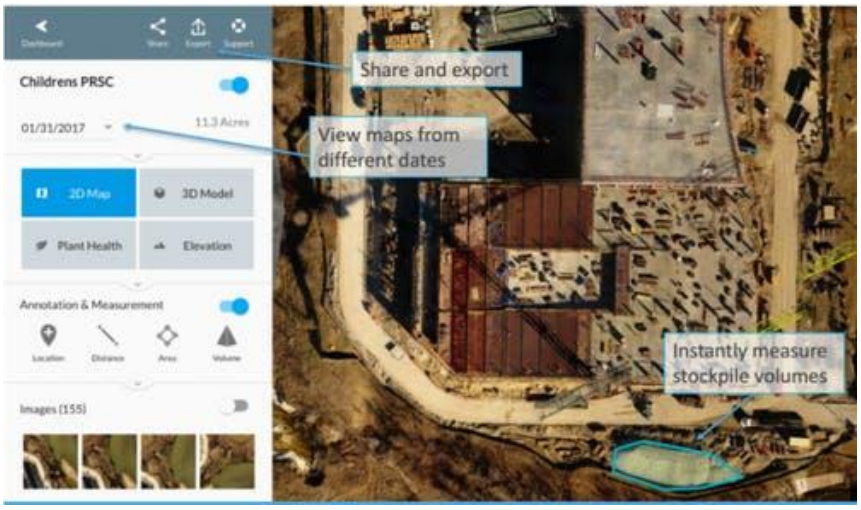

Figure 3.17. Use of DroneDeploy's tools for data sharing and analysis (source: McCarthy Construction).

Another technique (Figure 3.18) used by the company to improve communication and collaboration between project stakeholders was putting drone images on the job trailer wall at each construction site. Drone images, collected weekly, were placed in sequence on the job trailer wall to inform anyone on site about project's progress over time in a clear way, and provide him with a snapshot of any current site problems. These images were also used in site progress meetings and every owner meeting to give a clear picture of the current and past site conditions and hence minimize the occurrence of disputes between the project owner and contractors.

Figure 3.18. McCarthy's map wall (source: McCarthy Construction).

3.3.3. Case Study 3: Rail corridor mapping in Turkey using senseFly eBee drone

"Artu Mapping", a geomatics engineering company based in Ankara, was the company awarded the Turkish Government first UAV survey contract. It used a sensefly eBee drone (Figure 3.19) as a mapping tool for a huge 140 km-long rail corridor, aiming to build a railway for high-speed trains between Ankara and Izmir. The corridor was initially divided into three equal segments. Two of them were surveyed using traditional techniques such as GPS, base stations, and total stations while the third westernmost segment was surveyed by "Artu Mapping" using drones (Sensefly, 2017).

This segment connects Manisa with Uşak, and measures 140 km (87 miles) long by 600 m (1,968 ft) wide, with a total survey area of 11,000 hectares (over 27,000 acres). Using a UAV for surveying purposes allows for the collection of a large vectorized data set which is very important in Turkey since there is not a national GIS system to integrate data as stated by Yilmaz, the General Director of "Artu Mapping".

The followed methodology can be summarized as follows. First, drone flights were planned with eBee's eMotion software (Figure 3.20). The 140-km segment was divided into 16 km segments. At each of these segments, the drone take-off point was chosen to be at the center where the drone operator would start the flight in two directions at an altitude of about 320 m. 300 images were collected per flight resulting in a total of 9000 images with 30 flights. Then, geo-referencing by setting ground control points (GCP) and overlapping images in eMotion (50% lateral and 80% forward) was performed by field engineers and other freelancers in order to align images. This process took 60 days. Finally, eBee captured images were transferred to the office where data were processed and analyzed to be transformed into digital models and different types of drawings. This took about 40 days of work.

In this case study, the importance of using UAV for corridor mapping was recognized since it provided many benefits compared to the use of traditional techniques. Concerning the time, the survey performed by "Artu Mapping" was completed in only three months. However, the other two segments took almost a year to be completely surveyed with traditional techniques. Also, the use of drone allowed for more detailed point cloud and vector data with an average result accuracy of 10-15 cm.

Figure 3.19. eBee drone (geomatching).

Figure 3.20. eBee's eMotion software (geomatching).

3.3.4. Other Case Studies in Turkey

Drones are drawing the attention of a good number of construction companies as well as information technology (IT) and R&D companies in Turkey.

Arventek, a new IT and R&D startup company, is developing a new VTOL professional drone called Skywen having the characteristics shown in Table 3.1 in terms of speed, flight time, wind resistance, autonomy level and accuracy. Additionally, an "Artificial Intelligence (AI) supported Data Management Platform" is being developed to process and manage the geographic visual data collected from the drone automatically and more efficiently. With this platform, many construction applications can be easily automated such as volume, area and distance calculations, monitoring construction progress, creating a 2D digital map and 3D model (Photogrammetry), processing images, detecting and tracking objects and inventory at sites, and performing inspections for maintenance and repair. Arventek believes that analyzing digital and automated data efficiently in construction projects would save time (about 2.2 hours/day/employee), and cost by nearly 45% during the project lifecycle, also resource usage could be optimized with 57.2 man/hour/month. Moreover, the developed platform would enhance collaboration and cooperation among project stakeholders, and reporting.

Table 3.1. Skywen drone characteristics.

Drone name	Skywen
Type	VTOL
Speed	Max 120 km/h
Flight time	1.5 hours
Wind Resistance	Up to 12 m/s
Autonomy Level	Full autonomy
Accuracy	Up to 0-1 cm without GCPs

In addition, drone technology was also implemented by “Kalyon Holding” in their “solar panels” project located in Konya. The project occupies an area of 4 million square meters. The company managed to achieve efficiency in project management both in terms of cost and schedule by combining drone technology with 4D BIM. Synchro Software was used to visually link the schedule with the 3D model. Using ContextCapture software, reality models were created from the drone-based visual assets. Collaboration and information sharing among employees was accelerated over reality modeling outputs instead of site photographs. In addition, reality models helped in controlling occupational health and safety measures at site. Using real-time visual data extracted from drone technology, the quality of solar panels was inspected for an efficient detection of any defects present in the panels.

Another IT and R&D company called “i4Works” has released a software called “SahaGözü” in 2016 which is mainly a “web-based, photogrammetric data processing and field management software”. It allows viewing all kinds of areas using UAVs, mobile devices, and laser scanners. Digital 2D and 3D models can also be created. Length, area, slope, and angle measurements can be made over these digital models. Site progress monitoring and sharing needed information with stakeholders can be easily done via SahaGözü. The company provides free online webinars to promote its project and provide beneficial information to drone users.

3.4. Critical Success Factors (CSFs)

“Critical Success Factor (CSF)” term is used mainly in the management field to describe an element which is necessary for an organization or project to accomplish its mission successfully. Hence CSFs are critical factors which should be recognized by organizations or project stakeholders to ensure the success of their present and future actions.

The concept of success factors was developed by “D. Ronald Daniel” in 1961, *McKinsey and Company*. John F. Rockart, during the period of 1979-1981, introduced the refined term “critical success factor” to be used in the information systems and management field. It was then employed by other researchers, “James A. Johnson” and “Michael Friesen”, in 1995, in many sectors including healthcare. CSFs were also initially used in the field of data analysis and business analysis.

Rockart (1982) derived a definition for “critical success factors” for any business as “the limited number of areas in which results, once satisfactory, will guarantee successful competitive performance for the organization”. CSFs are those few key areas where “things must go right” for the company or industry to thrive. Boynton and Zmund (1984) defined critical success factors as "those few things that must go well to ensure success for a manager or an organization", and hence, they are “issues vital to an organization’s current operating activities and to its future success” which require special and continuous attention.

CSFs were defined by Bullen et al. (1981) as “the particular areas of major importance to a particular manager, in a particular division, at a particular point in time”. They need specific and diverse situational measures, many of which must be evaluated through soft, subjective information not currently gathered in an explicit formal way by the manager's organization. In addition, there are five different sources of CSFs to be considered which are “the industry”, “competitive strategy and industry position”, “environmental factors”, “temporal factors”, and “managerial position”.

Sanvido et al. (1992) studied the CSFs for construction projects. They defined CSFs as those factors predicting success on projects, referring to other definitions as well such as “events or circumstances that require the special attention of management because of their significance to the corporation; may be internal or external, positive or negative in their impact; and identified by evaluating corporate strategy, environment, resources, and operations.” [Ferguson and Dickinson (1982)]

Somers et al. (2001) studied the impact of CSFs across the stages of enterprise resource planning (ERP) implementations and defined CSFs as “situated exemplars which help extend the boundaries of process improvement, and whose effect is much richer if observed within the context of their importance in each phase of the execution process”. Alazmi et al. (2003) applied the CSF method on knowledge management practices in organizations stating that CSFs are “points, areas, or goals that have to be given extensive attention and support by the management to achieve the mission, quality and high performance”.

Winkler et al. (2019) studied the CSFs for the implementation of digitalization in intralogistics considering a CSF as “a critical factor or an activity with the aim of guiding a company or an organization to success”.

From the definitions stated above, a new definition of CSFs in relation with drone technology is extracted which is “those limited key areas which if defined and measured carefully can guide an organization to achieve better results and successfully adopt and implement the drone technology in its current and future projects”.

3.5. Critical Success Factors from the Literature

The uninterrupted advancements in technology along with the potential of its integration in construction projects has induced the interest of many researchers to study the critical success factors for the implementation of different kinds of innovation and

technologies in the construction industry such as drones, robotics and automating systems, smart devices, information and communication technology (ICT), etc. Some researchers also examined the barriers and opportunities for drone technology in construction projects which can be considered as significant indicators for the CSFs for UAVs in this sector. The CSFs list extracted from the literature together with the literature sources are presented in Appendix A.

Lu et al. (2015) reported on the top influential factors for the adoption of Information and Communication Technology (ICT) in the AEC sector which can also be considered important for the adoption of UAVs in construction as stated by Irizarry and Costa (2016). These factors were technology characteristics, information security, user's knowledge and skills, user's acceptance and participation, training and technical support, organizational characteristics, top management support, information security, external environment, project characteristics, and ICT investment and strategic planning. Some factors were classified under three categories which are personal characteristics, organizational characteristics and technology characteristics as shown in Figure 3.21.

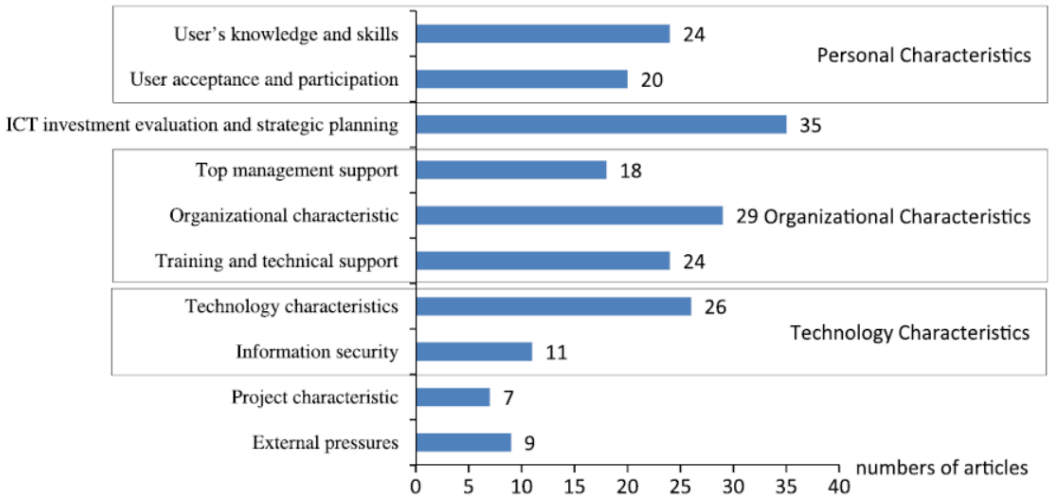

Figure 3.21. Top influential factors for ICT adoption and diffusion in the AEC sector (Lu et al., 2015).

Ozorhon and Oral (2016) investigated the drivers of innovation in construction at the industry, firm, and project levels. The identified factors which drive construction firms to invest in innovation are present in Table 3.2. The main innovation drivers were found to be (1) project complexity (project-related), innovation policy (firm-related), and environmental sustainability (industry-related). The study also pointed out that the most important resources required to successfully implement innovation are financial resources and knowledge resources.

Table 3.2. Innovation drivers in construction (Ozorhon and Oral, 2016).

Level	**Innovation Drivers in construction**
Project-level	Project Complexity
	Client requirement
	Improving project performance
	Project team approach
Firm level	Leadership
	Innovation Policy
	Improving firm performance
	Corporate social responsibility
Industry-level	Competition level
	Regulations and legislations
	Reward schemes
	Technology/design trends
	Environmental sustainability

Kim et al. (2016) identified 31 potential factors affecting the performance of UASs when integrated with safety control processes in construction site environments (see Table 3.3). These factors were identified based on the survey responses and their importance level was evaluated using the mean ranking scores (with a Likert scale from 1: no influence to 3: most influence).

Table 3.3. List of potential factors affecting UASs performance in safety control tasks (Kim et al., 2016).

Potential Factors	**Subdivisions**
UAS System Characteristics	Easy user interface for UAS operation
	Quality of visual assets
	UAS battery life
	UAS system reliability
	UAS system easy upgradability
	UAS camera features
	Maximum visible angle of the UAS camera
	Autonomous flight capability
	UAS control communication range
	Available sensors
	Equipped sensors
	Emergency response system
	Flight stability
Project Features	Project location (Urban vs. Rural)
	Owner type
	Project type
	Project Cost
	Project size
	Project duration
	Complexity of construction tasks
	Subcontractors' trades involved

Table 3.3. List of potential factors affecting UASs performance in safety control tasks (Kim et al., 2016) (Cont.).

Potential Factors	**Subdivisions**
Project Team's characteristics	Team's prior experience with UAS
	Team attitudes toward UAS in construction projects
	Team's prior experience with IT safety controls
	Team attitudes toward IT in construction projects
	Adequacy of resources for UAS use as safety control systems
	UAS control ability of users
	Knowledge of UAS based safety control
	Adequacy of training for UAS use
	Clear methods to measure the performance of UAS integrated safety control system
	User type (safety manager or hire pilot)

Among the factor groups, the most important one was found to be "UAS System Characteristics" group with "easy user interface for UAS operation" and "quality of visual assets" being the most significant factors, while the least important group was "project characteristics" group.

Small (2018) examined the opportunities of UAVs in construction planning, performance and contract close-out. In his study, Small (2018) stated that the main requirements for the implementation of UAV technology are proper licensure, proficiency with drone operation and very little investment.

Yildizel and Calis (2019) studied the current practices and regulations for UAVs in civil engineering. As reported, the main barriers for UAV technology were battery limitations,

payload balance problem, weather condition, rules and regulations, need for trained pilots, ethical, privacy and safety concerns, and resistance to the adoption of new technologies in the construction industry.

Nnaji et al. (2019) focused on technology adoption (e.g., virtual reality, UAV, BIM and wearable safety devices) in construction projects for safety management purposes. In the study done by Nnaji et al. (2019), a list consisting of 26 safety technology adoption predictors was generated from a review of the related literature and an expert panel. This list is shown in Table 3.4. Results showed that technology reliability, effectiveness and durability are the most important predictors.

Table 3.4. Safety technology adoption predictors (Nnaji et al., 2019).

Number	**Safety technology adoption predictors**
1	Technology capital cost
2	Client demand
3	Competitive advantage
4	Direct competition
5	Government regulations and policy regarding the technology
6	Industry-level change required for technology adoption
7	Compatibility level with current processes
8	Complexity level of the technology
9	Technical support from manufacturer
10	Technical support required for optimum performance
11	Training for optimum performance
12	Observability
13	Organization Culture
14	Partner’s adoption of similar technology
15	Peer influence
16	Potential cost savings

Table 3.4. Safety technology adoption predictors (Nnaji et al., 2019) (Cont.).

Number	Safety technology adoption predictors
17	Individual innovativeness
18	Proven technology effectiveness
19	Technical attributes and features
20	Technology brand
21	Technology budget within organization
22	Technology durability
23	Technology reliability
24	Top management involvement degree
25	Triability
26	Versatility

According to an article by Dennis Ayemba (2020), in which an exploration of the applications, opportunities and challenges of drone technology in African construction industry is presented, critical factors enabling a successful implementation of this technology in the construction sector can be derived as follow: flight safety consideration, ability for obstacle-, building- and people-avoidance, availability of good IT infrastructure, government regulations, pilot licensing and on-the job training, good education system for drone operation, governmental support for pilots, people trust in the technology, selection of right seller and team for service and repair works, other technologies (LiDAR, thermal imaging), and availability of right equipment (payload sensors, cameras).

According to Construction Dive's new series, Tech 101 (2020), the effectiveness of drones in construction projects can be enhanced by considering the following factors: presence of good thermal cameras, mapping tools and GPS units, improved transparency and collaboration, level of drone's autonomy (fully- to semi- autonomous, or remotely controlled), right UAV model selection for use, cost of drone acquisition, technical skills requirements, professional-grade hardware and software, and use of applications such as Drone Deploy, DJI

Go and Pix 4D, partnering with a specialized drone service subcontractor/provider (especially when there are multiple construction sites to manage), considering R&D investment, local and federal regulations' consideration, availability of trained and licensed operators, and data transfer security and safety requirement.

Bathrick (2016) explained what it takes to succeed in drone business at the "Commercial UAV Expo" in Las Vegas. According to Bathrick (2016), the four main competencies necessary for the success in commercial drone industry are: "Aviation" referring to companies' need for systems and processes in place for managing the safety and regulatory environments; "Privacy" including many practices such as "proactive communication, public transparency, thoughtful data collection, responsible data storage and sharing, continuous improvement for data security, and compliance with privacy laws"; "Security" to avoid vulnerabilities in the navigation system (GPS jamming, blocking, spoofing), control system (Electromagnetic Interference (EMI), Hacking), payload system (Live stream interception) and data (Storage, processing, and distribution); and "Organizational Culture" including culture of attention to detail, innovation, safety, security and most importantly flexibility.

Mohammed et al. (2014) studied the opportunities and challenges for UAV technologies in building smart cities. The challenges were divided into business challenges and technical challenges. Business challenges included cost, ethics and privacy, licensing and legislation, and business adoption. Technical challenges were adaptable middleware requirement, development of fail-safe systems, development of sense and avoid mechanisms, development of a Network Centric infrastructure, development of very efficient and low vibration engines and a gyro-stabilized platform technology, use of wireless sensors properly, development of automated data compression algorithms and data fusion software and flight precision demonstration.

Graham (2016) presented a study on the factors influencing the use of drones by specialty construction companies in the US. In this study, the highlighted potential factors were grouped under three categories: “human factors”, “technological factors”, and “legal /risk factors”. “Human factors” include management support, training and positive attitude towards new technology, experience (capabilities and skills), formal education (perceived usefulness and perceived ease of use of the technology), compatibility (easy adaptation), job relevance (related to user acceptance and perception), and age (affecting workforce attitude). “Technological factors” include cost associated with this innovation, its complexity, interoperability, and output quality. Finally, “Risk factors” refer to legal factors related to insurance, damage or privacy invasion, and innovation liability issues. As a result of the study, the most important factors are “Technological factors” followed by “Risk factors”, then “Human factors”.

As cited in a blog in “Propeller Aero” platform (2019), the key components of a successful construction drone program are choosing the right hardware and the right drone type for the worksite (according to the size of the survey area, the budget, and type of camera needed for surveying purposes), choosing the right software, choosing the right licenses, also considering the allocated budget, the availability and ease of maintenance and finally using a RTK (real-time kinematics) /PPK (post-processing kinematics)-enabled craft which provides higher accuracy for site’s survey.

Makdisi and Makadisi (2019) studied the factors influencing drone adoption for safety purposes in construction sites which are classified into five categories: “awareness”, “organization”, “workers”, “feasibility”, and “external environment”. The corresponding sub-categories are present in Table 3.5.

Table 3.5. Factors influencing drone adoption for safety purposes in construction sites (Makdisi and Makadisi, 2019).

Categories	**Sub-Categories**
Awareness	Current level of usage of drones within construction
	Current level of usage of drones in other industries
	Benefits
Organization	Fits into operations
	Hierarchy
	Size
	Safety priority
Workers	Reluctance to change and culture
	Ethical issues
Feasibility	Return on investment
	Time
	Result of pilot test
External environment	Pressure by other competitors
	Pressure from clients
	Companies pitching the technology
	Related technological advancements
	Regulations

Golizadeh et al. (2019) examined from the literature the barriers to the adoption of Remotely Piloted Aircrafts (RPAs), i.e., UAVs, in the construction industry which are present in Table 3.6.

Table 3.6. Barriers to the adoption of RPAs in construction (Golizadeh et al., 2019).

Barriers	**Sub-barriers**
Technical difficulties	Large volume of the generated data and data loss
	Failure of GPS signals
	Inefficient flight paths
	Lack of accuracy in detecting site dynamics
	Lack of communication with human objects
	Limited flight duration
	Limited payload
	Low resolution of the captured images
	Positioning system inaccuracies
	User friendliness of the mounted camera
Restrictive regulatory environment	Traffic restrictions
	Restrictive national regulations
	Certifications for pilot and flight
	Insurance issues
	Privacy issues
	Public safety
Site-related problems	Accidents
	Interferences with project activities
	Obstacles in construction sites
Weather	Sensitivity to weather
Organizational barriers	Acquisition, setup, operating, and maintenance costs
	Management and owner support

Li and Liu (2018) stated the opportunities of UAVs as well as their limitations which if addressed correctly may lead to the successful implementation of UAVs in construction projects. As opportunities, from the social perspective, UAVs can resolve work safety issues; from the economic perspective, UAVs are cost-effective, reducing the costs associated with

construction tasks and preventing delays; and from the environmental perspective, UAVs are environmentally friendly since they are electric motor-driven without using fossil fuels. However, the limitations of UAVs are local regulations, professional training need, 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. (2019) 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 environments, data management, hardware maintenance, and integration with other platforms. Other factors also which may increase the risk of failure of UAVs are wind and undesirable human interaction with the UAV.

In a study by Gheisari et al. (2014), the main features of an ideal safety inspection assistant drone for construction projects were discussed. These are autonomous navigation, voice interaction, improved battery life, environmental applicability, high-resolution cameras, multitasking application, and collaborative user interface environment and having an iPad (tablet-size)-compatible-application.

Since UAVs are being highly integrated with BIM in construction projects, the CSFs for UAV technology implementation may be similar to those of BIM implementation in the construction sector. For example, a study done by Ozorhon and Karahan (2016) listed 16 CSFs for BIM implementation in developing countries, mainly in Turkey, which were found to be as follow: "availability of information and technology", "availability of financial resources", "availability of qualified staff", "training of employees", "consulting", "supportive organizational culture", "experience level within the firm", "BIM policy of the company", "effective leadership", "coordination among project parties", "project size", "client requirement", "industry awareness level", "appropriate legislation", "governmental schemes" and "knowledge sharing within the industry" . The results of the study show that "availability of qualified staff", "effective leadership", and "availability of information and technology" were the most important CSFs, in decreasing order.

Fernandez et al. (2019) studied the critical factors for the successful implementation of smart devices (smartphones, tablets or smart bracelets etc.) and the paradigm of the Internet of Things (IoT) in the Dominican Republic construction sector. Cloud Computing (CC), Augmented Reality (AR), Building Information Modeling (BIM), and Geographical Information System (GIS) are the main technologies associated with smart devices in construction. In this study, six CSFs were listed in their descending order of importance, which are "governance and leadership", "technology awareness" (perception level of users towards technology), company size (linked to employees' number, number of project and projects size), usability (users' experience and interaction quality), cost of implementation (cost-benefit analysis), and finally interoperability (easiness of integration with other technologies).

Rashid et al. (2018) reported on the critical success factors for automation and robotics in the Industrialized Building System (IBS) to overcome productivity, safety and quality problems in the Malaysian Construction Industry. 28 CSFs were identified which are good working collaboration, effective communication channel, coordination of design, manufacture, transportation and installation, team members involvement during design stage, experienced workforce and technical capability, information and communication technology (ICT), risk management strategy, extensive planning and scheduling, management of supply chain, top-down commitment, economies of scale, partnering, standardization, Building Information Modeling (BIM), virtual reality (VR), improved speed to the market, scaling and adapting to changing demand or flexibility, consistent demand delivery, return on investment through cost reduction and added value, availability of Plant and Equipment/Machineries/Technology, demand and market factors, government initiatives, procurement method, mass customization, mass production, education and training, continuous improvement and learning, and sustainability.

Delgado et al. (2019) examined the critical factors which limits the adoption of robotics and implementation systems in construction. Eleven main limiting factors were identified from which four components were extracted using the "Principal Component Analysis" technique. These factors with their corresponding categories (components) are shown in Table 3.7.

Table 3.7. List of components and the corresponding limiting factors for robotics and automation systems (Delgado et al., 2019).

Components	**Factors**
Contractor-side economic factors	High initial capital investment
	Fragmented nature of the construction
	Low R&D budgets in the construction industry
	Easy access to labour
	No strong need to improve productivity
	Lack of government incentives
Client-side economic factors	Decreasing public infrastructure budget
Technical and work-culture factors	Untrained workforce
	Unproved effectiveness / immature technology
	Current work culture/aversion to change
Weak business case	Low return on investment/ insufficient demand

Other studies also showed similar results concerning the implementation of automation and robotics technologies in the construction industry.

In the study performed by Mahbub (2008), the “high cost of acquisition and implementation”, “fragmentary nature and size of the construction sector”, “complexity and non-standardization of construction product and work processes”, “difficulty to use the technology”, “culture and human factor (untrained or unskilled workforce)”, “unavailability of the technology”, and its “incompatibility with current workflows” are the limiting factors defined.

Buchli et al. (2018) studied the challenges and opportunities for robotic in situ fabrication in the architecture and construction industry. The study addresses the following challenges: design challenges such as low modularity, reusability, and information technology sophistication, technology immaturity referring to the lack of functional integration, ineffective algorithms, robot intelligence, uncontrolled environments, insufficient expertise in the field, complexity of construction tasks, lack of clear business case/unproved effectiveness, business entry difficulties, industry fragmented nature, and low R&D and inexistent innovation ecosystem.

Furthermore, some researchers studied the critical factors affecting the implementation of UAVs in the logistics sector. These identified factors can be also considered when integrating UAVs in the construction industry.

Raj and Sah (2019) examined and analyzed the CSFs of the implementation of drones in the logistics sector. Twelve CSFs were identified from the literature search and expert’s opinion as follow. “Technological advancements” and “Government regulations” were found to be the most important factors, followed by “Availability of skilled workforce”, “Customer perception”, “Technical aspect”, “Environmental considerations”, “Low initial cost”, “Consideration of low operational costs”, “Better responsiveness”, “Effective traffic management”, “Leadership commitment”, “Better infrastructure”, and “Conducive Research environment”.

Winkler and Zinsmeister (2019) studied the CSFs for the implementation of digitalization, including drones, in intra-logistics. The CSFs found are listed below (in decreasing order of their relevance degree):

- Communication between team members
- Data Security
- Training of IT-workforce and employees
- User acceptance
- Possibility of users' suggestions for improvement
- Excellent project management
- Project team technical and business knowledge
- Implementation transparency
- Clear and defined project plan, organized implementation
- Time, budget, and manageable workload
- Top management support
- Clear understanding of strategic goals and resources
- Innovation culture in the company
- Data quality management and analysis
- Adaptability of software / innovation; customization
- Interface to legacy system
- Available infrastructure (Software/ Hardware)
- Change management together with project management
- IT-systems maturity and security
- Pursuit of a strategy based on clear company visions
- Long-term political and institutional technology support
- Management and leadership training
- Active and well-connected project champion
- Early inclusion of other divisions / plants
- Consistent alignment of the innovation with business goals
- Organization flexibility

- Innovation expansion and integration capability

Sah et al. (2020) identified the barriers facing the drone technology implementation in the logistics sector in the United States (US); these barriers are considered significant indicators for the CSFs for UAVs in this sector. As concluded by the study, 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. The critical barriers and sub-barriers identified are shown (in decreasing criticality order) in Table 3.8.

Table 3.8. Barriers and sub-barriers of drone implementation in logistics (Sah et al., 2020).

Barriers	**Sub-barriers**
Regulations	Accountability for Drone Owners
	Insurance obligations
	Drone's route
	Determination of liability
	Pilot certification and training
Threat to privacy and security	Surveillance and privacy
	Violating rights
	Intentional hacking and cyber-attacks, terrorism
	Physical attacks, jammimg and spoofing
	Identification of non-authorized drones
Public perception	Higher perceived risk
	Societal anxiety towards automation
	Public annoyance (e.g., full skies)
	Private sector use of drones

Table 3.8. Barriers and sub-barriers of drone implementation in logistics (Sah et al., 2020) (Cont.).

Barriers	**Sub-barriers**
Public perception	Awareness about drone technology
	Transparency
Environmental issues	Harming wildlife
	CO2 Emissions
	Visual pollution and sound pollution
Technical issues	Obstacle avoidance and mid-air collisions
	Bad weather conditions
	Short flight range
	Limited carrying capacity
	Drone tracking
	Delivery and performance risk
Economic aspects	Economy and employment
	Higher initial costs
	Uneven distribution of income

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4. RESEARCH METHODOLOGY

4.1. Introduction

This chapter mainly covers the methodology followed in the research and the statistical methods used. Data were collected using a questionnaire survey method. Survey research as well as other research methods are discussed in the following section. Statistical analysis of data was done with the Statistical Package for Social Sciences (SPSS) software. The most important factors leading to the success of UAV technology in construction were determined with mean ranking of the collected data. Parametric tests such as T-test, Analysis of Variance (ANOVA), and Factor Analysis (FA) were also used to analyze the Likert-scale data, since they are believed by researchers to be more robust than non-parametric tests, even if there is a violation for normality or homogeneity assumptions.

4.2. Research Method Selection

There are mainly three research paradigms which are quantitative research, qualitative research, and mixed research. Quantitative research design is confirmatory depending mainly on collecting quantitative (numerical data) using structured and validated data collection instruments, e.g., surveys, and analyzes data using statistical methods. However, qualitative research is exploratory, primarily based on the collection of qualitative data (words, images, etc.) through in-depth interviews, participant observation, field notes, and open-ended questions, and generates hypotheses and knowledge. Mixed research comes between the qualitative and quantitative research paradigms (Creswell, 2008).

Many research methods exist such as experimental, non-experimental such as surveys, phenomenology, case study, ethnography, grounded theory, historical, and action research (Creswell, 2008). As suggested by Bell (1993) and Fellows and Liu (1997), five important

research styles in construction are case study, survey, action research, ethnographic and experimental research.

"Survey research" intends to generalize from a sample to a population through collecting statistical data by using questionnaires or structured interviews (Babbie, 1990 and Creswell, 2008) while experimental research is more specific, based on results comparison by dividing the sample into "experimental group" and "control group" to test the effect of a specific treatment (Fellows and Liu, 1997; Creswell, 2008). In ethnographic research, the researcher studies the culture of a certain group, in a flexible and natural way, over a prolonged period of time by collecting data through observations and interviews. Case Study research is a deeper and comprehensive sort of research, allowing in-deep investigation of specific instances or cases, bounded by time and activity, within the research topic. It mainly uses interviews as a data collection instrument (Creswell, 2008; Fellows and Liu, 1997). Action research can be distinguished from other research methods in that it tends to simultaneously solve a particular problem and generate scientific knowledge; it combines theory and practice (Hult and Lennung, 1980).

Since there are various important research methods, selecting the appropriate research method before starting is crucial. As suggested by Yin (1994), research method selection depends mainly on the research questions or scope (who, what, why, how? etc.), the degree of control the researcher should have over independent variables and the research focus on events (past, contemporary or future events).

This research is about UAV technology applications in the Turkish Construction Industry, focusing on determining the different critical success factors that affect its successful integration to construction tasks. Hence, the use of a large-scale questionnaire survey research method is found to be appropriate in this study since it is broad enough to provide the required answers for the research questions (who, what, where, how many, how much?) with a focus on contemporary events or conditions.

Hence, this study follows the quantitative research approach relying on the survey research method with the "questionnaire" as a tool to collect required data from the studied population. Numerous studies, such as social, healthcare, and scientific studies, are using "questionnaires" to investigate their research subject (Guldenmund, 2007; Fellows and Liu, 1997). In construction management research, a questionnaire has been recently the predominant measurement tool, with the challenge to get just sufficient appropriate and valid information from the representative sample. However, data collected from a questionnaire can be easily analyzed using statistical methods (determining means, medians, variance, correlations …) and comparing subgroups (Guldenmund, 2007).

Furthermore, questionnaires are characterized by their ability to provide quick action. They can be easily and quickly made accessible and distributed among a large group of people (Guldenmund, 2007). Also, they are considered a relatively cheap and reliable data source. Anonymity in questionnaires leads to the collection of more sincere and valid data, especially in sensitive cases. Additionally, quantitative and qualitative data can be obtained from both open and closed questions.

In this research, quantitative data were mainly collected by asking the respondents from both public and private sectors to state the degree of importance of the critical success factors for UAV technology in construction projects. The representative sample was selected based on appropriate sampling rather than random sampling; this is because there is not an identified or a large number of organizations using UAV technology (Fellows and Liu, 1997). Hence, random sampling could have led to inadequate or invalid collection of data.

A list of 78 CSFs was extracted from the literature review, and then it was reduced to include 28 factors. This final list was included in the questionnaire and obtained responses were then analyzed based on the mean values and categorized into groups using "Factor Analysis" technique.

4.3. Questionnaire Survey Objectives

As stated previously, the data collection tool used in this research is a questionnaire. It is used as an instrument for the survey research method to gather real information about the respondents including what they know about UAV technology, in which field they are working and how many years of experience they have, how they perceive the criticality of each CSF. Additionally, by using the questionnaire tool, the degree of prevalence and popularity of UAV technology in construction projects can be determined from the "project-specific questions". This section can be treated as a case study since participants provide information about a specific case/project using UAV.

However, the main purpose of the questionnaire survey is to investigate the critical success factors for UAV technology implementation in the Turkish construction industry from the perspectives of professionals working in the construction sector (private and public clients, contractors, subcontractors, and consultants).

4.4. Population and sample

The target population of the study was composed of 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. Using self-administered questionnaires, a response rate between 25% and 35% is considered acceptable and usable (Fellow and Liu, 2003). The core business of survey participants was mainly designated as Public Client, Private Client, Subcontractor, Contractor and Consultant. Under these categories, participants' positions in the company were namely Owner/Co-founders, General Managers, Managers, Project Managers, Safety Managers, Safety Engineers, Engineer/Architects, Planning Engineers, IT Managers, Project

Coordinators, Chiefs, Surveyors and CAD / BIM Manager or Modeler. Some positions of the survey participants are briefly described below.

The public sector client is mainly the government or semi government agencies initiating major construction projects for social service while the private sector client is those companies being assisted by contractors to build their own properties using their own funding or loans from the banks.

Contractors are responsible for the design and building of the project as well as for the management of the work in progress and after construction to respond to the owner's needs. They employ construction workers to perform and manage the works at the construction sites. They include "Subcontractors" who are self-employed workers responsible to manage and control various construction tasks.

Consultants are those helping the owner by providing advice and consulting services at the beginning and at different phases of the project. They help in developing and coordinating the design, are responsible for preparing tender documents as well as inspecting the contractors' work at site.

4.5. Questionnaire Design

4.5.1. Questionnaire Structure

The questionnaire was designed in a way to cover mainly the critical success factors for UAV technology, together with general information about the respondents. It is divided into three parts (Appendix B):

Part One: covers general information about the respondents and their organizations such as the name of the organization they are working in, their age group, position,

professional experience, technologies used, annual turnover of the organization and number of employees, and respondents' knowledge about UAV technology.

Part Two: deals with the Critical Success Factors (CSFs) for UAV technology. Participants were asked to state the degree of significance for each of the CSFs listed, based on their perceptions of the growing success of UAV technology in the construction industry worldwide.

Part Three: deals with project-specific information, asking the respondents to provide information about a project in which UAV technology was used. In this part, participants state the benefits acquired from the use of UAV at both project level and company level, as well as any drawback encountered.

4.5.2. Rating Scales

A Likert Scale has recently been used in many research studies in the construction management field. It consists of a five-point scale, i.e., from 1 to 5, and is used in the questionnaire as the rating system to measure the degree of criticality for each CSF in the list in Part Two (Table 4.1).

Table 4.1. Degree of criticality of variables: Likert scale.

Likert Scale	Degree of Criticality of Variables
1	Not significant
2	Fairly significant
3	Significant
4	Very Significant
5	Extremely significant

4.6. Statistical Methods

Data collected from the questionnaire were analyzed using several statistical methods such as mean ranking, analysis of variance (ANOVA), and factor analysis. IBM Statistical Package for Social Sciences (SPSS) Statistics 26 software was used for data analysis. The carried statistical analysis is described in the following sections.

4.6.1. Mean Ranking

Mean ranking was used to interpret the survey results using Likert Scale of 1 to 5 to determine the variable means of importance and rank them from low to high levels of importance. Similar descriptive statistics technique had been used by many researchers such as Graham (2016) and Kim et al. (2016). The mean is calculated using Equation (4.6.1).

$$Mean = \frac{\sum_{s=1}^{s=5} f(i) \times s}{N} \tag{4.6.1}$$

where "f" is the frequency of responses for each success factor, "s" is the score assigned to each success factor by the respondents, from *s=1* (not significant) to *s=5* (extremely significant), and N is the total number of responses in the survey (Kim et al., 2016). Hence, f(1) represents the number of respondents assigning a score *s=1* (not significant) to the variable, f(2) represents the number of respondents assigning a score *s=2* (fairly significant) to the variable, f(3) represents the number of respondents assigning a score *s=3* (significant) to the variable, f(4) represents the number of respondents assigning a score *s=4* (very significant) to the variable, and f(5) represents the number of respondents assigning a score *s=5* (extremely significant) to the variable.

4.6.2. One-Way ANOVA

Analysis of variance technique (ANOVA) is mainly used to test the variability of experimental data within some subgroups. ANOVA assumes that data are normally distributed and homogenous. It is used when there are more than two groups to compare; in case of comparing only two groups, t-test is used. It aims to see whether there are significant differences between the group responses in terms of one (One-way ANOVA) or n factors (N-way ANOVA).

The null hypothesis stating that the group means are equal is tested. To test the null hypothesis, in this study, one-way ANOVA is used to determine if there is a significant difference between different groups' means, which are Public Client, Private Client, Subcontractor, Contractor, and Consultant, in terms of the significance of each of the CSFs. Also, assuming data were normally distributed, t-test was performed in SPSS to determine whether there is a significant difference between the responses of the UAV technology users and nonusers in terms of the significance of the CSFs.

To test the null hypothesis, F test is used. F value is determined by getting the value of the ratio of "Mean Square between groups over Mean Square within groups" (Equation 4.6.2). The significance level is then determined by comparing the calculated value of F with the value of F in the distribution table, also considering the degree of freedom. If the significance level is less than 0.05 (5%) or 0.01 (1%), the null hypothesis should be rejected; hence, there is a significant difference between compared groups' square means (Walpole, 9th edition).

$$F = \frac{SS_A\,/(k-1)}{SS_{error}\,/(N-k)} \tag{4.6.2}$$

where: SS_A = Sum of mean squares between groups; SS_{error}= Sum of mean squares within groups; *(k-1)* = degree of freedom for SS_A; *(N-k)* = degree of freedom for SS_{error}; *N* = number of observations; *k* = number of categories.

4.6.3. Reliability Test

A reliability test uses a reliability coefficient to study whether multiple items measure or have the same construct in the administered population (Graham, 2016). This test is carried to give an indication on the reliability or consistency of the collected data which depends on the differences in the respondents' profiles. The most commonly reliability coefficient used is the one developed by Lee Cronbach in 1951, Cronbach's Alpha (α), which is based on the average correlation of items within a test; α is a measure of internal consistency (Glen, 2015) ranging from 0 to 1.

$\alpha = 0$ means that there is no reliability, i.e., no correlation between the items.

$\alpha = 1$ means that there is total reliability, i.e., 100% correlation between the items.

For the test to be reliable, Cronbach's α must have a value greater than 0.7 in most social science research situations. A value above 0.74 is acceptable to achieve reliable results (Norusis, 2012).

The equation of Cronbach Alpha (Equation 4.6.3) is (Glen, 2015):

$$\alpha = \frac{N \times \bar{c}}{\bar{v} + (N-1)\bar{c}} \tag{4.6.3}$$

where: N is the number of items; $\bar{c}$ is the average covariance between items; $\bar{v}$ is the average variance.

4.6.4. Factor Analysis

The popular definition of Factor Analysis is, as defined by Norusis, 1992, “a statistical technique used to identify a relatively small number of factors that can be used to represent relationship among sets of many interrelated variables”. This is illustrated in Figure 4.1 where several variables are grouped into mutually independent factors based on their degree of correlations (Kleinbaum et al., 2008).

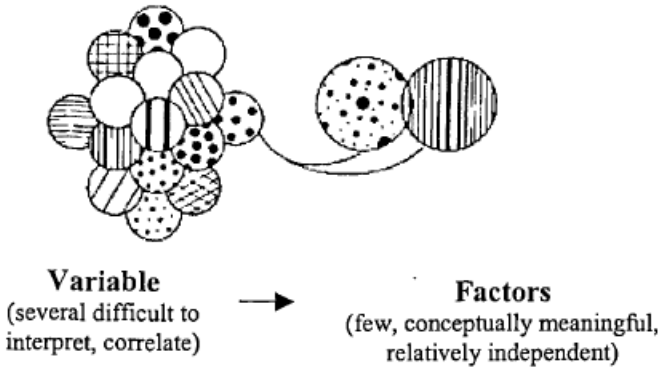

Figure 4.1. Factor analysis representation (Kleinbaum et al., 2008).

Factor Analysis (FA) is typically used to discover the underlying pattern of factors, using the correlations among the original variables’ set. It helps in reducing the original set of variables to a smaller, more meaningful set of “factors” or “components”. It is a model-based method which deals with the modeling of relationships between measured variables, latent factors, and errors. Latent factors are those unobserved variables that normally cannot be measured directly; however, they are assumed to result in the scores or “loadings” we observe on the measured variables (Jon Starkweather, 2018).

There are two types of Factor Analysis. Exploratory FA aims to explore and detect the pattern among variables to discover new concepts and possible ways to reduce data.

Principal Component Analysis is used in EFA. However, “Confirmatory FA” aims to test hypotheses regarding the structuring of variables in terms of expected factors. It tests whether a specified set of constructs has a predictable influence on responses.

Generally, Factor Analysis consists of four main steps as follows.

Step One: A correlation matrix is prepared for all variables. In this step, one set of loadings is computed yielding to theoretical variances and covariances that fit the observed ones as closely as possible according to a certain metric. However, these matrix loadings may not lead to the expected correlations among factors.

Step Two: This step consists of extracting the factors from the correlation matrix by Principal Component (PC) method (Equation 4.6.4). The number of the factors necessary to represent the data and the method of computing them (principal axis factoring, maximum likelihood …) should be determined.

$$z_j = a_{j1} F_1 + a_{j2} F_2 + \ldots . a_{jn} F_n \qquad (4.6.4)$$

where:

z_j = normalized original variable (*all variables are normalized before the analysis starts*)

a_{ji} = Factor Loadings (like standardized multiple regression coefficient)

F_i = Component (Common Factor)

All original variables are normalized first so the variance is 1. Hence, the total variance is equal to the number of variables, and the percentage of variance explained by each component can be calculated using Equation (4.6.5):

$$\% \text{ Variance } (F_i) = (\text{Eigenvalue (i)} / \text{Total Variance}) * 100. \quad (4.6.5)$$

The first principal component accounts for the maximum amount of the variance among all possible linear combinations of variables, while the second principal component accounts for the maximum variance subject to being uncorrelated with the first component and so on.

Step Three: In this step, the correlation matrix is rotated using "varimax correlation method" which 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.

Step Four: This step deals with the computation of factor scores for each case for further use. Scores are computed using Equation (4.6.6) below.

$$F_j = \sum_{i=0}^{p} W_{ij} X_{Ik} \quad (4.6.6)$$

where:

X_{ik} = standardized value of the ith variable for case k.

W_{ji} = Factor score coefficient for the jth factor and the ith variable.

Before starting with the FA technique, the suitability of the correlation matrix for further analysis must be checked using two main tests which are "Bartlett' test of sphericity" and "Kaiser-Meyer-Olkin (KMO) adequacy test".

4.6.4.1. Bartlett's test of sphericity. Bartlett's test of sphericity is carried to test the null hypothesis that the correlation matrix is an identity matrix, i.e., all terms of the diagonal are equal to 1 and the other terms are equal to zero. A large value of Bartlett's test statistic for sphericity with a small significance level ($p<0.00$) indicate that the correlation matrix is not an identity matrix and FA can be applied.

4.6.4.2. Kaiser-Meyer-Olkin (KMO) adequacy test. The KMO statistic is used for measuring sampling adequacy and evaluates the correlations and partial correlations to determine if the variables are likely to merge into components (Jon Starkweather, 2018). In other words, KMO adequacy test compares the magnitudes of the observed correlation coefficients with the magnitudes of the partial correlation coefficients using Equation (4.6.7) of KMO measure:

$$KMO = \frac{\sum\sum_{i\neq j} r_{ij}^2}{\sum\sum_{i\neq j} r_{ij}^2 + \sum\sum_{i\neq j} \alpha_{ij}^2} \tag{4.6.7}$$

where r_{ij} is the simple correlation coefficient between variables i and j, and α_{ij} is the partial correlation coefficient between variables i and j. A small value of the sum of the squared partial correlation coefficients between variables relative to the sum of the squared simple correlation coefficients indicates that KMO statistic is close to 1. The higher the KMO value is, the more correlations between pairs of variables can be explained by other variables. Basically, the Kaiser-Meyer-Olking (KMO) measure should be more than 0.6 and the Bartlett's test should be significant (e.g., $p < .05$) (Jon Starkweather, 2018). Factor analysis can be performed only when KMO value is high. Therefore, KMO values less than 0.5 are not satisfactory; values between 0.5 and 0.7 are average; between 0.7 and 0.8 are good, between 0.8 and 0.9 are great; and above 0.9 are terrific.

4.6.4.3. Factors' Interpretation. The factor pattern matrix is sorted in a way which gathers variables with high loadings on the same factor. Loadings less than 0.45 are deducted to make the factor a representation of the significant correlated variables.

5. RESEARCH RESULTS AND DISCUSSION

5.1. Introduction

This chapter presents and discusses the research results for the critical success factors of UAV technology as collected from the questionnaire survey. The first part provides information about the respondents. The following sections answer the research main question: "What are the critical factors leading to the successful implementation of UAV technology in construction projects?" as well as the other questions mentioned in Section 1.4.3.

Additionally, in this chapter, explanation on how data were collected and analyzed is presented in detail. Data were collected using a questionnaire survey designed as previously stated in Section 4.5. Then, data were analyzed with mainly two steps after conducting the reliability analysis test to determine whether collected data are reliable for further analysis or not. Statistical analysis methods were carried in the Statistical Package for Social Science software (SPSS). As a primary analysis, mean values were determined and compared to rank the factors. Additionally, a t-test was performed to compare the factor means between two groups which are UAV technology users and nonusers. Then, the means of each factor were compared between five groups (contractor, consultant, private client, public client, and subcontractor) along with performing the analysis of variance "ANOVA" technique.

The second step of analysis used factor analysis technique to explore and identify the underlying relationships between the critical success factors of drones. Principal Component Analysis (PCA) was used to extract and reduce the factors into main components.

5.2. Respondents' General Information

Efforts were made to gather the highest possible number of responses aiming to get a valid response rate.

The questionnaire survey was sent directly by email and on Linkedin platform to 313 people working in the construction industry, as mentioned in Section 4.4. 92 responses were collected out of the 313 surveys sent leaving a response rate of 29.4%. The obtained response rate is acceptable since it lies between 25% and 35%. However, not all 92 respondents provided responses to the three parts of the questionnaire since a part of them have not yet been involved directly in UAV technology. Part One and Part Two of the questionnaire received each 92 responses while Part Three received only 55 responses in total.

5.2.1. Respondents' Personal Information

This section provides a general overview on the personal information of the questionnaire respondents, as shown in Tables 5.1 to 5.5. Respondent information from consultants, contractors, public and private clients, and subcontractors, along with grand totals, are presented to display disaggregated and aggregated results. In this way, a context for the statistical analysis can be provided.

Concerning the respondents' ages (Table 5.1), 43.5% (40 in frequency) of the respondents have an age between 25-35 years, followed by the 36-46 years' old age group with a percentage of 37% (34). 17.4% (16) of the respondents are aged 47 years or older while only 2.2% (2) are aged less than 25 years. The responses provided by the two respondents with an age less than 25 years can still be thought as valid for this research since the respondents stated that their organizations have implemented UAV technology in one of their projects; hence, their feedback should be considered.

Table 5.1. Age group.

Age Group	Frequency	Percent
25 to 35 years' old	40	43.5
36 to 46 years' old	34	37.0
47 years old or older	16	17.4
Less than 25 years' old	2	2.2
Total	**92**	**100.0**

The average age of the 92 respondents is about 38 years old. Accordingly, the experience level of the respondents in the construction industry is in average 14.38 years (standard deviation 8.19). Table 5.2 shows how many years of experience the participants have in the construction industry. Only 9.8% (9) of the respondents have worked less than five years in the industry (Table 5.3) while the other respondents have spent a longer time in the industry. Hence, the experience level of the respondents in the construction industry which is in average 14.38 years (standard deviation 8.19) is in line with the average age of the respondents (Table 5.5).

Table 5.2. Respondents' professional experience (years).

Years of Experience	Frequency	Percent
0 - 5	9	9.8
5 -10	21	22.8
10 -15	19	20.7
15 -20	20	21.7
20-25	9	9.8
25-30	11	12.0
>30	3	3.3
Total	92	100.0

Positions as stated by the 92 participants are shown in Table 5.3. Participants have positions as owner/cofounders (O/CO) (frequency, 12), general managers (GM) (5), managers (M) (10), safety managers (SM) (2), planning engineers (PE) (4), project coordinators (PC)

(8), project managers (PM) (10), department chiefs (DC) (7), engineers/architects (E/A) (12) and others (22).

Table 5.4 shows the other positions as written by the 22 respondents. The "other" positions include business development engineers (2; 9.1%), executive director (1; 4.5%), engineering coordinator (1; 4.5%), project control chief (1; 4.5%), commercial manager (1; 4.5%), QA/QC engineer (1; 4.5%), technical office engineer (1; 4.5%), 4D/5D planner (1; 4.5%), business intelligence/reporting engineer (1; 4.5%), contracts manager (1; 4.5%), information management engineer (1; 4.5%), deputy project manager (1; 4.5%), structural health monitoring specialist (1; 4.5%), design group manager (1; 4.5%), project controls engineer (1; 4.5%), assistant project manager (1; 4.5%), director (1; 4.5%), technical manager (1; 4.5%), engineering director (1; 4.5%).

Table 5.3. Respondents' positions in the organization.

Experience (Years)	O/CO	GM	M	SM	SE	PE	PC	PM	DC	E/A	Other	Total
0-5	0	1	0	0	0	0	0	1	0	4	3	9
5-10	2	0	0	0	0	3	2	1	1	7	5	21
10-15	1	1	3	0	0	1	1	5	2	1	4	19
15-20	4	1	1	1	0	0	2	3	3	0	5	20
20-25	3	0	3	0	0	0	2	0	0	0	1	9
25-30	2	1	2	1	0	0	1	0	1	0	3	11
>30	0	1	1	0	0	0	0	0	0	0	1	3
Total	12	5	10	2	0	4	8	10	7	12	22	92

Table 5.4. Additional respondents' positions.

Position (Other)	Frequency	Percent
Executive Director	1	4.5
Business Development Engineer	2	9.1
Engineering Coordinator	1	4.5
Project Control Chief	1	4.5
Commercial Manager	1	4.5
Quality Assurance/ Control (QA/QC)	1	4.5
Technical Office Engineer	2	9.1
Business intelligence / reporting engineer	1	4.5
Contracts Manager	1	4.5
Quality Control Chief	1	4.5
4D/5D Planner	1	4.5
Information Management Engineer	1	4.5
Deputy Project Manager	1	4.5
Structural Health Monitoring Specialist	1	4.5
Design group manager	1	4.5
Project Controls Engineer	1	4.5
Assistant Project Manager	1	4.5
Director	1	4.5
Technical Manager	1	4.5
Engineering Director	1	4.5
Total	**22**	**100.0**

Table 5.5. Respondents' experience by core business.

Years of experience in the construction industry	**Consultant**		**Contractor**		**Private Client**		**Public Client**		**Subcontractor**		**Total**	
Position in the organization	**Mean (α)**	**Standard Deviation (δ)**	**α**	**δ**	**α**	**δ**	**α**	**δ**	**α**	**δ**	**α**	**δ**
Owner/ Co-founder	16.4	6.0	.	.	14.5	9.2	.	.	21.5	9.2	16.9	6.6
General Manager	12.0	.	26.3	8.1	3.0	.	.	.	.	.	18.8	12.2
Manager	23.0	10.8	18.8	6.7	25.0	.	20.0	.	.	.	20.8	7.2
Department Chief	26.0	.	13.0	4.0	.	.	19.0	.	.	.	15.7	6.0
Engineer/ Architect	5.3	1.5	5.7	4.0	4.5	2.1	8.3	3.2	2.0	.	5.8	3.0
Project Manager	12.2	5.4	.	.	10.0	.	.	.	.	.	12.0	4.0
Safety Manager	15.0	.	26.0	.	.	.	.	.	.	.	20.5	7.8
Safety Engineer	.	.	.	.	.	.	.	.	.	.	.	.
Planning Engineer	.	.	9.5	6.4	7.5	2.1	.	.	.	.	8.5	4.0
Project Coordinator	.	.	16.8	6.8	.	.	.	.	.	.	16.8	6.8
CAD/BIM Manager Modeler	.	.	.	.	.	.	.	.	.	.	.	.
IT Manager	.	.	.	.	.	.	.	.	.	.	.	.
Surveyor	.	.	.	.	.	.	.	.	.	.	.	.
Other	8.8	.	15.8	.	15.0	.	6.0	.	.	.	11.4	
Total	14.0	7.7	15.7	8.5	10.6	7.5	11.7	6.5	15.0	13.0	14.4	8.2

5.2.2. Respondents' Organization Information

Tables 5.6 to 5.11 provide information on the respondents' organizations in terms of main business, employees' number, annual turnover, technology types used and experience with UAV technology.

Table 5.6. Respondents' main business area.

Main Business Area	Frequency	Percent
Consultant	26	28.3
Contractor	47	51.1
Private Client	10	10.9
Public Client	6	6.5
Subcontractor	3	3.3
Total	92	100.0

Of the respondents, the majority (51.1%) are contractors, 28.3% are consultants, 10.9% are private clients, 6.5% public clients, and 3.3% are subcontractors (Table 5.6).

The participants' organizations differ significantly in terms of employees' number (Table 5.7). Fifty-two respondents out of 92 (56.5%) work in large organizations (>201 employees), whereas 21 (22.8%) work in medium-sized organizations (51-200), followed by 19 (20.7%) who are employed in small organizations (0-50 employees). Hence, the largest percentage of the respondents works in large organizations. This percentage (56.5%) is mostly occupied by "Contractors" with 39 respondents (75%) (Table 5.8). In addition, most of the respondents who reported working in medium-sized organizations stated that their organizations' core business is "Consultant" (42.8%), followed by "Contractors" (28.6%), and "Public Client" (19%). Similarly, there is a considerable percentage of small organizations having their core business as "Consultant" (57.9%) followed by "Private Client" (26.3%), and "Contractor" (10.5%) and "Subcontractor" (5.3%).

Table 5.7. Organizations' number of employees (size).

Employees' Number	**Frequency**	**Percent**
> 201	52	56.5
0-20	16	17.4
101-200	15	16.3
21-50	3	3.3
51-100	6	6.5
Total	92	100.0

Table 5.8. Organizations distribution by number of employees.

Respondents count and percentages within Employees Number		**Main business area in the construction industry**					**Total**
		Consult-ant	Contrac-tor	Private Client	Public Client	Subcontrac-tor	
Employees Number	0-20	11	0	4	0	1	16
		68.80%	0.00%	25.00%	0.00%	6.30%	100.00%
	21-50	0	2	1	0	0	3
		0.00%	66.70%	33.30%	0.00%	0.00%	100.00%
	51-100	1	3	0	2	0	6
		16.70%	50.00%	0.00%	33.30%	0.00%	100.00%
	101-200	8	3	2	2	0	15
		53.30%	20.00%	13.30%	13.30%	0.00%	100.00%
	> 201	6	39	3	2	2	52
		11.50%	75.00%	5.80%	3.80%	3.80%	100.00%
Total		26	47	10	6	3	92
		28.30%	51.10%	10.90%	6.50%	3.30%	100.00%

In terms of organizations' annual turnover, most of the respondents (61.2%) reported that their organizations have USD$100 million or more, 14.3% have between USD$ 10-100 million, and 24.5% have USD$10 million or less turnover values (Table 5.9).

Table 5.9. Organizations' annual turnovers.

Turnover (million $)	**Frequency**	**Percent**
< 10	12	24.5
10-100	7	14.3
> 100	30	61.2
Total	49	100

In terms of technology types used in the organizations to manage their construction projects, (Figure 5.1), AutoCad is the most used software as reported by 79 respondents, followed by BIM (59 responses), Navisworks (40), BIM 360 for Field or other collaborative site software for field management (36), Trimble or Total Station Layout (26), Synchro Pro Software (14), Synchro Field (9), and ContextCapture Software (9). Other technologies (Primavera, Revit, Hololens, Procore, ERP Systems, Solidworks, Tilos…) are also used by some respondents (25).

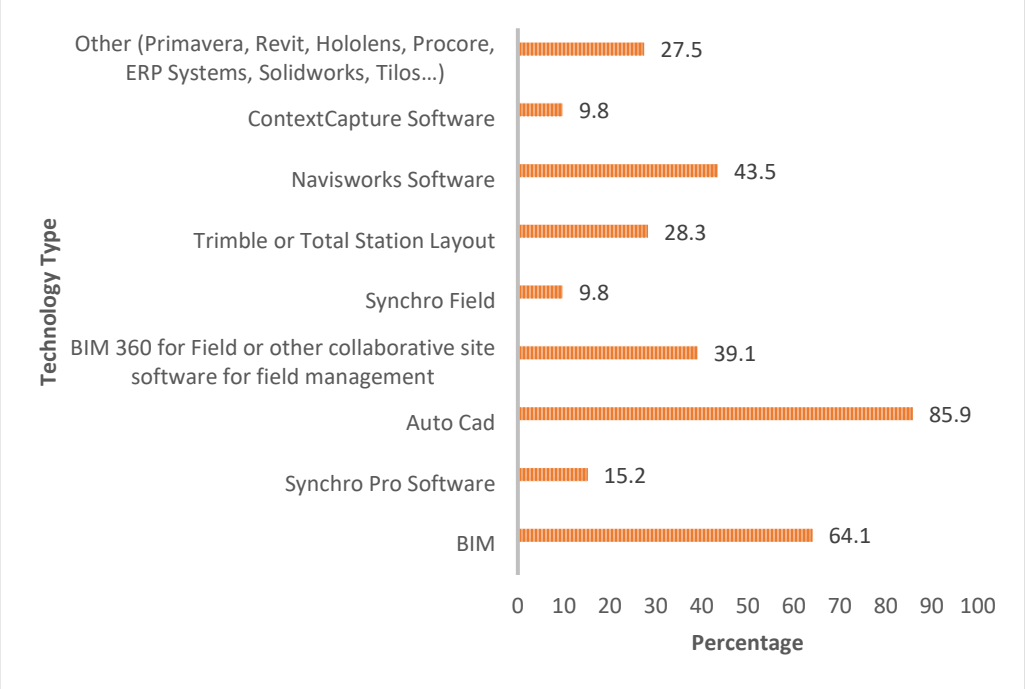

Figure 5.1. Technology types used in organizations.

Concerning the respondents' experience level with UAV technology, the following results are derived. Table 5.10 shows the general distribution of UAV experience among contractors, consultants, private clients, public clients, and subcontractors. Table 5.11 presents the distribution in detail according to the number of employees. About sixty percent of the respondents stated that they implemented UAV technology in their projects. Among these, 61.80% are contractors, 18.20% are consultants, 10.90% private clients, 5.50% public clients, and 3.60% are subcontractors. Therefore, contractors are more willing to use UAV technology to exploit its potential benefits and optimize the work at construction sites. They can use it for capturing infrared imagery and managing the project on site in a faster and easier way referring to drone visual assets for inspecting errors in the building (windows, doors, etc.); this can prevent future serious problems and high repair costs. Moreover, contractors can use this technology to track materials and equipment locations and inventory at the site by processing the captured data in the software; the software allows to place material orders easily and quickly before running out of used materials at site, preventing thereby delays occurring (Janssen, 2015). Consultants providing drone services can help contractors in performing a

certain complicated task, such as concrete integrity inspection, by providing them with their available resources and professional advice (Janssen, 2015). Private clients use drone imagery to have high quality images and videos of their private properties when trying to sell them to customers. Public clients or local government such as municipalities benefit from drone images to check the construction sites for given license violation conditions during the project or even after project completion (Janssen, 2015).

Also, among the respondents implementing drone technology, 63.6% (the majority) are companies having > 201 employees followed by 20% for medium-sized companies having 51-200 employees and 16.3% for small companies (0-50 employees). Among the 37 respondents who did not implement UAV technology, 45.90% are large organizations while 27% represent small organizations. From the results, it appears that the larger the organization is the more it becomes inclined to use UAV technology in its projects. Hence, smaller organizations tend to avoid using UAV technology. This may be due to the lack of financial and technical resources in these organizations.

Table 5.10. UAV technology experiences by organization.

Implemented UAV (Counts and Percentages)	**Core business**					Total
	Consultant	Contractor	Private Client	Public Client	Subcontractor	
No	15	14	4	3	1	37
	16.30%	15.20%	4.30%	3.30%	1.10%	40.20%
Yes	10	34	6	3	2	55
	10.90%	37.00%	6.50%	3.30%	2.20%	59.80%
Total	25	48	10	6	3	92
	27.20%	52.20%	10.90%	6.50%	3.30%	100.00%

Table 5.11. UAV technology experiences by organization employee numbers.

Implemented UAV	Employees Number	Core business					Total
		Consul-tant	Contrac-tor	Private Client	Public Client	Subcont-ractor	
No	0-20	7	0	1	0	0	8
		18.90%	0.00%	2.70%	0.00%	0.00%	21.60%
	21-50	0	2	0	0	0	2
		0.00%	5.40%	0.00%	0.00%	0.00%	5.40%
	51-100	1	1	0	2	0	4
		2.70%	2.70%	0.00%	5.40%	0.00%	10.80%
	101-200	3	2	1	0	0	6
		8.10%	5.40%	2.70%	0.00%	0.00%	16.20%
	>201	4	9	2	1	1	17
		10.80%	24.30%	5.40%	2.70%	2.70%	45.90%
Total		15	14	4	3	1	37
		40.50%	37.80%	10.80%	8.10%	2.70%	100.00%
Yes	0-20	4	0	3	0	1	8
		7.30%	0.00%	5.50%	0.00%	1.80%	14.50%
	21-50	0	0	1	0	0	1
		0.00%	0.00%	1.80%	0.00%	0.00%	1.80%
	51-100	0	2	0	0	0	2
		0.00%	3.60%	0.00%	0.00%	0.00%	3.60%
	101-200	4	2	1	2	0	9
		7.30%	3.60%	1.80%	3.60%	0.00%	16.40%
	>201	2	30	1	1	1	35
		3.60%	54.50%	1.80%	1.80%	1.80%	63.60%
Total		10	34	6	3	2	55
		18.20%	61.80%	10.90%	5.50%	3.60%	100.00%

Results of the best UAV application and most critical project phase for UAV technology application are displayed in Tables 5.12 and 5.13, respectively.

“Progress monitoring and reporting” is believed to be the best application of UAVs by 41 respondents (44.6%), mostly by contractors (19), followed by “Land surveying and mapping” with 22 responses (23.9%), also mostly by Contractors (14) (Table 5.12; Figure 5.2). Other UAV applications currently seems to be of less importance since they have got less responses from Turkish construction professionals.

Hence, again it is seen that contractors are the ones more involved in drone technology usage, mostly for progress monitoring and tracking, and for reporting the progress to their managers and consultants assigned by the owner. Also, land surveying and mapping is performed using drones at the planning phase for creating 2D maps and 3D models for the site.

Table 5.12. Best UAV technology application by core business.

Best UAV Application	**Core business**					**Total**
	Consul-tant	Contrac-tor	Private Client	Public Client	Subcont-ractor	
Land surveying and mapping	4	14	1	2	1	22
	4.30%	15.20%	1.10%	2.20%	1.10%	23.90%
Logistics management	0	1	0	0	0	1
	0.00%	1.10%	0.00%	0.00%	0.00%	1.10%
Progress monitoring and reporting	12	19	5	4	1	41
	13.00%	20.70%	5.40%	4.30%	1.10%	44.60%
Promotional Photography	1	6	0	0	0	7
	1.10%	6.50%	0.00%	0.00%	0.00%	7.60%
Quality control and inspection	3	2	2	0	1	8
	3.30%	2.20%	2.20%	0.00%	1.10%	8.70%
Risk Management/ Decision- making process	1	1	1	0	0	3
	1.10%	1.10%	1.10%	0.00%	0.00%	3.30%
Safety control and inspection	3	2	0	0	0	5
	3.30%	2.20%	0.00%	0.00%	0.00%	5.40%
Time management	1	3	1	0	0	5
	1.10%	3.30%	1.10%	0.00%	0.00%	5.40%
Total	25	48	10	6	3	92
	27.20%	52.20%	10.90%	6.50%	3.30%	100.00%

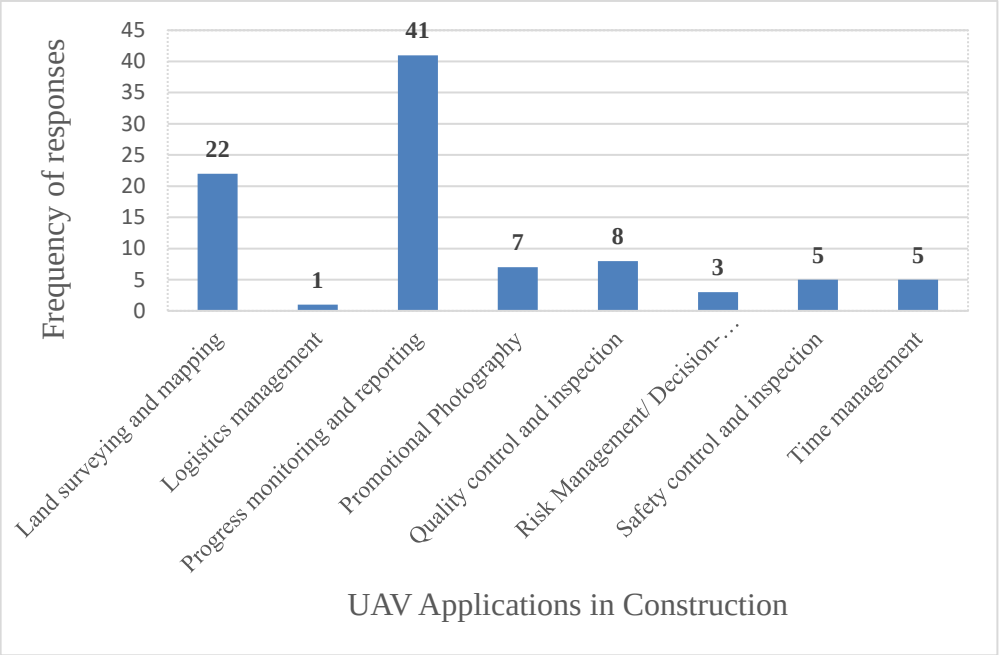

Figure 5.2. UAV applications in construction projects.

The most critical phase during which an UAV should be used is believed to be the "Construction phase" (54; 58.7 %) followed by "Feasibility and Preliminary Design" (24; 26.10%). Results show that from contractors' point of view (48; 52.20%), 28.3% (26) perceive "Construction phase" as the most critical phase while 15.20% (14) consider "Feasibility and Preliminary Design" as the most critical one. Also, for consultants (25; 27.2%), 18.5% (17) perceive "Construction phase" as the most important phase while 6.5% (6) consider "Feasibility and Preliminary Design" as the most critical one. These results are in line with the previously stated results regarding the mostly used application, since "progress monitoring and reporting" application occurs during the construction phase while "land surveying and mapping" occurs during the feasibility and preliminary design phase. However, for private clients (10; 10.9%), 6.5% (6) perceive "Construction phase" as the most important phase while 2.2% (2) consider "Detailed Design" as the most critical one. Similarly, for public clients (6; 6.5%), 4.3% (4) perceive "Construction phase" as the most important phase. Lastly, for subcontractors (3; 3.3%), 2.2% (2) perceive "Feasibility and Preliminary Design" as the most important phase while 1.1% (1) consider "Construction phase" as the most critical one (Table 5.13; Figure 5.3).

From these results, as perceived by Turkish construction professionals, it can be concluded that the construction phase is the most critical phase for UAV implementation. This might be because the most complex project management tasks take place during the construction phase such as managing risks and delays, decision-making, and safety and quality management.

Table 5.13. Critical project phase for UAV technology by core business.

Critical Project Phase	**Core business**					**Total**
	Consul-tant	Contrac-tor	Private Client	Public Client	Subcontrac-tor	
Construction	17	26	6	4	1	54
	18.50%	28.30%	6.50%	4.30%	1.10%	58.70%
Detailed Design	1	3	2	1	0	7
	1.10%	3.30%	2.20%	1.10%	0.00%	7.60%
Feasibility and Preliminary Design	6	14	1	1	2	24
	6.50%	15.20%	1.10%	1.10%	2.20%	26.10%
Operation and Maintenance	1	5	1	0	0	7
	1.10%	5.40%	1.10%	0.00%	0.00%	7.60%
Total	25	48	10	6	3	92
	27.20%	52.20%	10.90%	6.50%	3.30%	100.00%

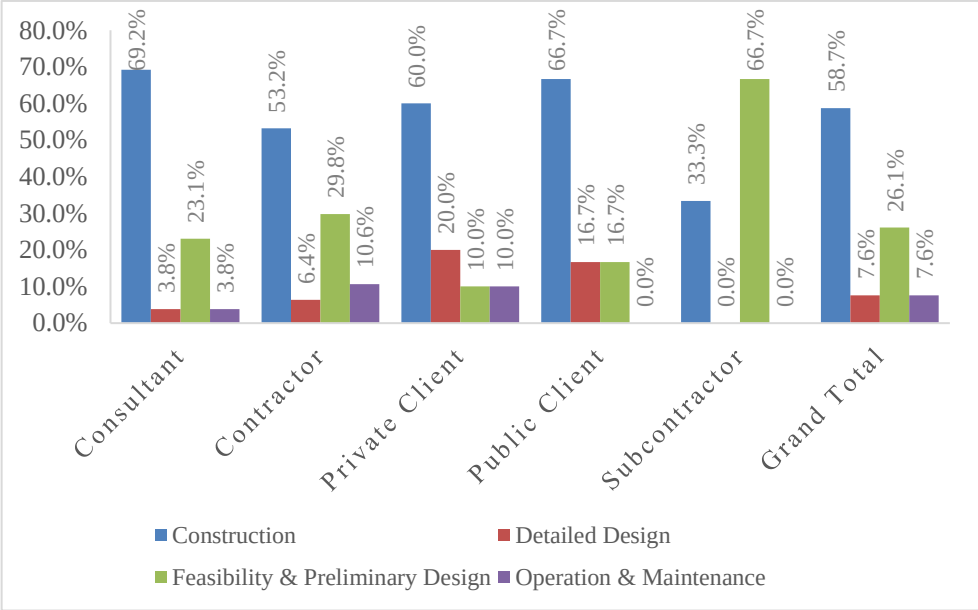

Figure 5.3. Critical project phase by core business.

5.3. UAV Technology Project Information

This section provides the information given by 55 respondents who stated that UAV technology has been implemented in one of their organization's projects. Project-specific information is presented in terms of project type, project size, project duration, project start year, and project phases during which UAV technology was implemented. Additionally, application(s) for which UAV technology was used in the project, the benefits acquired from its usage at the project and company levels as well as the encountered drawbacks are provided in this section.

5.3.1. Projects' Types, Sizes, Durations and Phases

This part presents project-specific information related to project type, project size, project duration and project phases.

Regarding project types, as shown in Table 5.14, UAV technology was mostly implemented in infrastructure and heavy construction projects (36.4%) followed by industrial construction (27.3%) and institutional and commercial construction (23.6%). Residential projects have the smallest percentage of 12.7%. Table 5.15 shows the general distribution of project types among contractors, consultants, private clients, public clients, and subcontractors. Eighty percent of infrastructure and heavy construction projects as well as 60% of industrial projects were carried by "Contractors". Concerning the project size (Table 5.16), 70.8% of the projects are large scale projects with a project cost greater than $50 million, 23.7% are medium-scale projects ($100,000 - $50 million) while only 5.5% are small projects (<$100,000). The general distribution of project types among the different project sizes is displayed in Table 5.17 and Figure 5.4. Therefore, it can be stated that UAV technology was more considered for use by contractors in large infrastructure and industrial project, and rarely used in small residential and commercial construction; this may be due to the fact that infrastructure and industrial projects are more complex necessitating the use of technologies such as drones to facilitate the visual monitoring and inspection of the existing structures' conditions as well as communication among the multiple project stakeholders.

Table 5.14. Responses frequency for project types.

Project Type	**Frequency**	**Percentage**
Industrial construction	15	27.3
Infrastructure and Heavy Construction projects	20	36.4
Institutional and commercial construction	13	23.6
Residential construction	7	12.7
Total	55	100

Table 5.15. Project types' results by core business.

Project Type	**Core business**					**Total**
	Consul-tant	Contrac-tor	Private Client	Public Client	Subcontra-ctor	
Industrial construction	3	9	2	1	0	15
	20.0%	60.0%	13.3%	6.7%	0.0%	100.0%
Infrastructure and Heavy Construction projects	1	16	1	0	2	20
	5.0%	80.0%	5.0%	0.0%	10.0%	100.0%
Institutional and commercial construction	5	5	2	1	0	13
	38.5%	38.5%	15.4%	7.7%	0.0%	100.0%
Residential construction	1	4	1	1	0	7
	14.3%	57.1%	14.3%	14.3%	0.0%	100.0%
Total	10	34	6	3	2	55
	18.2%	61.8%	10.9%	5.5%	3.6%	100.0%

Table 5.16. Responses frequency for project sizes.

Project Size	**Frequency**	**Percentage**
< $100,000	3	5.5
$100,000 - $1 Million (M)	3	5.5
$1M - $10M	3	5.5
$10M- $50M	7	12.7
>$50M	39	70.8
Total	55	100

Table 5.17. Project sizes' results by project types.

Project Size and Type	Industrial construction	Infrastructure and Heavy Construction	Institutional and commercial construction	Residential construction	Total
< $100,000	1	2	0	0	3
100,000 - $1 Million (M)	0	0	2	1	3
$1M - $10M	1	1	0	1	3
$10M- $50M	4	1	1	1	7
>$50M	9	16	10	4	39
Total	15	20	13	7	55

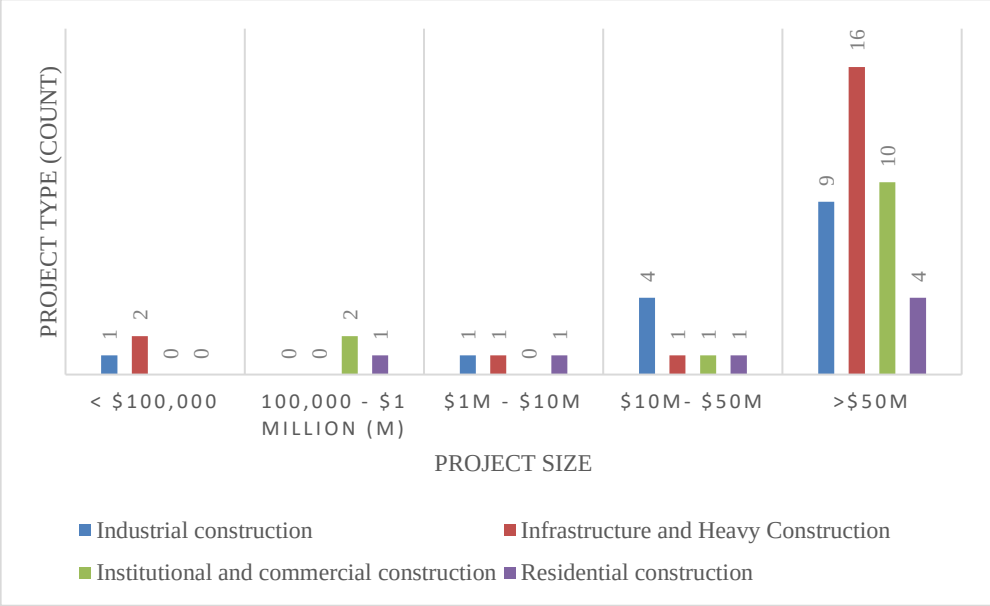

Figure 5.4. Project types' distribution by project sizes.

Project durations as stated by 52 respondents range from one year to ten years. Also, 49 responses were collected concerning the starting year of using UAV technology. From these responses, it appears that the earliest starting date of use is 2008 (two responses); also,

according to the responses, UAV technology is being used in the last eight years (2014-2021; 26 responses) and will be used in the coming years (two responses). Hence, UAV technology has been considered for present and future use in Turkey for over ten years, mostly in large-scale infrastructure and heavy construction projects (16 out of 39), as shown in Table 5.17.

Considering the project phases during which UAV technology was most implemented, 51 responses were gathered. As shown in Table 5.18 and Figure 5.5, nine respondents (17.6%) stated that they have used UAV technology in all project phases (Feasibility and Preliminary Design, Detailed Design, Construction, and Operation and Maintenance). On the other hand, in decreasing order, "Construction" phase has got the highest percentage (72.5%) followed by "Feasibility and Preliminary Design" (27.5%), "Detailed Design" (19.6%), and lastly "Operation and Maintenance" (9.8%). It is not surprising that drones were mostly used during the construction phase as stated in the previous section (5.2.2). They were also used in a lesser degree during the operation and maintenance phase, maybe for rooftop or building facade inspections to check materials' quality and possible damages.

Table 5.18. Responses for project phases for UAV technology implementation.

Project Phases	**Frequency**	**Percent**
Feasibility and Preliminary Design	14	27.5
Detailed Design	10	19.6
Construction	37	72.5
Operation and Maintenance	5	9.8
All phases	9	17.6

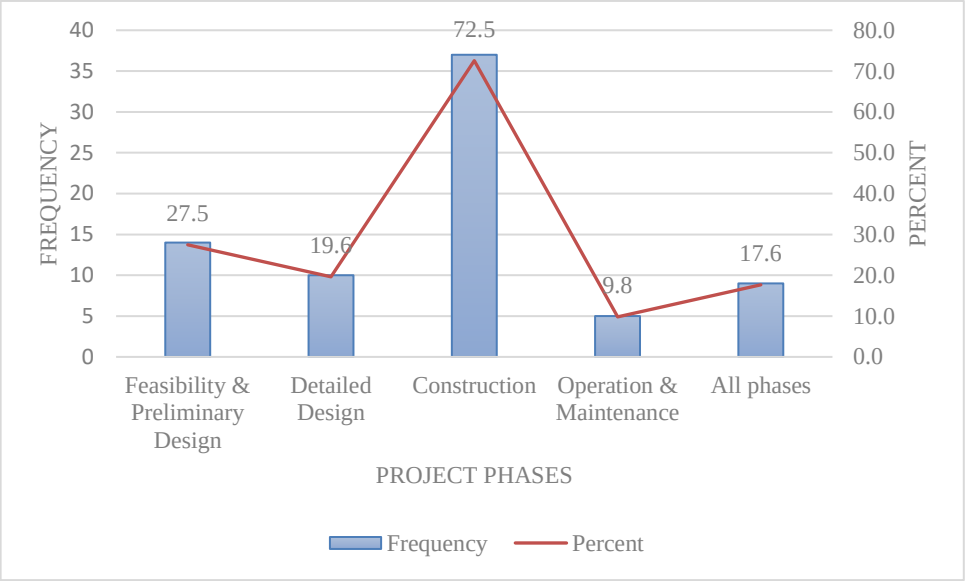

Figure 5.5. Responses frequency for project phases for UAV technology usage.

5.3.2. UAV Applications, Benefits and Drawbacks

This part is concerned with UAV technology applications in the projects, its benefits at the project and company levels, and its drawbacks.

Table 5.19 and Figure 5.6 show the frequency and percentages of the obtained responses for UAV technology applications. The participants were asked to provide which applications they used UAV technology for among five principal applications which are: Photography, Photogrammetry/3D Modeling, Progress monitoring and documentation, Inspections, and Equipment and Materials tracking. Most of the 54 responses (42; 77.8%) indicated the use of UAV technology for the purpose of “Photography”. Another important application getting 35 responses (64.8%) is “Progress monitoring and documentation”, followed by “Photogrammetry/3D Modeling” with 30 responses (55.6%). Lastly come “Inspection” applications (13 responses; 24.1%) followed by “Equipment and Materials tracking” (6; 11.1%).

Table 5.19. Responses frequency for UAV technology applications.

UAV Applications	Frequency	Percent
Photography	42	77.8
Photogrammetry / 3D Modeling	30	55.6
Progress Monitoring and Documentation	35	64.8
Inspections	13	24.1
Equipment/ Materials Tracking	6	11.1

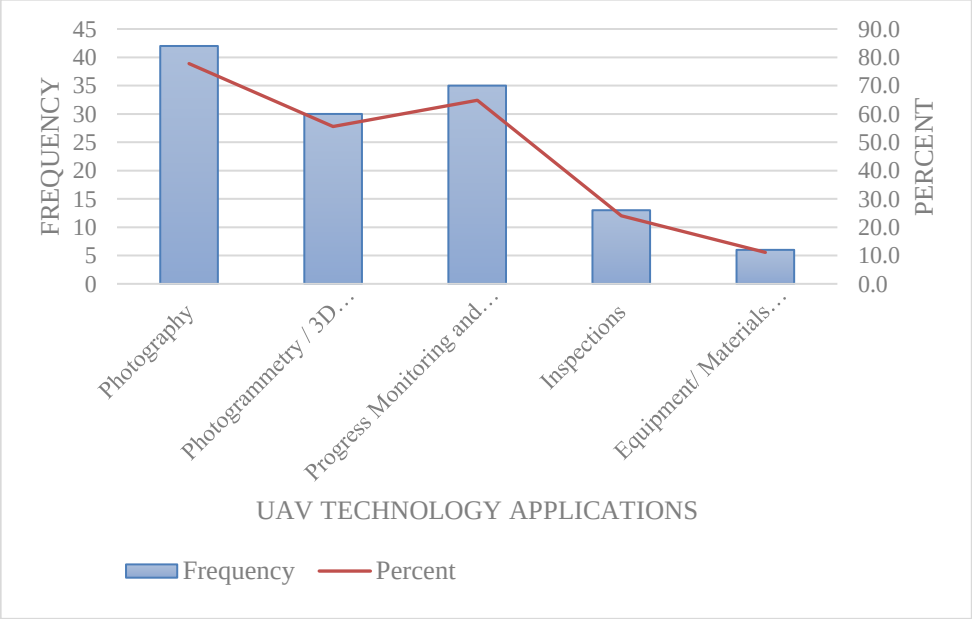

Figure 5.6. Responses frequency for UAV technology applications.

Benefits of UAV technology as acquired by 51 respondents at the project level with their respective frequency and percentages are presented in Table 5.20. Participants were asked to indicate the benefits they obtained from the use of UAV technology at the project level among the following benefits: a decrease in cost, a decrease in duration, improvement of quality, improvement of safety, improvement of client satisfaction, no benefits, and others. Results are shown in Table 5.20 and better illustrated in Figure 5.7. “Improvement of client satisfaction” got the highest record with 41 responses (80.4%). By using UAV technology, contractors and consultants were able to deliver their projects to their clients on-budget, without delays, and with good quality. Also, clients would be more satisfied since they can follow the project as it progresses using the drone visual assets shared with them and easily

share their comments and new suggestions with the project team. Only two respondents stated that they have not acquired any benefit from UAV technology while two other benefits were added which are improving progress tracking and lowering advertisement expenses.

Table 5.20. UAV benefits at the project level.

UAV Benefits at Project Level	Frequency	Percent
A decrease in cost	16	31.4
A decrease in duration	23	45.1
Improvement of quality	24	47.1
Improvement of safety	17	33.3
Improvement of client satisfaction	41	80.4
No benefits	2	3.9
Others (Lower advertisement expenses, improvement of progress tracking)	2	3.9

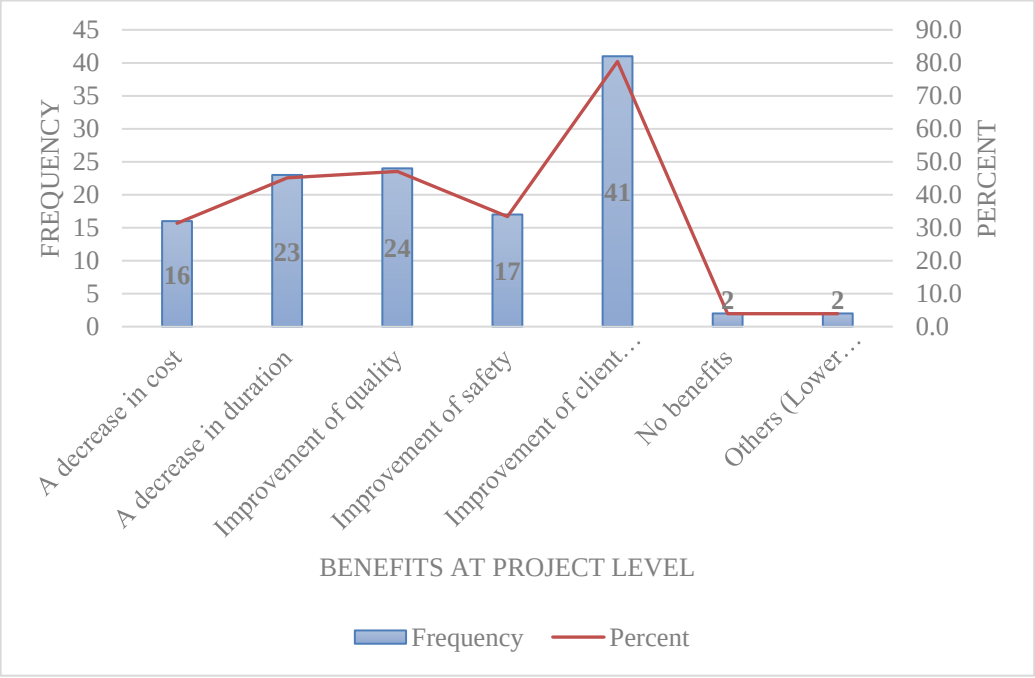

Figure 5.7. UAV technology benefits at the project level.

Additionally, benefits of UAV technology as acquired by 53 respondents at the company level with their respective frequency and percentages are presented in Table 5.21. Participants were asked to reveal the benefits they achieved from the use of UAV technology at the company level among the following benefits: improved company image, increase of technical capabilities, long term profitability, improved competitive advantage, no benefits, and others. Results are better illustrated in Figure 5.8. “Improved company image” got the highest record with 38 responses (71.7%), which is in line with “Improved client satisfaction” at the project level. When the client becomes more satisfied with the company’s delivered projects and services, this will enhance the company reputation among its competitors in the field. Only two respondents stated that they have not acquired any benefit from UAV technology while one another benefit was added which is its ability to provide nice photos to clients for commercial use.

Table 5.21. UAV benefits at company level.

UAV Benefits at Company Level	**Frequency**	**Percent**
Improved company image	38	71.7
Increase of technical capabilities	32	60.4
Long term profitability	20	37.7
Improved competitive advantage	22	41.5
No benefits	2	3.8
Others (Ability to provide nice photos to clients for commercial use)	1	1.9

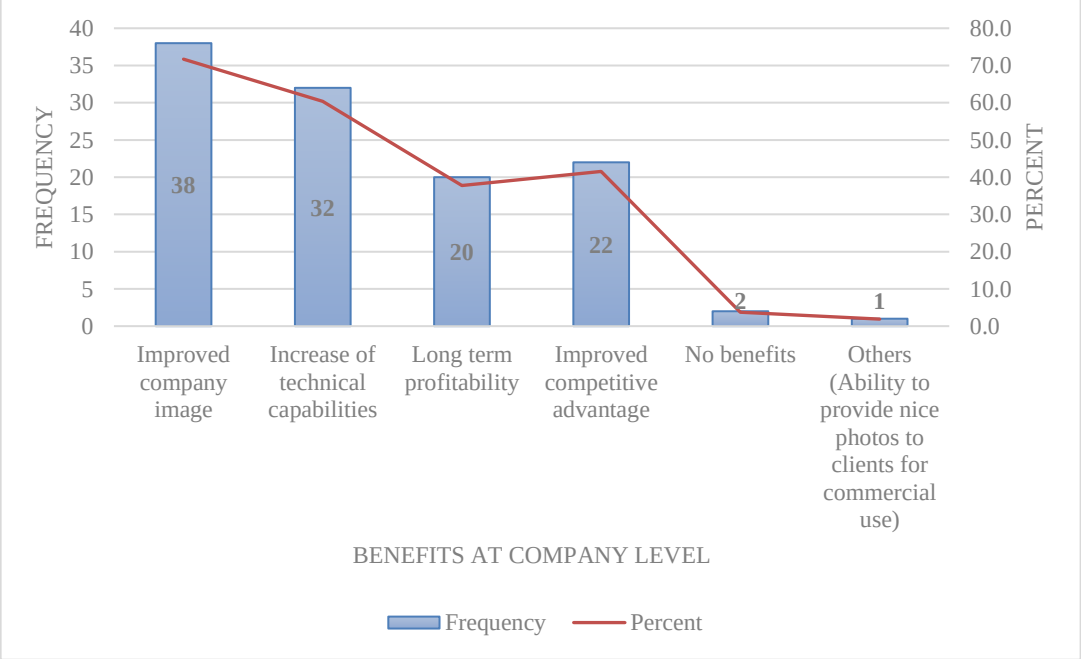

Figure 5.8. UAV technology benefits at company level.

Table 5.22 shows UAV drawbacks as stated by the respondents with their frequency and the corresponding project type. The most frequently mentioned drawbacks are the requirement of flight permits (3) and unsuitable weather conditions (3). Additionally, battery problems (2) and unsuitability for use in residential buildings, tall buildings, and covered areas (2) are considered obstacles for the use of UAV technology. Lack of qualified personnel (1), adaptability with other software (1), cost of education, hardware, and software (1), ban of using UAV over industrial zones (1) are also among the mentioned drawbacks. Lastly, it should be stated that UAV technology is still somehow regarded as only a fancy tool used for presentations (1), not performing “magic”.

Table 5.22. UAV technology drawbacks by respondents.

UAV Drawbacks as stated by the respondents	Frequency	Project type
Ban of using UAV over industrial zones	1	Industrial
Flight permits and military zones	3	-Infrastructure and Heavy Construction -Industrial
Adaptability with other software	1	Infrastructure and Heavy Construction
Not a "magical" tool as "advertised", a fancy tool for presentations	1	Institutional and commercial construction
Weather conditions	3	-Residential -Industrial -Institutional and commercial
Cost of education, hardware, and software	1	Industrial
Not suitable for tall buildings and covered areas	2	-Institutional and commercial construction -Industrial
Battery problems	2	-Infrastructure and Heavy Construction -Institutional and commercial
Lack of qualified personnel	1	Infrastructure and Heavy Construction

5.4. Web Questionnaire Survey

The questionnaire survey was web-based, conducted, and administered via Google Drive (drive.google.com). It was conducted from June 15, 2021, to July 15, 2021. Information on the target population was presented in Section 4.4. Invitations to participate in the survey were sent to participants via emails and Linkedin messaging to improve the response rate. 92 responses were collected as previously mentioned.

The survey is composed of three parts. Part One asked eleven questions gathering personal information about the respondents as shown in Section 5.2. Part Two is the part concerned with the critical success factors; it included 28 CSFs and asked the respondents to evaluate the importance level of each factor based on a five-point Likert Scale as follows: 1 = "Not Significant", 2 = "Fairly Significant", 3 = "Significant". 4 = "Very Significant ", 5 = "Extremely Significant". The last part asked questions related to a specific project where UAV technology was implemented as shown in Section 5.3.

5.5. Analysis and Ranking

The significance levels of the critical success factors (CSFs) are best defined and compared on an attribute basis using “mean ranking” technique. Table 5.24 shows the final list of the 28 CSFs with their corresponding descriptions and literature sources. Mean ranking results of the CSF attribute of UAV technology are presented in Table 5.25, showing the total ranking values, and in Table 5.26, comparing variable rankings between five respondents’ groups.

5.5.1. Reliability Test

It is important to test the reliability of the collected data, i.e., to ensure that data are reliable and acceptable for analysis before starting with the analysis process.

For this purpose, Cronbach's alpha reliability is determined in SPSS for the CSFs of UAV technology as shown in Table 5.23.

Table 5.23. Reliability statistics.

Cronbach's Alpha	**N of Items**
0.938	28

Cronbach's alpha value is 0.938. Since 0.938 is above 0.74, this means that the test is reliable, and the collected data are internally consistent (Norusis, 2012). Hence, reliable results can be obtained from the data analysis. More explanation on the reliability test can be found in Chapter 4, Section 4.6.3.

5.5.2. Critical Success Factors

The main aim of this study is to investigate the critical success factors for UAV technology implementation in construction projects in Turkey. In this regard, 28 critical success factors were identified from the literature (see Appendix A) to test their significance (Table 5.24). From the mean value obtained for each factor, it can be noted that all the factors are significant factors having mean values between 3 and 4. No value above 4 was recorded, meaning that all factors have the same criticality level (Table 5.25). Based on the perception of construction professionals, they are all significant factors but with different ranking.

Table 5.24. Critical success factors list.

Identifier (V)	List of CSFs	Description	Sources (A)
Internal Factors			
1	Technology Capital Cost (Availability of financial resources in the Organization)	Sufficient budget allocation to meet drone technology acquisition costs	1,4,8,17,19,22,23,24, 26,28,29,33,34,36,37, 38,39,40,41
2	Effective leadership and top management support	The degree of significance and support for drone technology adoption by top management	8,17,18,23,30,31,34, 37,38,39,40,41
3	Organization's innovation culture and flexibility	Organization's willingness to innovate and ability to adapt to new technological changes	17,18,23,24,30,31,34, 35,37,39,40
4	Availability of ICT infrastructure support	Existence of sufficient support and attention for ICT infrastructure	4,8,21,22,23,29,30, 31,32,33,34,40
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	2,3,4,7,15,16,17,18,22, 23,26,31,34,35,37,38
6	Availability of qualified or skilled workforce/ experts	Presence of adept and qualified people within the organization	5,8,17,18,20,23,24, 25,28,31,32,34,38,40
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	17,18,20,23,24,30, 31,32,33,34,39,40
8	Project structure and type	Consideration of the project structure and type before investing in UAV technology	18,20,30

Table 5.24. Critical success factors list (cont.).

Identifier (V)	List of CSFs	Description	Sources (A)
9	Collaboration, communication and coordination among project stakeholders	Existence of a collaborative environment throughout the project to successfully exploit drone technology	3,18,21,23,31,31, 33,40
10	Project cost and size	Consideration of the project cost (resources) and size (small or large) before investing in UAV technology	18,20,23,24,30,31, 36,40
11	Advanced UAV technical characteristics (camera, payload, sensors, battery, autonomy)	Ability to capture high-resolution and interpretable images and videos with its advanced features.	2,4,12,14,15,16,19, 20,21,22,23,24,26, 27,29,32,33,34,36, 38,39
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	3,12,14,15,16,17,18, 19,20,21,22,23,24, 37,28,29,30,31,33, 34,36,37,38,39
13	Flight reliability and safety (obstacle-avoidance)	Technology's capability to avoid obstacles and collisions with workers and building elements	3,4,8,10,12,14,15,17, 19,20,21, 22,26,27,32, 34,37,38,39
14	UAV technology interoperability	Technology's ability to be integrated with other technologies (BIM, RFID, LIDAR, AR, etc.)	3,7,15,16,21,22,27, 29,30,31,32,34
15	Technological advancements (Web, BIM, Wireless technology, AR/VR, LIDAR, RFID)	Continuous development of other technologies and their use in construction	5,8,9,11,17,18,21, 23,29,32,37,41
16	Technology's cost effectiveness (ROI)	Technology's ability to provide a quick return on investment (costs versus benefits)	12,14,15,16,17,18, 23,24,29,30,31,33, 34,36,37,39
17	Proved effectiveness of the technology	Level of maturity of drone technology in the industry	11,12,17,23,24,25, 37,39
External Factors			
18	Availability of multiple functional UAV platform types for selection	Continuous production and development of UAVs with different features for specific functions	3,6,12,14,18,21,23, 28,33,36
19	Availability of required hardware and software	Presence of the necessary components in the market for the efficient operation of UAVs	3,4,14,23,29,31,35, 36,38
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	2,4,5,14,15,23,24, 26,30,31,37

Table 5.24. Critical success factors list (cont.).

Identifier (V)	List of CSFs	Description	Sources (A)
21	Complexity of construction tasks/ Fragmented nature of the industry	Project-based and complex nature of the industry, difficulty to standardize practices	18,20,24,25,37,38,41
22	Society or users' awareness of drone technology	Users' perception level and familiarity towards the state of drone technology	6,8,14,15,17,18,20, 23,26,30,31,32,34, 37,38,39,40,41
23	Competition	Companies competing to innovate and adopt drone technology earlier	18,24,33,37,39,41
24	Market demand	Sufficient demands for drone technology by construction companies and other businesses	11,18,23,24,29,34,41
25	Weather and site conditions	UAVs' sensitivity to weather conditions	2,3,4,8,11,12,15,16, 17,18,21,22,26,29, 30,32,38
26	Proper licensure and certification requirement	Necessity to acquire a licence / certification before piloting a drone	1,4,9,14,21,22,23,26, 32,33,36,38,40
27	Government regulations and support	Existence of adequate government regulations and incentives to promote the use of drones in construction	2,3,6,8,9,12,15,17, 18,21,22,23,24,26, 31,32,33,34,35,37, 38,39,40,41
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	8,11,13,15,21,23, 24,25,33

Ranking and mean value results as well as literature sources mentioned in the next paragraphs are based on Tables 5.24, 5.25, and 5.26. As found from the questionnaire survey responses, the most significant 10 critical success factors are first presented as follows, with mean values ranging from 3.91 to 3.64.

Table 5.25. Mean ranking of the critical success factors.

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

Table 5.26. Means of the critical success factors by core business.

CSF	Main business area in the construction industry										Total		F	Sig. (5%)
	Consultant		Contractor		Private Client		Public Client		Subcontractor					
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank		
(V1) Technology Capital Cost	3.88	3	3.64	6	3.40	12	3.67	14	2.67	27	3.65	9	1.031	0.396
(V2) Effective leadership and top management support	4.08	1	3.87	1	3.50	9	4.33	3	3.67	14	3.91	1	0.834	0.507
(V3) Organization's innovation culture and flexibility	4.08	1	3.81	2	3.70	4	3.83	8	2.33	28	3.83	3	2.017	0.099
(V4) Availability of ICT infrastructure support	3.46	19	3.43	18	3.00	27	4.00	5	3.33	23	3.42	20	0.896	0.47
(V5) Awareness of ethical, privacy and safety issues in the organization	2.92	28	3.23	26	3.20	20	3.50	16	3.33	23	3.16	28	0.547	0.701
(V6) Availability of qualified personnel or skilled workforce/ experts	3.65	15	3.57	13	3.30	16	3.33	22	4.00	6	3.57	15	0.371	0.829
(V7) Education and training programs for UAV operators and workers	3.85	4	3.51	17	3.40	12	3.17	26	3.67	14	3.58	13	0.833	0.508
(V8) Project structure and type	3.38	21	3.60	10	3.30	16	3.17	26	4.00	6	3.49	17	0.404	0.805
(V9) Collaboration, communication and coordination among project stakeholders	3.73	9	3.09	28	3.10	25	3.83	8	4.00	6	3.35	24	2.374	0.058
(V10) Project cost and size	3.81	6	3.64	6	3.70	4	3.33	22	4.33	2	3.70	8	0.431	0.786
(V11) Advanced UAV technical characteristics	3.73	9	3.62	8	4.20	1	3.50	16	4.33	2	3.73	6	0.92	0.456

Table 5.26. Means of the critical success factors by core business (cont.).

CSF	Consultant		Contractor		Private Client		Public Client		Subcontractor		Total		F	Sig. (5%)
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank		
(V12) Easy-to-use, maintainable and controllable systems (fits into operations)	3.77	8	3.53	16	3.20	20	3.83	8	4.00	6	3.60	11	0.785	0.538
(V13) Flight reliability and safety (obstacle-avoidance)	3.65	15	3.57	13	3.40	12	3.67	14	3.67	14	3.59	12	0.176	0.95
(V14) UAV technology interoperability	3.69	14	3.36	20	3.20	20	4.00	5	3.33	23	3.48	18	1.102	0.361
(V15) Technological advancements	3.85	4	3.60	10	3.90	2	4.17	4	4.33	2	3.76	4	0.873	0.484
(V16) Technology's cost effectiveness (ROI)	3.81	6	3.62	8	3.60	6	4.50	1	4.00	6	3.74	5	1.027	0.398
(V17) Proved effectiveness of the technology	3.73	9	3.79	3	3.90	2	4.50	1	4.33	2	3.85	2	1.100	0.362
(V18) Availability of multiple functional UAV platform types for selection	3.23	26	3.15	27	3.40	12	3.50	16	3.67	14	3.24	27	0.519	0.722
(V19) Availability of required hardware and software	3.65	15	3.60	10	3.60	6	3.83	8	4.00	6	3.64	10	0.249	0.91
(V20) Attitude towards new technology adoption in the industry	3.73	9	3.70	4	3.50	9	3.83	8	4.00	6	3.71	7	0.21	0.932
(V21) Complexity of construction tasks/ Fragmented nature of the industry	3.27	25	3.55	15	3.30	16	3.50	16	4.00	6	3.46	19	0.432	0.785
(V22) Society or users' awareness of drone technology	3.38	21	3.32	23	3.30	16	3.83	8	3.67	14	3.38	22	0.41	0.801
(V23) Competition	3.23	26	3.32	23	3.10	25	3.50	16	3.67	14	3.29	25	0.269	0.897
(V24) Market demand	3.46	19	3.28	25	3.20	20	3.50	16	3.67	14	3.35	23	0.336	0.853

Table 5.26. Means of the critical success factors by core business (cont.).

CSF	Consultant		Contractor		Private Client		Public Client		Subcontractor		Total		F	Sig. (5%)
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank		
(V25) Weather and site conditions	3.31	23	3.68	5	3.60	6	3.33	22	4.67	1	3.58	13	1.025	0.399
(V26) Proper licensure and certification requirement	3.31	23	3.34	21	3.20	20	2.83	28	3.33	23	3.28	26	0.288	0.885
(V27) Government regulations and support	3.73	9	3.34	21	3.00	27	3.33	22	3.67	14	3.42	20	0.94	0.445
(V28) R&D investments for UAV technology adoption	3.62	18	3.40	19	3.50	9	4.00	5	3.67	14	3.52	16	0.467	0.76

An “effective leadership and top management support” is the most significant factor to consider for a successful implementation of drone technology. It occupies the first place with the highest mean value of 3.91. It also should be mentioned that it is ranked in the first place by contractors (3.87) and consultants (4.08) which means that it is considered a very significant factor for these groups (Table 5.26). This factor was also highly considered in the literature as shown in Table 5.24 (e.g., Kim et al., 2016; Golizadeh et al., 2019; Ozorhon and Oral, 2016; Ozorhon and Karahan, 2016; Idries et al, 2015). An essential role has been played by top management in the adoption of new business processes such as sustainability, business process organization, ERP, BIM; this case can be applied also for drone technology adoption (Raj and Sah, 2019). The degree of the top management support and the effectiveness of leadership concept in the organization strongly affect the decision to adopt any new technology in its projects. An organization with a strong leadership and top management commitment towards innovation is more inclined to implement a new technology in its construction projects. Lack of support for UAV technology from management might be due to the additional liabilities incurred with its use and acquisition (Kim et al, 2016). However, implanting a “collective mentality” that UAV technology is important and beneficial is of the main steps towards increasing or strengthening leadership concept in Turkish construction companies. Creating and enhancing the awareness of decision-makers through providing successful case studies in the company about the benefits as well as the potential risks brought by such new technology will create a considerable change in leadership (Fernandez et al., 2019). Top management will be more eager to be involved in innovative practices and support the implementation of UAV technology in their projects. Such top management involvement provides the organization with a strong strategic vision, plans and clear direction towards a successful implementation of the technology. Consideration of the organization needs and resources as well as integration of all departments into the implementation plan are crucial points for success (Glenn Graham, 2016).

In the second place comes the “proved effectiveness of the technology” issue with a mean value of 3.85. As shown in Table 5.26, this critical factor is ranked in the first place by public clients (4.5: mean value) which indicates that it is very significant for this group. It

describes the maturity level of drone technology in the construction industry. A technology's effectiveness is proved when the technical attributes satisfy the stated performance requirements; pilot tests are conducted in small scale to test the feasibility of drone technology (Nnaji et al., 2019; Makdisi and Makadsi, 2019). The more the technology is tested in the field the more its technical aspects become mature and well developed. Conducting test trials in field-realistic environments is necessary for the validation of the successful UAV technology applicability for civil engineering applications (Siebert and Teizer, 2014). A good maturity of drone technology gives it the potential to occupy an important place among other technologies such as BIM, RFID, LIDAR etc. Once its effectiveness is proved, it will attract the attention of construction professionals and workers in Turkey. This encourages companies thinking about using innovative technologies to consider the early adoption of drone technology. This factor was also considered significant in previous research in the literature, occupying for example a place among the most important first six factors [Nnaji et al., 2019 (rank 2); Delgado et al., 2016 (6)].

"Organization's innovation culture and flexibility" is the third most important critical factor affecting the adoption of drone technology. This factor has a mean value of 3.83. As shown in Table 5.26, consultants ranked this factor at the same significance level with V2; according to this group, it is very significant with a mean value of 4.08. It can be defined as the organization's willingness to innovate and ability to adapt to new technological changes. Hence an organization fostering innovation and eager to adapt to new technologies is more likely to succeed in innovation practices. However, there is still a weak innovation culture dominant in the Turkish construction industry. That is why it is very important to consider the organizational cultural traits since they affect the decision-making process regarding the use of new technologies (Irizarry and Costa, 2016; Lu et al., 2015). Developing an innovation and change culture in the organization or establishing an innovation hub in the organization by the management is one step towards accepting change in their future projects (Winkler and Zinsmeister, 2019). Better innovation management will raise the awareness of construction professionals about their attitude to innovation and drive the workforce to support change and new technologies such as drone technology (Ozorhon and Oral, 2016).

“Technological advancements” such as Web, BIM, Wireless technology, artificial intelligence (AI), AR/VR, LIDAR, RFID etc. factor is ranked at the fourth place with a mean value of 3.76. It is a significant factor well mentioned in the literature. For example, Raj and Sah, in 2019, found that this factor is the most influential factor affecting the adoption of drone technology in the logistics sector. Drone technology advances along with the related technological advancements which leads to an increase in the benefits of such investment (Albeaino et al., 2019). For instance, drones by using AI will have the ability to scan the construction site and report on broken equipment such as isolators, as well as safety conditions such as hazardous areas (Makdisi and Makadsi, 2019). Additionally, continuous development of new sensors such as thermal cameras, laser scanners, ultrasonic beacon system (UBS), and RFID together with their use in construction projects affect positively the use of drone technology (McCabe et al., 2017). Such technologies can be mounted on a drone to optimize the tasks done such as progress and materials tracking and monitoring, inspections of difficult-to-reach areas, etc. Many studies in the literature mentioned that technology advances make drone technology more reliable and safer to use; drones will gain the ability to avoid obstacles and collisions by detecting workers’ locations at construction sites (Tatum and Liu, 2017; Raj and Sah, 2019; Alizadehsalehi et al, 2018).

“Technology's cost effectiveness”, i.e., return on investment (ROI) by reducing cost and adding value, comes in the fifth position with a 3.74 mean value; it is a significant critical factor for a successful implementation of drone technology in construction. It is also considered very significant by “public clients” with a first-place rank and same importance level with V17 (mean value of 4.5). Convincing the management of the economic advantages linked with drone technology is crucial for its adoption (Makdisi and Makadsi, 2019). Before considering entering in any new business or adopting a new technology, a company must perform a cost-benefit analysis to foresee if it is a successful option or not (Fernandez et al., 2019; Graham, 2016). Adoption of drone technology requires such analysis. Decision-makers will be encouraged to adopt drone technology in their construction projects if the cost-benefit analysis result is positive. A positive cost-benefit analysis implies that it is worthy to invest in drone technology in terms of cost and time savings earned. In other words, the benefits

acquired from such investment covers the high initial capital cost incurred by the organization in the long-term (Abd Rashid et al., 2018) This depends on the type of drone used, the type of construction project, as well as the size of the company implementing the technology. Large contractor companies are most likely more inclined to invest in such a new technology since they have larger budgets, higher number of employees and larger projects; however, for small companies lacking sufficient resources, e.g., subcontractors, high capital investments are regarded as major challenge (Delgado et al., 2019). In a large complex project, the need for new technologies which will help in saving costs and time as well as enhancing communication between project parties is increasing. Another justification for investing in drone technology is the accompanied costly manual labor reduction and increase in productivity. For instance, as stated by Siebert and Tiezer (2014), commercial UAVs provide cost- and time-competitive options to conventional surveying applications.

"Advanced UAV technical characteristics (camera, payload, sensors, battery, autonomy)" is another critical factor leading to a successful integration of UAV technology to construction tasks. It has a mean value of 3.73 and is widely mentioned in the literature as shown in Table 5.24. It is regarded as a very significant factor by "private clients" with first rank and a mean value of 4.2 (Table 5.26). It consists of the drone ability to capture high-resolution and interpretable images and videos with its advanced features and autonomous flight capabilities (Albeaino et al., 2019). As previously mentioned, depending on their lift capability and payload specifications, drone technologies can be equipped with different types of sensors for different applications. Readily available cameras, LiDAR or laser scanning sensors for geolocation and element detection, radio frequency identification (RFID) for tracking tagged materials, gas and thermal sensors etc. can be mounted on UAVs to perform a wide variety of tasks in construction projects. UAVs' applications in construction projects are illustrated in Chapter 3. Battery life is also an important issue to consider when implementing drone technology. The use of advanced batteries allows the drone to perform a longer flight covering a larger area. DJI has been developing advanced intelligent lithium polymer (LiPo) UAV flight batteries allowing for up to 30-minute flight time. Other known battery types are nickel metal hydride (NiMH) and nickel cadmium (NiCd) batteries (Golizadeh et al.,2019).

Limited battery life could cause a problem if the operator's position is not in the drone's flight range (Sah et al., 2020). High resolution camera mounted on gimbals will enable the drone to capture high-quality images and videos of the construction site with great accuracy and stability for photogrammetry and 3D mapping. Thermal cameras are used for thermal imaging to detect gas leaks on platforms or towers; this avoids workers from being directly exposed to gas emissions (Accenture, 2016).

"Attitude towards new technology adoption in the industry" occupies the seventh place with a mean value of 3.71. It describes the degree of resistance from construction workforce towards drone technology adoption and their general inclination to stick to traditional practices. In general, construction industry is conservative and prefers to stick to traditional practices to avoid the possible risks and costs coming from innovative practices. Risk of failure after paying technology's acquisition and training costs is the main reason behind this resistance. Moreover, construction workers at sites, especially elderly, are generally reluctant to change because they are not always willing to learn, they prefer to keep doing what they are used to do, to use pen and pencils rather than using tablets and new technologies (Makdisi and Makadsi, 2019). That is why the organization should convince them by highlighting the benefits of using this new technology.

"Project cost and size" is found to be an important factor to consider which comes in the eighth place with a mean value of 3.70; however, there was not a considerable reference for this factor in the literature compared with others (Table 5.24). The consideration of the project cost (material and manhour resources) and size (small or large) before investing in UAV technology should not be ignored by the Turkish construction companies. This means to consider the project area or the altitude of project structures which can be covered with UAVs (Kim et al., 2016). Also, it is certain that the larger the project size is the larger its cost will be. Only medium and large companies can handle large projects since they have more resources and budget (Fernandez et al., 2019); also, they need drone technology more than small companies to perform complex project tasks effectively (inspections at high altitudes; surveying of larger areas, etc.). This was also demonstrated in Section 5.2.2 where most

companies involved in UAV technology used it in large projects (> $50M). Additionally, larger companies might have whole departments that evaluates and tests drone technology (Makdisi and Makadsi, 2019).

"Technology Capital Cost" or in other terms "Availability of financial resources in the Organization" is a factor very frequently mentioned in the literature. Mean ranking results shows that this factor got a mean value of 3.65 (ninth place). It refers to the sufficient budget allocation to meet drone technology acquisition, operation, maintenance, and training costs by the company. Low technology initial cost as well as operational and maintenance costs (Raj and Sah, 2019) encourage companies to be involved with drone technology, especially after the recognition of its potential benefits during the project. However, as stated in recent research, UAVs' acquisition, setup, operation, and maintenance costs at the present state are somewhat high (Opfer and Shields, 2014; Kim et al., 2016; Golizadeh et al., 2019). The purchase price of UAVs depends on its size, type, payload, range, and mode of operation (Siebert and Teizer, 2014).

"Availability of required hardware and software" is another issue to pay attention for by construction companies. It is the 10^{th} most significant factor with a mean value of 3.64. It is moderately mentioned in the literature. This factor mainly refers to the presence of the necessary components in the market for the efficient operation of UAVs. An example of the composition of a multi-copter was shown in Chapter 2, Section 2.5. Mainly the resources used in the development of a drone are divided into two categories which are: "Physical resources (hardware)" including processors, memory, peripheral devices, storage, APIs, workstations, workshops, network elements and sensors; and "Logical resources (software)" including all software, data, control modules (Idries et al., 2015). Any lack of these resources can cause a significant problem during the project. In summary, the continuous availability of the required tools such as batteries, propellers, processors, sensors, etc. in the local and international market is critical in case any damage occurs in the drone to avoid data loss, delays, and cost overruns.

The following 11 critical success factors have a less significance level with mean values ranging from 3.60 to 3.42.

“Easy-to-use, maintainable, and controllable systems (fits into operations)” factor follows with a mean value of 3.60 (11th place). User friendliness, i.e., users' ability to easily use, control and maintain drone outputs and components, will encourage drone users to develop and extend their skills in this field (Graham, 2016). To be successfully implemented, UAV systems should not interrupt the existing way of performing construction tasks (Makdisi and Makadsi, 2019); they should fit into current operations, considering the project conditions and any possible change before the implementation (Fernandez et al., 2019). Such new implementation in an organization requires special effort in terms of redefining the current relevant processes to leverage drone technology in the daily work (Makdisi and Makadsi, 2019). Also, the user friendliness and the interactivity function of the drone operating interface are very important for operators when performing inspection tasks and hovering the drone around a specific area; users can then easily be familiar with the drone control system (Kim et al., 2016; Golizadeh et al., 2019).

“Drones’ flight reliability and safety” (obstacle-avoidance) is another significant issue (mean value: 3.59; 12th place). It can be defined as the drone system’s consistency and capability to avoid obstacles and collisions with workers and building elements. When planning a drone flight, a focus should be on obstacle avoidance factor to prevent any collision of the drone with buildings, structures, other drones, aircrafts, and birds (Sah et al., 2020; Raj and Sah, 2019; Kim et al.,2016; Dupont et al., 2017).

“Weather and site conditions” also should not be ignored when flying a drone over the construction site (mean value of 3.58; 13th place). As shown in Table 5.26, it is a very significant factor for subcontractors; it is ranked by this group in the first position with a mean value of 4.65. Drone’s sensitivity to weather conditions must be recognized to avoid any problem occurrence due to bad weather conditions such as rain, fog, storms, or strong winds. Flying a drone in such bad conditions can cause drone crashing leading to physical injuries or

property damage (Sah et al., 2020; Raj and Sah, 2019). The low weight of commercial UAVs is a main reason behind their sensitivity to severe weather conditions. For instance, high winds (>30 km/h) lead to an overuse of drone battery power while trying to maintain its position; this causes a reduction in the flight time (Golizadeh et al., 2019). Furthermore, stronger winds can damage or blow the drone completely. The visual assets' quality will also be reduced due to drone's vibration (Siebert and Teizer, 2014). Finally, the drone battery is highly affected by weather conditions: chilly temperatures cause a charge loss while heat forms excessive wear and tear on batteries, propellers, and engines (Golizadeh et al., 2019).

"Education and training programs" for UAV operators and workers has the same mean value (3.58; 13th place). The increase in education can increase the probability of adopting drone technology in construction. Providing education and training sessions and workshops in Turkish companies to UAV potential users, IT workforce and employees before and during the technology's implementation is important since it will facilitate drone technology use and enhance the users' knowledge and skills for the technology. Hence, trained workers can have an advantage over others using the technology. Training can be reduced by prior experience. Allocating sufficient resources such as money and manpower for training purposes is essential. Formal education allows users to perform tasks of higher order rather than performing routine workplace tasks (Graham, 2016).

The "availability of qualified personnel or skilled workforce and experts" in the project is believed to have a significant effect on the implementation of drone technology. It has a mean value of 3.57 with a rank of 15. The presence of adept and qualified project team within the organization can enhance the chance of success from UAV technology adoption (Graham, 2016; Raj and Sah, 2019). Drone pilots having prior experience and expertise in the field know very well how to plan drone flights and collect data, manage, and control the drone in mid-air to avoid mid-air collisions and get adequate and high-quality images of the site for construction management tasks (Kim et al., 2016). Skilled contractors' and consultants' project team can apply machine-learning and AI technology to get better outcomes from drone data processing (Raj and Sah, 2019). This factor can also be considered as a result of the

previous factor since the offered education and training will surely help staff in developing new qualifications and skills related to the use of drone technology.

"R&D investments for UAV technology adoption" was less mentioned in the literature than other factor; however, it is still significant occupying the 16th position among the CSFs with a mean value of 3.52. A sufficient budget should be allocated in organizations for Research and Development (R&D) practices on drone technology and other related technologies in the construction industry. Low R&D budgets is a characteristic perceived in the construction industry compared with the manufacturing and automotive industries (Delgado et al., 2019). However, in recent years, the Turkish construction industry has been trying to increase its R&D practices as noted in Chapter 3, Section 3.3.4. Implementing an innovation such as drone technology necessitates experimentation and "trial and error" learning capability. Drone application development projects may be complex due to drone systems' complexity and software requirements (Idries et al., 2015). On the other hand, as stated in the literature, drone technology was previously tested for many applications such as search and rescue, surveillance, photography, and traffic control (Raj and Sah, 2019); the same can be done for construction applications (e.g., surveying) since we are talking about the same technology. This can be solved by testing drone technology's small-scale prototypes in a realistic safe environment or field conditions (Siebert and Teizer, 2014). Therefore, a research, development, and innovation (RDI) ecosystem must be created where all actors (e.g., drone operators, engineers, software developers) must discover roadmaps and opportunities helping in developing drone technology (J. Buchli et al., 2018). The involvement of several actors in the construction industry is necessary to have an open, dynamic RDI ecosystem which allows the development of agreed upon standards and interfaces to scale drone technologies beyond the academic world and occasional testing on construction sites.

"Project structure and type" factor has a mean value of 3.49 with a rank of 17. It is rarely mentioned in the literature; however, to consider the project type and how it is structured have somehow an essential role in deciding whether to adopt drone technology or not in the project. For example, as demonstrated Section 5.3.1, drone technology was mostly

applied in infrastructure and heavy construction projects. Use of drone technology in residential buildings and covered areas is still not very liked maybe for safety and privacy reasons.

"UAV technology interoperability" is another critical issue having a mean value of 3.48 with a rank of 18. It describes the technology's ability to be integrated with other technologies, software, and devices (BIM, RFID, LIDAR, AR, etc.). The easiness of integration and interoperability of drone technology with other systems, such as GPS systems and other sensors, facilitates the implementation of the technology (Fernandez et al., 2019). Drone data interoperability with other services (e.g., BIM) is important since shared data are stored only once and maintained by the data producer in one specific location to avoid producing redundant versions of data definitions (Graham, 2016; Dupont et al., 2017). That is why organizations and consultants in Turkey must consider the currently used software systems and devices when examining drone technology.

"Complexity of construction tasks or Fragmented nature of the industry" makes it difficult to standardize tasks related to the used technology. This factor exists moderately in the literature (Kim et al., 2016; Golizadeh et al., 2019; Fernandez et al., 2019; J. Buchli et al., 2018; Ozorhon an Oral, 2016) and is also applicable for the Turkish construction industry. It has a mean value of 3.46 at the 19th position. As previously mentioned, the construction industry has a project-based and complex nature. Each project has multiple stakeholders (suppliers, owners or clients, engineers, designers, managers, etc.). The more a project is complex and structured, the more there will be data needed to be collected, stored, and shared from the technology. Data storage and sharing is critical in a construction project. The complex and unique characteristic of construction projects encourages organizations to look for implementing innovative technologies (Ozorhon and Oral, 2016) to facilitate the execution of time-consuming and difficult tasks (surveying of large areas and photogrammetry; quality and safety inspections etc.). Also, construction tasks at sites can be automated using robotic technologies such as drones (J. Buchli et al., 2018). However, a special attention must be

considered on the avoidance of drone data loss due to bad documentation process or bad data exchange among offices in different locations (Golizadeh et al., 2019).

"Government regulations and support" critical factor follows with a mean value of 3.42 in the 20th place. It is one of the most mentioned critical factors in the literature; decision to adopt an innovation in the organization is affected by the related present regulations (Ozorhon and Oral, 2016). With the rapid emergence and use of drone technology for civil applications, governments have released associated regulations to protect the public safety (Raj and Sah, 2019; Golizadeh et al., 2019; Dupont et al., 2017). According to the obtained results, this factor significantly affects the company's decision regarding drone technology adoption in construction projects in Turkey. The existence of adequate Turkish government regulations and incentives for drone technology adoption will promote the use of drones in the construction industry. GCDA's current regulations in Turkey are illustrated in Chapter 2, Section 2.4. However, government regulations are still in continuous development and change. This might hinder drone technology adoption by some construction companies that might not want to be engaged in and concerned with these restrictive regulations. On the other hand, government initiatives encourage companies to invest in drone technology (Abd Rashid et al., 2018; Delgado et al., 2019).

"Availability of Information and Communication technologies (ICT) infrastructure support" comes at the same significance level of importance with V27. It has the same mean value of 3.42 occupying thereby the 20th position. The existence of sufficient support and attention for ICT infrastructure, e.g., hardware, software, telecommunications, Intranet and Extranet, wireless connection, and social media (Lu et al., 2015) in Turkish organizations is essential for successfully adopting drone technology in their projects. A mature and secure ICT system improves UAVs' data management practices and security through the selection of appropriate software (Winkler and Zinsmeister, 2019; Mohammed et al., 2014).

Finally, the last seven critical success factors mentioned below have the least significance level with mean values ranging from 3.38 to 3.16.

“Society or users' awareness of drone technology” was highly mentioned in previous literature. However, it was not rated among the most significant CSFs by Turkish construction practitioners. It has a mean value of 3.38 with a rank of 22. This factor is concerned with the users' perception level and familiarity for the state of drone technology. Generally, the society still perceives drones as tools used only for surveillance and military purposes; additionally, most people do not like to see a drone hovering above them for privacy and security reasons (Raj and Sah, 2019). However, informing the public about the different drone types and applications in the construction sector would affect their perception positively and increase their approval of drones. Similarly, Fernandez et al. (2019) mentioned that a collective mentality about the benefits of a technology should be built in an organization to encourage employees to embrace this new technology. Hence, raising the awareness of employees about drone technology’s benefits in construction is crucial. One way to achieve that is by education, by providing webinars, workshops, seminars, and continuous professional development sessions for employees. Young professionals tend to be more willing to learn and gather information about the technology changes; but also, older professionals should be encouraged to understand the currently available technological tools. Hence, creating a common sense of awareness of drone technology in the Turkish construction industry can increase the chance of successfully implementing drone technologies.

Following is the “Market demand” factor with a mean value of 3.35 and a 23rd ranking. Drone technology market has recently been in constant growth and is expected to grow more in the coming years as mentioned in Chapter 2, Section 2.3. This growth is due to the high demand of drone technology in many industries, such as agriculture, oil and gas, and construction industry. Hence, sufficient demands for drone technology by construction companies and other businesses will enhance drone technology adoption in Turkish construction companies since there will be new and better drone products and services as well as production cost reductions (Abd Rashid et al., 2018). However, the project-based and fragmented nature of the construction industry makes it difficult to predict the demand levels for drone technologies in the future (Delgado et al., 2019).

With the same mean value and rank as “Market demand”, 3.35 and 23 respectively, “Collaboration, communication and coordination among project stakeholders” critical factor has an impact on the adoption of drone technology. The implementation of any new technology in an organization requires the existence of a collaborative environment throughout the construction project to successfully exploit the technology. Collaboration and coordination among different project stakeholders are important to avoid any misunderstanding and potential conflicts throughout the execution process (Ozorhon and Cinar, 2015). Having site and office meetings with the different project parties such as owner/client and contractors, on a regular basis, is crucial to discuss the latest updates or issues related to the use of drone technology at the site such as safety issues.

“Competition” is in the 25th place with a mean value of 3.29. This factor was also not frequently mentioned in the literature. But still, it should be considered since competition level between construction companies affects the attitude of decision-makers towards drone technology adoption. Competition is considered a driver to innovation. Companies are frequently competing to innovate and adopt drone technology earlier to withstand the competition and gain a competitive advantage in the industry. Using innovative technologies, such as drone technology, in their projects helps them to devise new solutions to their current problems (Ozorhon and Oral, 2016). Clients and workers may perceive companies using drone technologies as more superior than others using traditional methods; this will encourage other companies to invest in drone technologies to stay in the competition and satisfy client demands which will drive drone technology adoption in construction (Makdisi and Makadsi, 2019).

“Proper licensure and certification requirement” has a mean value of 3.28 with a rank of 26. It is also a significant factor mentioned in the literature but for Turkish construction professionals it seems to have a less significance degree than other critical factors. It can be defined as the necessity to acquire a license or certification before piloting a drone. Like other countries, the GCDA in Turkey requires a drone pilot license for drone operators. Hence, licensed operators should be hired to execute drone flights on construction sites needed for

complex construction tasks. However, hiring skilled operators also raises concerns regarding the extra costs related to the project and employment of licensed drone operators (Kim et al., 2016; Irizarry et al., 2012; Golizadeh et al., 2019). This issue may be solved by subcontracting the task, e.g., performing site video or still photography, to another external company specialized in drone technologies (Opfer and Shields, 2014).

"Availability of multiple functional UAV platform types for selection" factor can also be considered significantly critical based on its mean value (3.24); however, it is for sure of less criticality than the other stated factors since it occupies the 27th position. This factor is concerned with the continuous production and development of UAVs with different features for specific functions in Turkey as well as worldwide. For example, there are currently many UAV platforms developed with several technical features and sensors as stated in Chapter 2, Section 2.5, and in the literature (Siebert and Teizer, 2014; Makdisi and Makadsi, 2019; Greenwood et al. 2019; Accenture, 2016; Graham, 2016). First, drone users select between "fixed-wing drones" and "rotary-wing drones" depending on the type of the project. For instance, contractors wishing to use a drone in a horizontal construction project (pipeline) will prefer to use fixed-wing drones since these drones have higher flight times and can cover large areas. However, rotary-wing drones are preferred for vertical construction to perform inspection tasks by hovering over the specified area with GPS-stabilization and taking high-quality images; among rotary-wing drones, multirotor drones are preferred more than single rotor drones because the latter type requires more expertise (Opfer and Shields, 2014).

The last critical success factor (28th) with the least significant level is "Awareness of ethical, privacy and safety issues in the organization" having a mean of 3.16. Considering the ethics, privacy and safety of workers and people near the construction site when flying a drone is critical. Flying a drone over a construction site can raise safety concerns for on-site workers (Golizadeh et al., 2019) since a drone, if not properly and safely operated, might be subject to mechanical failure or power loss during flights; also, workers might be distracted by drones' noise and motion (Moud et al. 2018; Opfer and Shields, 2014). Hence, drone operators should read well the safety or operational instructions related to the drone as specified by the

manufacturer and test the drone first in open areas. Also, a drone can be operated in areas where access is restricted for the workers (Kim et al., 2016). Concerning privacy, people have a right to have a private life and they perceive a drone hovering over their properties as a threat to their privacy. Also, the use of drones as a weapon in wars to kill civilians raises ethical issues (Yildizel and Calis, 2019).

Difference in the opinions between UAV technology users and nonusers on CSFs:

Normality test showed that data were not normally distributed. Despite this assumption violation and based on evidence from previous research as stated previously, it was believed that T-test, as a parametric test, is suitable to determine whether there is a significant difference between the opinions of UAV technology users and nonusers in terms of the importance of CSFs. T-test results (see Table C.1, Appendix C) show that for only two variables [(1) organization's innovation culture, and (2) project cost and size], the significance is lesser than 0.05 ($p < 0.05$). This implies that whether the respondent is a user of the UAV technology or not is important only at the understanding of these two CSFs. Nonusers of UAV technology (40.2%) provide more importance to the organization's innovation culture than the users of the technology (respective means, 4.11 versus 3.64). Having a culture in the organization which fosters the use of innovative technologies in its projects enhances the willingness of decision-makers to adopt UAV technology. On the other hand, an absence of such culture and the preference of traditional methods hinder the adoption; this might be the reason behind the importance given by UAV's nonusers to this critical factor. Also, for the project cost and size, it is considered more critical by nonusers of UAV technology (means, 4.03 > 3.47 by users); hence they might not be using drone technology because the projects that they are currently involved in are small and do not require them to invest in innovation.

Difference in the opinions between the five business area groups on CSFs:

Homogeneity test shows that data are homogeneous; hence the second assumption was not violated for ANOVA. Table 5.26 shows ANOVA results which test whether there are

significant differences in the responses of “Contractor, Consultant, Private/Public Client, and Subcontractor” group on the identified 28 CSFs (5% significance level). The F value and the significance level for each factor indicate that there is no statistically significant difference in the opinions of these five groups. Otherwise, a posthoc test (a posteriori test) should have been carried out to determine which groups have significantly different means. Since this is not the case, a posthoc test (Tukey test, assuming equal variances or Games-Howell test assuming non-equal variances) is not carried in this study. However, results show that there is a considerable difference in the ranking of factors between the groups. For example, “technology capital cost (availability of financial resources in the organization)” is considered very important by consultants ranking it in the third place; while private clients, public clients and subcontractors rank it in 12^{th},14^{th}, and 27^{th} place, respectively. Another example can be “weather and site conditions” factor which is perceived as the most important one by subcontractors (Rank 1) while it is ranked by contractors, consultants, private and public clients in 23^{rd}, 5^{th}, 6^{th}, and 22^{nd} place, respectively. Also, it is interesting that “Organization's innovation culture and flexibility” factor was ranked in the first place by contractors; on the contrary, it was perceived as the least critical factor by subcontractors (Rank 28).

5.6. Factor Analysis of UAV Technology Features

Factor analysis of the UAV technology characteristics was performed in SPSS. SPSS program generated output files in the form of correlation matrix, eigenvalues and total variance explained, scree plot, component matrix, rotated component matrix, and component transformation matrix. This analysis is carried to explore and identify the underlying relationships among the critical factors, and illustrate them in fewer, but more concise and comprehensive factors.

5.6.1. Critical Success Factors (CSFs) for UAV Technology Implementation

The correlation matrix of the 28 community variables is shown in Table C.2 (Appendix C). As shown in Table C.3 (Appendix C), the value of the test statistic for sphericity is large (Bartlett test of sphericity = 1429.902) and the related significance level is very small (p.000), which means that the correlation matrix is not an identity matrix. KMO statistic value is acceptable with a value of 0.856. However, the examination of the correlation matrix shows that not all the variables have a significant correlation 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 means that there is no singularity effect, and no factor should be eliminated. However, $2.08*10^{-8}$ is smaller than 0.00001, suggesting that there is a need to eliminate some of the variables for the principal component analysis. The initial factor analysis performed in SPSS has led to seven components; however, eight variables having loadings less than 0.5 and which are less correlated with other factors were eliminated taking into consideration that a component must have more than two factors. These eight variables are "(V4) Availability of ICT infrastructure support", "(V8) Project structure and type", "(V10) Project cost and size", "(V18) Availability of multiple functional UAV platform types for selection", "(V19) Availability of required hardware and software", "(V21) Complexity of construction tasks/ Fragmented nature of the industry", "(V22) Society or users' awareness of drone technology", and " (V28) R&D investments for UAV technology adoption". The correlation matrix of the 20 variables is found in Table C.4 (Appendix C). After eliminating these factors, the matrix is now considered appropriate for analysis. The value of the KMO statistic is 0.837 (Table C.5, Appendix C), which according to Kaiser (Norusis, 2012) is acceptable for factor analysis.

Principal component analysis (PCA) was then performed producing a five-factor solution with eigenvalues greater than 1.000, explaining 65.865% of the variance (see Table C.6, Appendix C). Table 5.27 shows factors' grouping based on varimax rotation. Each factor belongs to only one of the components, with a loading on each factor exceeding 0.45. Based on the variables' descriptions, the five factors can be explained as follows:

- Factor 1 represents “UAV and Technology Characteristics” (Internal Factor).
- Factor 2 represents “Organizational Characteristics” (Internal Factor).
- Factor 3 represents “Project teams Characteristics” (Internal Factor).
- Factor 4 represents “Market-related Factors” (External Factor).
- Factor 5 represents “Legal and Environmental Factors” (External Factor).

After the calculation of the average of the variables’ mean values to obtain a mean value for each group, it can be reported that organizational characteristics (mean, 3.8) and UAV and technology characteristics (3.65) are the most indispensable for a successful UAV technology implementation, which are followed by market-related factors (3.55) and legal and environmental factors (3.43). Project teams characteristics (3.41), however, seem to have less influence on UAV technology implementation.

Table 5.27. Rotated factor matrix (loadings) of critical success factors for UAVs.

Common Factors	**Variables**	**Component**				
		1	2	3	4	5
UAV and 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 teams 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**

Table 5.27. Rotated factor matrix (loadings) of critical success factors for UAVs (cont.).

Common Factors	**Variables**	**Component**				
		1	2	3	4	5
PCA (Total Variance Explained)	Initial Eigenvalues	7.619	1.834	1.441	1.212	**1.067**
	Percentage of Variance	38.097	9.171	7.203	6.061	**5.333**
	Cumulative Percentage of Variance Explained	38.097	47.268	54.471	60.532	**65.865**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 7 iterations.						
KMO and Bartlett's Test	Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.837				
	Bartlett's Test of Sphericity	Approx. Chi-Square	874.861			
		df	190			
		Sig.	0			

5.6.1.1. Factor 1. The UAV and technology characteristics accounts for 20.442% of the total variances in the critical success factors' correlation matrix. This principal factor consists of 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).

All sub-factors in Factor 1 have high loadings ranging from 0.817 to 0.663. The most three important aspects in this component having loadings greater than 0.7 are easy-to-use, maintainable, and controllable systems (fits into operations), flight reliability and safety (obstacle-avoidance), and advanced UAV technical characteristics with loadings of 0.817, 0.763, and 0.746, respectively. The easiness of operating drone technology, of assembling, controlling, and maintaining its different components (mean, 3.60) as well as processing of the collected data is suggested to significantly influence the drone technology adoption, also considering its ability to fit and be integrated into currently implemented operations and construction management tasks in the organization. The more complex drone technology is, the more it will require attention and training as well as changes and redefining of the current processes, which will in turn make the technology less used or liked by young and elderly construction professionals. An example of an easily operated drone could be a quadcopter used for photogrammetric applications. It has a high flexibility to take-off and land in very small surveying tasks, can be easily and reliably steered in autonomous and pilot mode, and kept under control in severe environments such as strong winds (Siebert and Teizer, 2014).

Additionally, when conducting drone flights over a construction site for a certain application, such as site surveying, identifying ground features, creating georeferenced 2D and 3D models or building inspection, drone operators or pilots must be sure that the drone takeoff and landing, i.e., flight, is reliable and safe (mean, 3.59); the drone should be capable of avoiding obstacles along its way as planned by the operator. Good flight control practices such as obstacle-avoidance using range sensors, avoiding power loss and path planning using related applications/software within the visual line of site (Mohammed et al., 2014), lead to a successful application of drone technology on construction sites. Fortunately, new

technologies allowing drones to discover more reliably their navigable paths, sense and avoid other aircraft are rapidly developing. For instance, using a drone for inspecting the identified locations on the construction site requires flight path planning optimization to capture reliable and safe data in less time; this can be done using optimization techniques such as Particle Swarm Optimization (PSO) (McCabe et al., 2017). Advanced UAV technical characteristics (3.73) also contributes 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 (McCabe et al., 2017).

The other three subfactors with less but still high loadings are UAV technology interoperability, technological advancements, and technology's cost effectiveness (ROI) with a significance of 0.696, 0.686, and 0.663, respectively.

Interoperability is considered a critical characteristic of UAV technology (mean, 3.48). Especially, interoperability of UAV technology data with BIM was discussed in the literature. Integration of drone captured reality models to a BIM software such as Revit helps in tracking the project progress, phase by phase, for delays by overlaying the reality models over BIM models., hence comparing the actual state with the planned state. Drone data should be successfully linked to a BIM software to improve productivity (Dupont et al., 2017). The industry foundation classes IFC open data exchange format, facilitates the exchange of drone captured data with BIM platform which can be both a data provider and storing platform for UAV (McCabe et al., 2017).

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. As previously stated, 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 (Dupont et al., 2017; McCabe et al., 2017).

The last subfactor in this category which adds an important advantage to UAV technology characteristics is the technology's cost effectiveness (3.74). It is true that in addition to the initial cost of adopting a drone, adapting to a new technology and workflow in an organization can cost time and money. However, it is suggested that investment in drone technology will cover these expenses and provide gains in terms of cost and time to the company. The cost effectiveness of drone 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 week; however, using a multirotor drone, for example, reduces the time to few minutes at a low cost. For instance, the cost of surveying a 5 km road is about $5,200 in six days using a laser scanner while it is only $970 completed in nine hours using a multirotor drone (Wingtra.com). Also, accurate and impartial drone data provide accurate earthwork estimates, thus reducing possible extra payments to the contractors due to estimation errors. Moreover, decisions can be made faster after collecting and processing images collected from the drone and moving to later construction tasks can be done earlier which saves time and costs to the employee and subcontractors. Additionally, using drone high-resolution images reduces maintenance cost, allows for early detection of construction mistakes as well as post project documentation which helps when bidding for a similar project.

5.6.1.2. Factor 2. The organizational characteristics are responsible for 12.278% of the total variances in the critical success factors' correlation matrix. There are three factors in this category which are effective leadership and top management support, technology capital cost (availability of financial resources in the organization), and organization's innovation culture and flexibility.

The subfactor with the highest loading of 0.749 is the effective leadership and top management support, which was found to be the most significant CSF among the 28 CSFs

used in this study (with a mean value of 3.91). An organization which possesses a leadership spirit, focusing on its people and on positive change in its construction management practices, creates an internal environment open to innovative practices and staff training. Successful project leaders play an important role in solving conflicts and communication difficulties between people and departments (Ozorhon and Cinar, 2015). Top management is responsible for developing clear and comprehensive strategic plans aligned with the use of drone technology in the organizations' current and future construction projects (Glenn Graham, 2016). Allocation of sufficient financial, manpower and material resources as well as project manager's confidence towards top management support in case of the occurrence of an undesired situation are significant critical points to consider for a successful implementation of drone technology.

The second subfactor in this category, technology capital cost (availability of financial resources in the organization) (mean, 3.65), also have a high loading of 0.707 (greater than 0.7). It 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. With the rapid, continuous technological improvements, UAVs have gained many advanced functional characteristics, 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 small UAVs' cost change usually from less than $50 for a low-resolution camera quadrotor to $50,000 or more for a more sophisticated multirotor platform (Greenwood et al., 2019). The organization, depending on its financial resources and its objectives behind UAV technology adoption, should select the appropriate UAV type to leverage its usage in its current projects. Additionally, a drone is bought once but can be used in several construction projects carried by the organization, in case of similar site conditions.

Organization's innovation culture and flexibility (mean, 3.83) is another important subfactor having a relatively high significance of 0.543. It is the third most important critical success factor. An important 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 in relation with the top management support for new technologies (Alohan, 2019).

5.6.1.3. Factor 3. Project teams characteristics account for 11.923% of the total variances in the critical success factors' correlation matrix. There are four variables in this component: (1) awareness of ethical, privacy and safety issues in the organization, (2) availability of qualified personnel or skilled workforce/ experts, (3) collaboration, communication, and coordination among project stakeholders, and (4) education and training programs for UAV operators and workers.

The factor with the highest loading in this category is the awareness of ethical, privacy and safety issues in the organization (0.725). It is the least important CSF as found in this study with a mean value of 3.16. However, for the successful implementation of drone technology in the project, it is important 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 take into consideration the regulations (issued by GDCA in Turkey) for conducting a safe and reliable drone flight. Invading the privacy of workers or putting workers at risks (injuries, distractions) due to bad drone operation should be avoided by drone users (McCabe et al., 2017).

Availability of qualified personnel or skilled workforce/ experts (mean, 3.57) is the second important variable in Factor 3 with a high loading of 0.655. A qualified project team having previous knowledge and experience with drone hardware and software as well as performing safe and reliable drone flights for data collection would surely benefit from the use of drone technology (Kim et al., 2016). An experienced drone pilot can fly and control a drone quickly and safely to capture aerial images, for instance, for a bridge inspection task; also skilled site engineers and subcontractors will be able to interpret these images after data processing using the software and share them with the owner.

The third important subfactor is collaboration, communication, and coordination among project stakeholders (mean, 3.35) with also a relatively high loading of 0.554. Communication between project stakeholders, from the project planning phase till the operation and maintenance phase, is crucial for successfully integrating drone technology to construction management tasks and creating educated decisions regarding this new technology. Coordination meetings between project parties (project managers, consultants, engineers, clients) during which the drone-collected data are shown, interpreted, and discussed for project progress tracking against the planned schedule, are necessary for each project. Such regular meetings help in resolving potential conflicts, delay and cost overrun issues (Ozorhon and Cinar, 2015).

The last subfactor having a lower but relatively high loading of 0.475 in this category is the education and training programs for UAV operators and workers (mean, 3.58). These training programs build competent project teams in the organization which help in achieving a proper drone technology implementation. Hence, sufficient budget must be allocated by the top management for training purposes to raise employees' competence and acceptance level regarding the use of drone technology (Graham, 2016).

5.6.1.4. Factor 4. Market-related factors are responsible for 11.294% of the total variances in the critical success factors' correlation matrix. This category consists of four factors which are market demand, competition, proved effectiveness of the technology, and attitude towards new technology adoption in the industry.

The most two important aspects in this component are market demand (mean, 3.35), and competition (3.29), with high loadings of 0.777 and 0.764, respectively. The low costs and availability of wide range of functional drone platforms have been catching the interest of the public in the last years. The growing demand for commercial drones for civil applications is continuously driving drone manufacturers (DJI, Parrot, Yuneec, etc.) to offer a wider range of choices at different price levels (Greenwood et al., 2019) 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 drone technologies to outperform their competitors (Alohan, 2019). Additionally, competition among drone manufacturers to develop advanced drone platforms is making the drone market highly competitive (Mordor Intelligence Report, 2020)

The other two factors are proved effectiveness of the technology (mean, 3.85; rank, 2), and attitude towards new technology adoption in the industry (mean, 3.71) with relatively high loadings of 0.557 and 0.494, respectively. It is suggested that the proved effectiveness and maturity of drone technology in construction projects will increase the demand for it in the construction market (Delgado et al., 2016). The attitude towards the adoption of drone technology in the construction is in its turn affected by the level of maturity of drone technology. The more the effectiveness of drone 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. Change resistance and the traditionally driven workers who are used to perform routine tasks, such as taking building materials' measurements, and not acquainted with IT, pose a challenge for organizations looking for implementing drone technology (Mahbub, 2008; Alohan, 2019). This challenge can be overcome by raising the awareness of construction workers and changing their perception of drone technology; this, of course, cannot be easily done (Alohan, 2019); it requires special effort from Turkish construction companies to make employees amazed and excited to deal with such technology.

5.6.1.5. Factor 5. Legal and environmental characteristics account for 9.929% of the total variances in the critical success factors' correlation matrix. This component consists of three factors with high loadings: weather and site conditions (0.765), government regulations and support (0.703), and proper licensure and certification requirement (0.669).

Weather and site conditions (mean, 3.58) is an important factor of this category which affect the ability of construction companies to integrate drone technology into construction tasks. A harsh environment, such as strong winds or rain, would significantly make it difficult to operate a drone for any construction management task (Siebert and Teizer, 2014; Golizadeh

et al., 2019). Drone's sensitivity level to weather conditions should not be ignored by drone pilots.

Government regulations and support (mean, 3.42) is also another important aspect in this category responsible for a successful drone technology implementation. Turkey is mostly known for developing and adopting drones for military use. As mentioned in Chapter 2, Section 2.4, there is a lack of investments and government incentives in Turkey in the commercial drone market. Providing incentives by the government such as reinvestment loans, allowances, and funds (Abd Rashid et al., 2018) for the use of drone technology in the construction sector will encourage the sector to implement the technology. Regulations concerning airspace restrictions, altitudes and drone weights are important to avoid safety- and privacy-related risks (Golizadeh et al., 2019). However, such restrictive regulatory environment was stated as a barrier for drone adoption by some of the respondents as shown in Section 5.3.2. This might be due to the regulations being in continuous update, so the company do not want to deal with these changes. A solution to this problem may be by subcontracting this issue to drone service providing companies; however, this also may cause delays and resulting extra costs since the drone will not be ready for data collection at the time it is needed, and planning of site visits' dates might be required from the contractor.

Finally, the last subfactor related to the legal and environment characteristics is the requirement of a proper licensure and certification by the GDCA in Turkey as well as in other countries (FAA in USA, CASA in Australia, for example) (Golizadeh et al., 2019; Mohammed et al., 2014). Remote pilot license and drone registration in the system are required for piloting a drone over Turkey's construction sites. This will ensure that the drone is piloted and controlled by a skilled operator since construction sites are generally complex.

5.7. Summary

This chapter has generated investigative findings concerning the reasons for adopting UAV technology in construction projects in terms of critical success factors for UAV

technology implementation in Turkey based on a questionnaire survey. Mean value and ranking statistical methods (mean ranking, t-test, and ANOVA) were used to perform the analysis. Furthermore, factor analysis was performed to establish the underlying relationships between the critical factors.

The study mainly aims to examine the critical success factors for UAV technology implementation in construction projects. As shown from the questionnaire survey results, all factors are somehow responsible for achieving a successful UAV technology implementation. However, the first most significant ten factors with mean values greater than 3.6 are, in decreasing significance order, effective leadership and top management support, proved effectiveness of the technology, organization's innovation culture and flexibility, technological advancements, technology's cost effectiveness (ROI), advanced UAV technical characteristics, attitude towards new technology adoption in the industry, project cost and size, technology capital cost, and availability of required hardware and software. The other eleven factors with lower but also considerable significance (mean values ranging from 3.6 to 3.42) are: easy-to-use, maintainable and controllable systems, flight reliability and safety, weather and site conditions,), education and training programs for UAV operators and workers, availability of qualified personnel or skilled workforce/ experts, R&D investments for UAV technology adoption, project structure and type, UAV technology interoperability, complexity of construction tasks/ fragmented nature of the industry, government regulations and support, and availability of ICT infrastructure support. The last seven factors regarded as critical, with mean values ranging from 3.38 to 3.16, are society or users' awareness of drone technology, market demand, collaboration, communication and coordination among project stakeholders, competition, 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. Lastly, five underlying components were found from factor analysis named as “UAV and technology characteristics”, “Organizational characteristics”, “Project teams characteristics”, “Market-related factors”, and “Legal and environmental factor”.

6. SUMMARY AND CONCLUSIONS

This research mainly aims to determine the most significant critical success factors which are indispensable for a successful UAV technology implementation in the construction sector, especially in Turkey. Research findings are based on the responses provided by the Turkish contractors, consultants, subcontractors, and public and private clients using a questionnaire survey.

The research provides a general overview on unmanned aerial vehicles (UAVs) under four headings: UAVs history and development, UAVs international use and market trends, UAVs' use and regulations in Turkey, and UAV types and characteristics. UAVs were initially designed and used for military applications, especially in Turkey. However, year by year, their civilian applications are growing in many sectors, such as agriculture, oil and gas (industrial), transportation, photography, and most importantly construction. Asia-Pacific region was found to be the fastest growing market, mainly China, Japan, and Australia, while the largest drone market was in North America (US and Canada). In Europe, France, Germany, Italy, and UK are among the top commercial drone markets. As stated in the "Drone Market Report 2020-2025" (DroneII.com, 2020), the global commercial drone market is projected to grow to $42.8B by 2025 at 13.8% CAGR. Turkey was more concerned with the use of drones in military, but during nearly the last decade, the country has started to regard drones as important civilian tools for use in many Turkish sectors, especially in agriculture and construction sectors. However, there is still a small number of private businesses using drones for commercial purposes, mainly because of the regulations set by the GDCA.

The drone market presents many types of drones with different characteristics and functions which can be divided into four types: fixed-wing drones, multi-rotor drones, fixed-wing hybrid VTOL (Vertical Take-off and Landing), and single rotor drones (like helicopters).

The literature review focused on the different potential applications of drones in construction projects which are land surveying, 3D modeling/ photogrammetry, progress monitoring and reporting, quality inspection, time management, post-disaster assessment or damage assessment, safety control and inspection, and promotional photography. Case studies were also presented on the use of drone technology in construction projects in both US and Turkey; these case studies report on the importance of drone technology in facilitating surveying tasks, photogrammetry, monitoring of construction activities, volumetric measurements and materials and equipment tracking on site. Cost and time effectiveness of the technology were demonstrated.

The third research step focused completely on determining the critical success factors extracted from an extensive review of the relevant literature (journal articles, conference papers, web articles, theses, books). Firstly, a list of 78 CSFs was obtained, then it was reduced to include 28 factors by grouping them under categories based on their shared aspects or similarities.

In the following phase, a questionnaire survey was developed as a data collection tool. The questionnaire was composed of three main sections, the first section being concerned with collecting general personal and organizational information from the respondents, the second one including the CSF list and asking the participants to rate the significance of each CSF based on a five-point Likert Scale, while the last optional section collected project-specific information from participants being involved with UAV technology. The survey was sent via emails and Linkedin platform to experts and professionals working in 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, also to members of the Turkish Contractors Association (TCA), Association of Turkish Consulting Engineers and Architects (ATCEA), and the Turkish Employers' Association of Construction Industries (TEACI). Ninety-two respondents completed the survey with an acceptable response rate of 29.4%.

The fifth stage consisted of analyzing the collected data by conducting different statistical methods in SPSS such as descriptive statistics, mean ranking, t-test, ANOVA, and Factor Analysis. Data analysis was performed based on five different respondents' groups, as stated previously. From the analysis, based on the respondents' perception, the most significant critical success factors of the list are determined; then the factors were grouped into five categories using Factor Analysis which, based on their shared characteristics, are named as UAV and Technology Characteristics, Organizational Characteristics, Project Teams Characteristics, Market-related factors, and Legal and Environmental Factors.

After the research objectives have been met, the following conclusions were made based on the findings to answer the research questions.

The Turkish construction sector together with the employment rate have decreased during the last quarter of 2020 due to the COVID-19 pandemic (EPY, 2020/4). On the other hand, it should be mentioned that COVID-19 pandemic has enhanced the integration of digital tools to construction projects (McKinsey and Co, 2020) since all work is done remotely. Turkish construction practitioners' main concern should be on how to successfully benefit from the emerging digital technologies, especially drone technology, to improve the productivity, quality, and safety at construction sites by saving cost and time and improving communication between different project stakeholders.

The study findings revealed that slightly more than half of the respondents are involved with UAV technology during the last ten years which implies that UAV technology has been diffused in the Turkish construction sector. The technology is mainly used by the Turkish contractors and consultants in the construction phase and the feasibility and planning phase in large infrastructure and heavy construction. The findings suggest that large organizations, which might be involved in large complex construction projects, are more likely to invest in innovation and drone technology since they have sufficient budget and resources. However, small and medium organizations are still somewhat away from UAV usage. This study results are expected to influence the way Turkish construction stakeholders

perceive UAV technology by influencing their implemented strategies towards innovation. An important finding suggests that the most acquired benefits from UAV technology are the improvement of client satisfaction at the project level and improvement of company image at the company level. Hence, to maintain these benefits for the long-term, the research provides Turkish companies with the most important success factors of UAVs for a successful construction project delivery to their clients.

The statistical analysis results show that effective leadership and top management support, proved effectiveness of the technology, organization's innovation culture and flexibility, technological advancements, technology's cost effectiveness (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.

Similar results were found in the literature including several countries publications, mainly US, UK, Canada, Chile, Malaysia, China, Japan, Cyprus, Spain, Australia, and Turkey. In Turkey, there is still a very limited number of publications related to the use of drone technology in the construction sector. For instance, Kim et al. (2016) investigated the potential factors affecting the use of drone technology in US construction sector and found that the most important factor group is “UAS System Characteristics” group with “easy user interface for UAS operation” and “quality of visual assets” being the most important factors, while the least significant group was “Project characteristics” group. Nnaji et al. (2019) focused on technology adoption (e.g., virtual reality, UAV, BIM and wearable safety devices) in US construction projects for safety management purposes and showed that technology reliability, effectiveness and durability are the most important predictors. Graham (2016) studied the factors influencing the use of drones by specialty construction companies in the US and found that the most important factors are “Technological factors” followed by “Risk factors”, then “Human factors”. Similarly, Raj and Sah (2019) found that “Technological advancements”, “Government regulations”, and “Skilled workforce” are the most important factors for the

adoption of drones in the logistics sector. Golizadeh et al. (2019) reported that UAV technical characteristics, restrictive regulatory environment, site-related problems, weather, and organizational barriers affect considerably UAV technology adoption in the construction sector in Australia. The Turkish construction sector has similarly showed that the six most important factors are related to their organizations (effective leadership and top management support, innovation culture and flexibility) and the UAV technology itself (proved effectiveness, technological advancements, cost effectiveness, advanced technical characteristics).

One-way ANOVA results suggest that there is no significant difference between the responses of contractors, consultants, private clients, public clients, and subcontractors, in terms of CSFs significance levels. An important step in this study is the identification of a set of five underlying factors using Factor Analysis. Of these five factors, organizational characteristics (mean, 3.8) and UAV and technology characteristics (3.65) are the most important for a successful UAV technology implementation, followed by market-related factors (3.55), legal and environmental factors (3.43), and project teams characteristics (3.41). This makes it clear 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.

Hence, a successful implementation of UAV technology in Turkish construction projects, depends mainly on the organizations' ability to follow up with the technology. Leaders and senior managers should focus on the people working in their organizations as well as on change, on proceeding beyond their comfort zone. This can be done by raising an innovation culture among employees in all departments (Lu et al, 2015; Winkler and Zinsmeister, 2019). They should have clear goals and objectives aligned with the use of drone technology in their projects. To benefit from this technology, an effective leader should encourage employees to participate in the training programs, workshops, seminars, and webinars organized by the company to enhance their awareness of IT and drone technology effective usage and benefits on construction sites, in terms of cost and time effectiveness.

Additionally, the project team will develop technical and software skills allowing them to process the high-resolution images captured by the drone in the drone photogrammetry software. 3D models or reality models can be developed over which different measurements (e.g., cut and fill volumes) would be easily calculated, also quality and safety checks (e.g., bridge or tower inspection) easily performed. Moreover, top management commitment and support provided to the project manager and teams during all project phases is crucial for achieving a productive drone technology use. They should be able to provide sufficient financial, manpower and material resources necessary to carry out the project. All stakeholders must be involved in the developed drone technology implementation plan (Graham, 2016); scheduling meetings regularly between surveyors, designers, contractors, consultants, owners, and other stakeholders, are necessary for better communication and collaboration to solve the encountered problems and share the visual data collected by the drone for checking and monitoring the daily, weekly, or monthly progress at site according to the planned schedule. Putting drone's site images at a site office wall to show the work progress to subcontractors and owners or clients is another way used to convince and remind workers about the importance of drone technology.

Furthermore, the characteristics of the drone technology itself and the other related technologies (cameras, sensors, batteries…) are found to affect significantly drone technology adoption in Turkey. Drone manufacturers are in continuous competition to provide drone platforms with better features and functions in the market. Selecting an appropriate drone 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 to construction management tasks. Together with the continuous technological advancements, the available drones in the market can provide a user-friendly interface encouraging thereby potential users to enhance their skills to easily plan and control drone flights over the site. Quadcopters are most used for surveying and photogrammetry tasks due their easy operation, high flexibility and stability, and good cost (Siebert and Teizer, 2014). Also, VTOL multirotor drones' use is tending to increase in the construction industry.

These drones combine the characteristics of both multi-rotor drones and fixed wing drones leading to higher flight times and hovering ability (Makdisi-Somi and Makadsi, 2019).

Additionally, for construction companies to ensure a successful drone technology adoption, i.e., to benefit from the technology use and meet its objective, they should be aware of the challenging factors of such adoption such as restrictive government regulations, site and weather conditions, and the ethical, privacy and safety issues. This will allow drone pilots to perform safer and reliable drone flights. It should also be noted that, despite the improvements in drone technology, fully autonomous drone flights are still not common. Drones still rely on a pilot to assist them in their flight using GPS.

Recommendations for improving drone adoption in Turkey and developing countries

After deriving the previously stated conclusions, the following general recommendations and guidelines can be made to the construction industry in developing countries, particularly to the Turkish construction sector, regarding drone technology. They provide a good starting point to begin with. However, a more extensive research is needed to provide more specific guidelines related to drone technology adoption in Turkey's construction sector. The main guidelines include:

- Establishing a better change strategy – It is evident that implementing change through innovation in any construction company is not easy. A good way to make this change successfully happen is by adopting Kurt Lewin three-step model (Alohan, 2019) which consists of three steps: unfreezing, change or moving, and freezing. "Unfreezing" creates the needs of change among employees which would motivate them to accept change and use of new technologies, especially drone technology in this study. "Change or moving" involves learning new things such as "how drones operate" by introducing new information, developing new concepts, and training which would positively change the employees' behavior towards the technology. They would be able to recognize the value of the technology and therefore feel

ready to be a part of this new adventure. “Refreezing” is the most important phase since it refreezes the change, i.e., make it permanent in the organization without allowing employees to return to their traditional ways of thinking and working.

- Investing more on research and development of drone technologies – Turkish construction companies are invited to allocate sufficient budget for R&D and increase their R&D practices in the drone technology field. They should establish an effective, well-defined innovation R&D process to research drone technologies by communicating with drone suppliers and current users as well as testing the technology. Technology testing over a prolonged period can prove its effectiveness and ROI. New Turkish IT start-up companies are currently developing their own professional drone prototypes, performing flight tests, and developing AI-supported data management platforms. This is considered an important step towards drone technology adoption, which should persist and evolve in the future. Some Turkish construction companies might not be able to have their own R&D departments due to budget constraints; in this case, they could consider joint ventures with academia or other industries such as IT, or they can get the technology from other countries where it is more affordably available.

- Implications on drone technology’s acquisition cost – A clear study on the different drone types and prices is needed for the Turkish construction industry. Turkey’s economic condition will affect construction companies’ decision to invest in new technologies. This research gives an overview of the types of drones available in the market and some price ranges. But there is still not enough diffusion of cost information regarding the technology.

- Establishing better collaboration and communication within the construction industry regarding drone technology – This can be done through scheduling site and office meetings with the different project stakeholders, on a regular basis; also, communication can be enhanced by setting up associations in the industry and government policies for drone technologies. The Turkish government should support the use of innovative technology by

providing incentives to contractors, which leads to improved technology implementation in construction.

- Providing training programs to construction workers – Workshops and seminars help to upgrade the skills and perception of the workers regarding drone technology. They should be convinced that the aim behind implementing a new technology such as drones is not to replace them at the site.

- Incorporating elective courses or topics related to drone technology in the civil engineering/ construction management curriculum – Courses including a topic related to drone technology (e.g., innovation management course) during which undergraduate or graduate students would widen their knowledge on potential drone applications in construction should be provided in Turkish universities. Also, a separate elective drone technology course can be provided. Future construction professionals would have the opportunity to learn how to safely and reliably collect, process and manage site visual data from drones in accordance with the related government regulations.

Study Limitations and Recommendations for future research

The study contributes to the body of knowledge of the AEC sector by widening the understanding of the different project parties on drone applications in the construction industry. It provides guidelines which assist drone pilots, managers, contractors, consultants, and owners in effectively implementing drone technology in the construction industry in developing countries.

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, similar studies can be carried in other countries using the identified CSFs in this study; differences in the construction markets can be then identified, in terms of UAV technology adoption.

Moreover, by providing the most significant success factors for drone technology implementation in Turkey's construction projects, together with strategies to deal with them, the study can be considered a groundwork for future research. The scope and methodology of the research can be extended to provide case studies in Turkey to better understand the implementation process of UAV technology in construction.

Finally, all new technologies (drones, BIM, RFID, LiDAR) require financial resources, professional training and education, acceptance, and support for their successful usage. Implementing a new technology such as drone technology in construction projects has its own challenges as government regulations, safety and weather issues, availability of replacement components, as well as opportunities like cost-effectiveness and accessibility when compared to the other technologies. Adopting other technologies such as RFID, for example, to locate tagged materials at site doesn't require being on the line of sight; RFID technologies have good durability in bad weather conditions. Also, implementing BIM and ground-based LiDAR for 3D mapping of the building does not pose safety issues like those reported in case of drone technology usage.

Future research should focus on the interoperability of UAVs with other technologies, especially BIM. Integrating UAV technology with 4D BIM is catching the interest of construction experts. After processing drone images in a reality modeling software, such as ContextCapture, 3D reality meshes which show real-world conditions in 3D are produced. These meshes can be integrated with GIS data for better data navigation and visualization to provide quick and efficient support for the design process. Furthermore, integrating drone-based reality models with 4D BIM is important to compare the planned state of the project with its actual state, hence, to check for time and cost overruns. Connecting drone data with an augmented reality device such as HoloLens allows for remotely visualizing the building project (e.g., a tower) and performing inspections safer and faster. Machine learning and AI-based data management platforms are also important for an efficient and intelligent use of drone data. All these study areas shall be considered for investigation in the future to enhance the use of drone technology and possibly create standards for its use in construction projects.

REFERENCES

Alazmi, M., and M. Zairi, 2003, "Knowledge Management Critical Success Factors", *Total Quality Management and Business Excellence*, Volume 14, Issue 2, pp. 199-204.

Albeaino, G., M. Gheisari, and B. W. Franz, 2019, "A Systematic Review of Unmanned Aerial Vehicle Application Areas and Technologies in the AEC Domain", *Journal of Information Technology in Construction (ITcon)*, Volume 24, pp. 381-405.

Alizadehsalehi, S., I. Yitmen, T. Celik, and D. Arditi, 2018, "The Effectiveness of an Integrated BIM/UAV Model in Managing Safety on Construction Sites", *International Journal of Occupational Safety and Ergonomics*, 26(4), pp. 829-844.

Alohan, E., 2019, *Exploring the Role of Building Modeling and Drones in Construction*, Master Thesis, Department of Infomatics, UMEA University.

Anwar, N., F. Najam and M. Amir Izhar, 2018, "Construction Monitoring and Reporting using Drones and Unmanned Aerial Vehicles (UAVs)", *Proceedings of the Tenth International Conference on Construction in the 21st Century (CITC-10)*, July 2-4, 2018, at Colombo, Sri Lanka.

Ayemba, D., *Utilizing Drone Technology in Construction*, 2020, https://constructionreviewonline.com, accessed in August 2020.

Babbie, E., 1990, *Survey Research Methods*, Second Edition, Wadsworth, Belmont, CA.

Bathrick, M., *What it Takes to Succeed in Drones: The Four Key Competencies*, 2016, https://dronelife.com, accessed in November 2016.

Boynton, A.C., and R.W. Zmud, 1984, "An Assessment of Critical Success Factors", *Sloan Management Review*, 17(27), pp. 84-98, Summer 1984.

Buchli J., M. Giftthaler, N. Kumar, M. Lussi, T. Sandy, K. Dorfler, N. Hack, 2018, "Digital in Situ Fabrication - Challenges and Opportunities for Robotic in Situ Fabrication in Architecture, Construction, and Beyond", *Cement Concrete Research,* 112 (2018), pp. 66-75.

Calantropio, A., 2019, "The Use of UAVs for Performing Safety-Related Tasks at Post-Disaster and Non-Critical Construction Sites", *Lab G4CH—Laboratory of Geomatics for Cultural Heritage, DAD—Department of Architecture and Design, Politecnico di Torino, Viale Mattioli,* 39, 10125 Torino, Italy.

Canhete, F. D. and R. L. Machado, 2021, "The Use of Drones in Urban Constructions: Literature Review", *International Journal of Development Research,* 11, (02), pp. 44388-44396.

Christophe, G., and F. Laurent, 2016, *A Business Approach for the Use of Drones in the Engineering and Construction Industries*, Accenture Drones Construction Service Report 2016.

Ciampa, E., L. De Vito, and M. R. Pecce, 2019, "Practical Issues on the Use of Drones for Construction Inspections", *Journal of Physics: Conference Series,* Volume 1249, pp. 012016-1- 012016-11.

Creswell, 2008, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, Third Edition, Sage, Thousand Oaks, CA.

Daily Sabah, *Growing Drone Market Expands to Civil Aviation,* 2019, https://www.dailysabah.com/defense/2019/12/08/growing-drone-market-expands-to-civil-aviation, accessed in December 2019.

Delgado, J. M., L. Oyedele, A. Ajayi, L. Akanbi, O. Akinade, M. Bilal, and H. Owolabi, 2019, "Robotics and Automated Systems in Construction: Understanding Industry-Specific Challenges for Adoption", *Journal of Building Engineering,* Volume 26, pp. 100868-1- 100868-11.

Devers, W., 2019, *A Case Study on the Use of Drones on Heavy Civil Construction Projects*, BS in Construction Management, College of Architecture and Environmental Design.

DeYoung, R. E., 2018, *An Industrial Overview for the Standardization of Drones in Construction,* Thesis for MBA in Construction Management, Everglades University, December 2018.

Drone Industry Insights, *Drone Market Growth in 2021 and Beyond*, 2021, https://www.droneii.com/product/drone-market-report, accessed in June 2021.

DroneDeploy eBook, *Drones for Construction Project Management*, 2018, https://www.dronedeploy.com/resources/ebooks/an-introduction-to-drones-for-construction-project-management, accessed in March 2017.

DroneDeploy, *Drones Keep Construction of Manufacturing Plant on Track,* 2018, https://medium.com/aerial-acuity/drones-keep-construction-of-manufacturing-plant-on-trackdrone-73337597e223, accessed in March 2017.

DroneDeploy, *Proving the ROI of Drone Programs in Construction*, 2018, https://www.dronedeploy.com/resources/stories/mccarthy-construction, accessed in March 2017.

Dupont, Q. F. M., D. K. H. Chua, A. Tashrif, and E. L. S. Abbott, 2017, "Potential Applications of UAV along the Construction's Value Chain", *Procedia Engineering,* 182, pp. 165-173.

El Mohtar, C., G. Abou-Jaoude, C. Abdallah, and J. Hareb, 2016, "The Kfarnabrakh Landslide of November 30th, 2015: A Geological and Geotechnical Evaluation of the Landslide and Risk of Future Failures", *Geotechnical Extreme Events Reconnaissance (Geer) Association*, pp. 047-1- 047-27.

Ellenberg, A., A. Kontsos, F. Moon, and I. Bartoli, 2016, "Bridge Related Damage Quantification Using Unmanned Aerial Vehicle Imagery", *Structural Control and Health Monitoring*, Volume 23, Issue 9, pp. 1168-1179.

Ellenberg, A., L. Branco, A. Krick, I. Bartoli, and A. Kontsos, 2014, "Use of Unmanned Aerial Vehicle for Quantitative Infrastructure Evaluation", *Journal of Infrastructure Systems*, Volume 21, Issue 3, pp. 04014054-1- 04014054-8.

Entegre Project Management, *Turkey Construction Industry Report 2020 / 4*, 2021, https://www.epy.com.tr/Images/Image/en-turkey-construction-industry-report-2020-q4-122, accessed in March 2021.

Ezequiel CAF, M. Cua, NC Libatique, GL Tangonan, R. Alampay, RT Labuguen, CM Favila, JLE Honrado, V Canos, C Devaney, et al., 2014, "UAV Aerial Imaging Applications for Post-Disaster Assessment, Environmental Management and Infrastructure Development", *IEEE 2014 International Conference on Unmanned Aircraft Systems (ICUAS)* – May 27-30; Orlando, FL, USA, pp. 274-283.

Fang Y, JD Chen, Y. Cho, and P. Zhang, 2016, "A Point Cloud-Vision Hybrid Approach for 3D Location Tracking of Mobile Construction Assets", *33rd International Symposium on Automation and Robotics in Construction (ISARC 2016)*, Auburn, USA.

Fellows, R., and A. Liu, 1997, *Research Methods for Construction*, First Edition, Blackwell, UK.

Ferguson, C. R, and R. Dickinson, 1982, "Critical Success Factors for Directors in the Eighties", *Business Horizons*, pp 14-18.

Field, A., 2005, *Discovering Statistics Using SPSS*, Second Edition, Sage, London.

General Directorate of Civil Aviation, *SHGM - İHA Kayıt Sistemi*, 2020, https://iha.shgm.gov.tr/public/index?language=2, accessed in November 2005.

Gheisari, M., J. Irizarry, and B. N. Walker, 2014, "UAS4SAFETY: The Potential of Unmanned Aerial Systems for Construction Safety Applications", *American Society of Civil Engineers Construction Research Congress 2014* - Atlanta, Georgia, May 19-21, 2014, pp. 1801-1810.

Giones, F., and A. Brem, 2017, "From Toys to Tools: The Co-Evolution of Technological and Entrepreneurial Developments in the Drone Industry", *Business Horizons,* Volume 60 (6), pp. 875-884.

Glen, S., *Cronbach's Alpha: Simple Definition, Use and Interpretation,* 2015, https://www.statisticshowto.com/probability-and-statistics/statistics definitions/cronbachs-alpha-spss, accessed in March 2015.

Golizadeh, H., M.R. Hosseini, D. J. Edwards, S. Abrishami, N. Taghavi, and S. Banihashemi, 2019, "Barriers to Adoption of RPAs on Construction Projects: A Task–Technology Fit Perspective", *Construction Innovation*, Volume 19, No. 2, pp. 149-169.

Goodman, J., *Tech 101: Construction Drones,* 2020, https://www.constructiondive.com, accessed in January 2020.

Graham, G., 2016, *Factors Influencing and Risk Associated with the Use of Drones by Specialty Construction Companies in the United States of America*, PhD Thesis, Indiana State University.

Greenwood, W. W., J. P. Lynch, and D. Zekkos, 2019, "Applications of UAVs in Civil Infrastructure", *Journal of Infrastructure Systems,* Volume 25(2), pp. 04019002-1 - 04019002-21.

Guldenmund, F. W., 2007, "The Use of Questionnaires in Safety Culture Research – An Evaluation", *Safety Science*, 45(6), pp. 723-743.

Gündüz, M., Y. Nielsen, and M. Özdemir, 2013, "Quantification of Delay Factors Using the Relative Importance Index Method for Construction Projects in Turkey", *Journal of Management in Engineering*, Volume 29(2), pp. 133-139.

Ham, Y., Kevin K. Han, J. J. Lin, and Mani G-F, 2016, "Visual Monitoring of Civil Infrastructure Systems via Camera-Equipped Unmanned Aerial Vehicles (UAVs): A Review of Related Works", *Visualization in Engineering*, Volume 4 (1), pp. 1-8.

Hubbard B, H. Wang, M. Leasure T. Ropp, T. Lofton, S. Hubbard, and S. Lin, 2015, "Feasibility Study of UAV Use for RFID Material Tracking on Construction Sites", *51st ASC Annual International Conference Proceedings,* College Station (TX): The Associated Schools of Construction, pp. 1-8.

Idries, A., N. Mohamed, I. Jawhar, F. Mohamed, and J. Al-Jaroodi, 2015, "Challenges of Developing UAV Applications: A Project Management View", *IEEE 2015 International Conference on Industrial Engineering and Operations Management (IEOM)* - Dubai (2015.3.3-2015.3.5), pp. 1-10.

Investopedia, *Artificial Intelligence*, 2021, https://www.investopedia.com, accessed in March 2021.

Irizarry J., M. Gheisari, and B.N. Walker, 2012, "Usability Assessment of Drone Technology as Safety Inspection Tools", *Journal of Information Technology in Construction (ITcon)*, Volume 17, pp. 194-212.

Irizarry, J., and D. B. Costa, 2016, "Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks", *Journal of Management in Engineering*, Volume 32, Issue 3, pp. 05016001-1- 05016001-10.

ISO 19650 Series, 2019, *Information Management According to BS EN ISO 19650*, Second Edition, July 2019.

IWM, A *Brief History of Drones*, 2018, https://www.iwm.org.uk/history/a-brief-history-of-drones, accessed in September 2018.

Jenkins, D., 2013, “The Economic Impact of Unmanned Aircraft Systems Integration in the United States”, *Association for Unmanned Vehicle Systems International*, Arlington, VA.

Jones, K., *4 Major Challenges Facing the Construction Industry*, 2018, https://www.constructconnect.com, accessed in February 2018.

Kaamin, M., S.N.M. Razali, N.F.A. Ahmad, S.M. Bukari, N. Ngadiman, A.A. Kadir, and N.B. Hamid, 2017, “The Application of Micro UAV in Construction Project”, *AIP Conference Proceedings 1891*, pp. 020070-1- 020070-6.

Kahvecioglu, S. and H. Oktal, 2014, "Turkish UAV Capabilities as a New Competitor in the Market", *International Journal of Intelligent Unmanned Systems*, Volume 2, Issue 3, pp. 183-191.

Kim, S., J. Irizarry, and D. B. Costa, 2016, “Potential Factors Influencing the Performance of Unmanned Aerial System (UAS) Integrated Safety Control for Construction Worksites”, *Construction Research Congress 2016*, San Juan, Puerto Rico, May 31–June 2.

Kumavat, V. L., and P. M. Jain, 2019, “Use of Drone Technology in Infrastructure Projects”, *International Research Journal of Engineering and Technology (IRJET)*, Volume 6, Issue 3, pp. 3323-3325.

Li, Y., and C. Liu, 2018, “Applications of Multirotor Drone Technologies in Construction Management”, *International Journal of Construction Management*, Volume 19, Issue 5, pp. 401-412.

Lin, A., 2018, *Use of Drone Technology on Commercial Construction Projects*, BS in Construction Management, California Polytechnic State University, San Luis Obispo, California.

Lin, J. J., K. K. Han, and G-F Mani, 2015, “A Framework for Model-Driven Acquisition and Analytics of Visual Data Using UAVs for Automated Construction Progress

Monitoring", *American Society of Civil Engineers, 2015 International Workshop on Computing in Civil Engineering* - Austin, Texas, Computing in Civil Engineering 2015, pp. 156-164.

Lu, Y., Y. Li, M. Skibniewski, Z. Wu, R. Wang, and Y. Le, 2015, "Information and Communication Technology Applications in Architecture, Engineering, and Construction Organizations: A 15-Year Review." *Journal of Management in Engineering*, Volume 31(1), pp. A4014010-1- A4014010-19.

Mahbub, R., 2008, *An Investigation into the Barriers to the Implementation of Automation and Robotics Technologies in the Construction Industry*, PhD Thesis, Queensland University of Technology.

Makdisi-Somi, M., and I. Makadsi, 2019, *An Exploratory Study of Drones Used for Safety Purposes on Outdoor Construction Sites*, Master of Science Thesis, Kth Royal Institute of Technology School of Industrial Engineering and Management, KTH Industrial Engineering and Management, Stockholm.

Margareta, H., and L. Sven-Åke, 1980, *Towards a Definition of Action Research: A Note and Bibliography,* Volume 17(2), pp. 241-250.

Martinez, J. G., M. Gheisari, and L.F. Alarcon, 2020, "UAV Integration in Current Construction Safety Planning and Monitoring Processes: Case Study of a High-Rise Building Construction Project in Chile", *Journal of Management in Engineering*, Volume 36(3), pp. 05020005-1- 05020005-15.

McCabe, B. Y., H. Hamledar, A. Shahi, P. Zangeneh, and E. Rezazadeh Azar, 2017, "Roles, Benefits, and Challenges of Using UAVs for Indoor Smart Construction Applications", *ASCE International Workshop on Computing in Civil Engineering 2017*, pp. 349-357.

Mckinsey and Company, 2017, *Reinventing Construction: A Route to Higher Productivity,* Executive Summary, McKinsey Global Institute, February 2017, UK.

Mckinsey and Company, 2020, *The Next Normal in Construction: How Disruption Is Reshaping the World's Largest Ecosystem,* June 2020, UK.

Melo, R. R. S. de, D. B. Costa, J. S. Álvares, and J. Irizarry, 2017, "Applicability of Unmanned Aerial System (UAS) for Safety Inspection on Construction Sites*", Safety Science*, Volume 98, pp. 174-185.

Mohammed F., N. Mohamed, J. Al-Jaroodi, and I. Jawhar, 2014, "UAVs for Smart Cities: Opportunities and Challenges", *IEEE 2014 International Conference on Unmanned Aircraft Systems (ICUAS)* - Orlando, FL, USA (2014.5.27-2014.5.30), 2014, pp. 267-273.

Mordor Intelligence, *Drones Market - Growth, Trends, Covid-19 Impact, And Forecasts (2018 - 2026),* 2020, https://www.mordorintelligence.com/industry-reports/drones-market, accessed in December 2020.

Morrison, R., *Survey Drones: Rethinking the Construction Industry*, 2021, https://www.iotforall.com, accessed in April 2021.

Moud, H., A. Shojaei, I. Flood, and X. Zhang, 2018, "Monte Carlo based Risk Analysis of Unmanned Aerial Vehicle Flights over Construction Job Sites", *Proceedings of 8th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2018)*, pp. 451-458.

Newcome, L.R., 2004, "Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles", *American Institute of Aeronautics and Astronautics,* Reston, VA.

Nnaji, C., J. Gambatese, A. Karakhan, and C. Eseonu, 2019, "Influential Safety Technology Adoption Predictors in Construction", *Engineering, Construction and Architectural Management*, 26(11), pp. 2655-2681.

Norusis, M., 2012, *IBM SPSS Statistics 19 Statistical Procedures Companion*, 1 Lake Street Upper Saddle River, NJ 07458: Prentice Hall.

Nouacer R., H. Espinoza Ortiz, Y. Ouhammou, and R. Castiñeira González, 2019, "Framework of Key Enabling Technologies for Safe and Autonomous Drones' Applications", *2019 22nd Euromicro Conference on Digital System Design (DSD)*, pp. 420-427.

Opfer, N., and D. Shields, 2014, "Unmanned Aerial Vehicle Applications and Issues for Construction", *Conference: 2014 ASEE Annual Conference and Exposition*, June 15-18, Indianapolis, pp. 10444-1- 10444-16.

Organization for Economic Cooperation, and Development (OECD), 2005, *Oslo manual*, Third Edition, OECD/Eurostat, Paris.

Ozorhon, B., 2013, "Analysis of Construction Innovation Process at Project Level", *Journal of Management and Engineering*, pp. 455-463.

Ozorhon, B., and E. Cinar, 2015, "Critical Success Factors of Enterprise Resource Planning Implementation in Construction: Case of Turkey", *Journal of Management in Engineering*, Volume 31, No. 6, pp. 04015014-1- 04015014-8.

Ozorhon, B., and K. Oral, 2016, "Drivers of Innovation in Construction Projects", *Journal of Construction Engineering and Management*, Volume 143, No. 4, pp. 04016118-1- 04016118-9.

Ozorhon, B., and U. Karahan, 2016, "Critical Success Factors of Building Information Modeling Implementation", *Journal of Management in Engineering*, Volume 33, No. 3, pp. 04016054-1- 04016054-10.

Propeller Aero, *Using Drones in Construction: The Beginner's Guide,* 2019, http://www.propelleraero.com, accessed in April 2019.

Raj, A., and B. Sah, 2019, "Analyzing Critical Success Factors for Implementation of Drones in the Logistics Sector Using Grey- DEMATEL based approach", *Computers and Industrial Engineering*, Volume 138.

Rashid, M. N. A., M.R. Abdullah, and D. Ismail, 2018, "Critical Success Factors CSFs to Automation and Robotics in Industrialized Building System IBS", *International Journal of Academic Research in Business and Social Sciences*, 8(12), pp. 2207-2221.

Rockart, J., 1979, "Chief Executives Define their own Data Needs", *Harvard Business Review*, 52(2), pp. 81-93.

Rockart, J., and C. V. Bullen, 1981, "A Primer on Critical Success Factors", *I Center for Information Systems Research,* Paper no.69, Sloan School of Management Massachusetts Institute of Technology.

Sah, B., G. Rohit, and B. H. Dana, 2020, "Analysis of Barriers to Implement Drone Logistics", *International Journal of Logistics Research and Applications*, pp. 1-20.

Sanvido, V., F. Grobler, K. Parfitt, M. Guvenis, and M. Coyle, 1992, "Critical Success Factors for Construction Projects", *Journal of Construction Engineering and Management*, 118(1), pp. 94-111.

SenseFly, W., *Drones vs Traditional Instruments: Corridor Mapping in Turkey,* 2017, https://geo-matching.com/content/drones-vs-traditional-instruments-corridor-mapping-in-turkey, accessed in October 2017.

Siebert, S., and J. Teizer, 2014, "Mobile 3D Mapping for Surveying Earthwork Projects Using an Unmanned Aerial Vehicle (UAV) System", *Automation in Construction*, 41, pp. 1-14.

Silverio-Fernández M., S. Renukappa, and S. Suresh, 2019, "Evaluating Critical Success Factors for Implementing Smart Devices in the Construction Industry: An Empirical Study in the Dominican Republic", *Engineering, Construction and Architectural Management*, 7 (1), pp. 15-29.

Small, E. P., 2018, "Opportunities for UAVs in Construction Planning, Performance and Contract Close-Out", Edited by Miroslaw J. Skibniewski and Miklos Hajdu,

Proceedings of the Creative Construction Conference, CCC 2018, 30 June - 3 July 2018, Ljubljana, Slovenia, pp. 595-601.

SmartMarket Report, 2017, *Safety Management in the Construction Industry 2017*, Dodge Data and Analytics, Bedford, MA.

Somers, T. M., and K. Nelson, 2002, "The Impact of Critical Success Factors across the Stages of Enterprise Resource Planning Implementations", *Proceedings of the 34th Annual Hawaii International Conference on System Sciences*, 6-6 January 2001, Maui, HI, USA, pp. 1-10.

Starkweather, J., *Principal Components Analysis in SPSS*, 2018, http://bayes.acs.unt.edu:8083/BayesContent/class/Jon/SPSS_SC/Module9/M9_PCA/SPSS_M9_PCA1.htm, accessed in November 2018.

Tatum, M. C., and Liu, J., 2017, "Unmanned Aircraft System Applications in Construction", *Procedia Engineering*, Volume 196, pp. 167-175.

The Business Research Company, 2020, *2020 Drones Market (Commercial and Consumer) Growth, Trends, Market Size and Forecasts By TBRC*, March 9, 2020.

Turkish Statistical Institute, TURKSTAT, *Construction and Housing*, 2021, https://www.tuik.gov.tr/Home/Index, accessed in March 2021.

Uyanık, S., 2019, *Performing Better and Faster – Drones Becoming Fundamental in Many Businesses*, Aviation Turkey.

Vacanas, Y., K. Themistocleous, A. Agapiou, and D. Hadjimitsis, 2016, "The combined use of Building Information Modelling (BIM) and Unmanned Aerial Vehicle (UAV) technologies for the 3D illustration of the progress of works in infrastructure construction projects", *Fourth International Conference on Remote Sensing and Geoinformation of the Environment*, Paphos, Cyprus, August 2016, pp. 96881Z-1- 96881Z-8.

Walpole, 2011, *Probability and Statistics for Engineers and Scientists*, Ninth Edition, Pearson.

Wang, J, W. Sun, W. Shou, X. Wang, C. Wu, H-Y Chong, Y. Liu, and C. Sun, 2015, "Integrating BIM and LiDAR for Real-Time Construction Quality Control", *Journal of Intelligent and Robotic Systems*, Volume 79(3-4), pp. 417-432.

Wikipedia, the free encyclopedia, *Industry Foundation Classes (IFC)*, 2017, https://en.wikipedia.org/wiki/Industry_Foundation_Classes, accessed in March 2017.

Winkler, H., and L. Zinsmeister, 2019, "Trends in Digitalization of Intralogistics and the Critical Success Factors of its Implementation", *Brazilian Journal of Operations &Production Management*, Volume 16(3), pp. 537-549.

Wiratunga, K., *6 Productivity Issues (New and Old) the Construction Industry Faces*, 2018, https://www.e-arc.com, accessed in December 2018.

Yamazaki F., T. Matsuda, S. Denda, and W. Liu, 2015, "Construction of 3D Models of Buildings Damaged by Earthquakes Using UAV Aerial Images", *Proceedings of the Tenth Pacific Conference on Earthquake Engineering Building an Earthquake-Resilient Pacific 6-8 November 2015*, Sydney, Australia, pp. 204-1- 204-8.

Yildizel, S. A., and G. Calis, 2019, "Unmanned Aerial Vehicles for Civil Engineering: Current Practices and Regulations", *European Journal of Science and Technology*, Volume 16, pp. 925-932.

Yin, R. K, 1994, *Case Study Research: Design and Methods*, Second Edition, Sage, Thousand Oaks, CA.

APPENDIX A: SUCCESS FACTORS CONSIDERED IN THIS STUDY

| # | Critical Success Factors for UAV technology in Construction_Final Revision | Literature Source | | |

APPENDIX A: SUCCESS FACTORS CONSIDERED IN THIS STUDY (Cont.)

#	List of Literature Sources		
1	Edgar P.Small 2018	20	Kim et al. 2016
2	Yildizel and Calis 2019	21	Dupont et al. 2017
3	William W. Greenwood et al. 2019	22	Alizadehsalehi et al. 2018
4	Mohammed et al. 2014	23	Idries et al. 2015
5	Efosa Alohan 2019	24	Delgado et al. 2019
6	Nouacer et al. 2018	25	Buchli et al. 2018
7	McCabe et al. 2017	26	Sah et al. 2020
8	Raj and Sah 2019	27	Calentropio 2019
9	Tatum 2017	28	Kumavat et al. 2019
10	Ibrahim et al. 2019	29	Albeaino et al. 2019
11	Siebert and Teizer 2014	30	Fernandez et al. 2019
12	Opfer and Shields 2014	31	Winkler et al. 2019
13	Ham et al. 2016	32	Dennis Ayemba 2020
14	Devers 2019	33	Jenn Goodman 2020
15	Li et al. 2018	34	Glenn Graham 2016
16	Chen et al. 2019	35	Mark Bathrick 2016
17	Irizarry et al. 2016	36	Propeller 2019
18	Lu et al. 2015	37	Makdisi and Makadisi 2019
19	Melo et al. 2017	38	Golizadeh et al. 2019
		39	Nnaji et al. 2019
		40	Ozorhon et al. 2016
		41	Ozorhon and Oral 2016

APPENDIX B: 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 is 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? ***

      - ○ Less than 25 years' old
      - ○ 25 to 35 years' old
      - ○ 36 to 46 years' old
      - ○ 47 years old or older

   3. **What is your main business area in the construction industry? ***

      - ○ Private Client
      - ○ Public Client
      - ○ Subcontractor
      - ○ Contractor
      - ○ 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? ***

      - ○ 0-20
      - ○ 21-50
      - ○ 51-100
      - ○ 101-200
      - ○ > 201

7. **Which of the following best describes your position in the organization? ***

- ○ Owner/ Co-founder
- ○ General Manager
- ○ Manager
- ○ Safety Manager
- ○ Safety Engineer
- ○ Planning Engineer
- ○ Project Coordinator
- ○ Project Manager
- ○ Department Chief
- ○ Engineer/ Architect
- ○ Surveyor
- ○ CAD / BIM Manager or Modeler
- ○ IT Manager
- ○ Other

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

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

- ○ Land surveying and mapping
- ○ Logistics management
- ○ Progress monitoring
- ○ Documentation and reporting
- ○ Safety control and inspection
- ○ Quality control and inspection
- ○ Time management
- ○ Damage assessment
- ○ Promotional Photography
- ○ 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. ***

- ○ Feasibility and Preliminary Design
- ○ Detailed Design
- ○ Construction
- ○ Operation and Maintenance

11. **Has your organization implemented UAV technology in any of its projects? ***
    - ○ Yes
    - ○ No

2. Critical Success Factors (CSFs)

In this study, the critical success factors “CSFs” 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 Turkey 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
Technology Capital Cost (Availability of financial resources in the Organization)	O	O	O	O	O
Effective leadership and top management support	O	O	O	O	O
Organization's innovation culture and flexibility	O	O	O	O	O
Availability of ICT infrastructure support	O	O	O	O	O
Awareness of ethical, privacy and safety issues in the organization	O	O	O	O	O
Availability of qualified personnel or skilled workforce/ experts	O	O	O	O	O
Education and training programs for UAV operators and workers	O	O	O	O	O
Project structure and type	O	O	O	O	O
Collaboration, communication and coordination among project stakeholders	O	O	O	O	O
Project cost and size	O	O	O	O	O
Advanced UAV technical characteristics (camera, payload, sensors, battery, autonomy)	O	O	O	O	O
Easy-to-use, maintainable and controllable systems (fits into operations)	O	O	O	O	O

CSFs	1	2	3	4	5
Flight reliability and safety (obstacle-avoidance)	O	O	O	O	O
UAV technology interoperability	O	O	O	O	O
Technological advancements (Web, BIM, Wireless technology, AR/VR, LIDAR, RFID)	O	O	O	O	O
Technology's cost effectiveness (ROI)	O	O	O	O	O
Proved effectiveness of the technology	O	O	O	O	O
Availability of multiple functional UAV platform types for selection	O	O	O	O	O
Availability of required hardware and software	O	O	O	O	O
Attitude towards new technology adoption in the industry	O	O	O	O	O
Complexity of construction tasks/ Fragmented nature of the industry	O	O	O	O	O
Society or users' awareness of drone technology	O	O	O	O	O
Competition	O	O	O	O	O
Market demand	O	O	O	O	O
Weather and site conditions	O	O	O	O	O
Proper licensure and certification requirement	O	O	O	O	O
Government regulations and support	O	O	O	O	O
R&D investments for UAV technology adoption	O	O	O	O	O

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?

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

14. What is the project size?

- ○ < $100,000
- ○ 100,000 - $1 Million (M)
- ○ $1M - $10M
- ○ $10M- $50M
- ○ >$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 and Preliminary Design
- ☐ Detailed Design
- ☐ Construction
- ☐ Operation and 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.

……
……
……

APPENDIX C: STATISTICAL DATA ANALYSIS

Table C1. T test results for UAV users and nonusers.

Variables	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
(V1)	1.504	0.223	-0.718	90	0.475	-0.175	0.244
			-0.735	83.166	0.465	-0.175	0.238
(V2)	1.04	0.31	-1.777	90	0.079	-0.417	0.234
			-1.796	80.119	0.076	-0.417	0.232
(V3)	4.638	0.034	-2.004	90	0.048	-0.472	0.235
			-2.071	85.31	0.041	-0.472	0.228
(V4)	0.931	0.337	0.139	90	0.89	0.031	0.222
			0.136	71.203	0.892	0.031	0.227
(V5)	0.723	0.397	1.018	90	0.311	0.228	0.223
			1.013	76.042	0.314	0.228	0.225
(V6)	1.645	0.203	-0.394	90	0.695	-0.094	0.24
			-0.407	85.458	0.685	-0.094	0.232
(V7)	0.633	0.428	-0.722	90	0.472	-0.167	0.231
			-0.735	81.676	0.465	-0.167	0.227
(V8)	0.018	0.894	0.903	90	0.369	0.23	0.255
			0.901	76.953	0.37	0.23	0.256
(V9)	0.645	0.424	-0.601	90	0.549	-0.142	0.236
			-0.59	72.487	0.557	-0.142	0.24
(V10)	2.225	0.139	-2.29	90	0.024	-0.554	0.242
			-2.354	84.256	0.021	-0.554	0.235
(V11)	0.048	0.827	-0.011	90	0.991	-0.002	0.227
			-0.011	79.076	0.991	-0.002	0.225
(V12)	0.25	0.619	-0.819	90	0.415	-0.175	0.214
			-0.829	80.748	0.409	-0.175	0.212
(V13)	1.591	0.21	-0.238	90	0.812	-0.058	0.244
			-0.232	70.514	0.817	-0.058	0.25
(V14)	1.3	0.257	-0.734	90	0.465	-0.149	0.204
			-0.749	82.429	0.456	-0.149	0.2
(V15)	1.149	0.287	-1.033	90	0.305	-0.219	0.212
			-1.034	77.753	0.304	-0.219	0.212

Table C1. T test results for UAV users and nonusers (cont.).

Variables	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
(V16)	0.34	0.561	-1.76	90	0.082	-0.391	0.222
			-1.748	75.554	0.085	-0.391	0.224
(V17)	0.046	0.831	-0.822	90	0.413	-0.164	0.2
			-0.822	77.129	0.414	-0.164	0.2
(V18)	0.657	0.42	0.19	90	0.849	0.038	0.201
			0.196	85.04	0.845	0.038	0.195
(V19)	0.069	0.793	-0.263	90	0.793	-0.057	0.219
			-0.263	77.298	0.793	-0.057	0.219
(V20)	0.029	0.866	0.03	90	0.976	0.006	0.214
			0.03	78.225	0.976	0.006	0.213
(V21)	0.292	0.59	0.187	90	0.852	0.04	0.216
			0.183	72.677	0.855	0.04	0.22
(V22)	0.985	0.324	0.429	90	0.669	0.094	0.219
			0.436	81.966	0.664	0.094	0.215
(V23)	0.85	0.359	-0.869	90	0.387	-0.187	0.215
			-0.854	72.612	0.396	-0.187	0.219
(V24)	0.036	0.849	-1.973	90	0.052	-0.413	0.209
			-1.973	77.283	0.052	-0.413	0.209
(V25)	3.954	0.05	1.657	90	0.101	0.421	0.254
			1.575	63.636	0.12	0.421	0.267
(V26)	1.349	0.249	1.249	90	0.215	0.292	0.234
			1.204	67.371	0.233	0.292	0.242
(V27)	0.234	0.63	0.302	90	0.763	0.076	0.252
			0.304	78.967	0.762	0.076	0.25
(V28)	1.602	0.209	0.061	90	0.951	0.014	0.225
			0.059	69.947	0.953	0.014	0.231

Table C2. Correlation matrix of the 28 CSFs variables for UAVs (Part 1).

Variables (V)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(V1) Technology Capital Cost	1	0.527	0.346	0.477	0.112	0.421	0.448	0.366	0.201	0.39	0.248	0.307	0.378	0.486
(V2) Effective leadership and top management support	0.527	1	0.495	0.449	0.153	0.373	0.342	0.319	0.292	0.199	0.184	0.252	0.403	0.39
(V3) Organization's innovation culture and flexibility	0.346	0.495	1	0.392	0.284	0.435	0.444	0.186	0.288	0.236	0.163	0.258	0.337	0.334
(V4) Availability of ICT infrastructure support	0.477	0.449	0.392	1	0.318	0.527	0.523	0.404	0.483	0.343	0.315	0.438	0.501	0.635
(V5) Awareness of ethical, privacy and safety issues in the organization	0.112	0.153	0.284	0.318	1	0.415	0.351	0.154	0.329	0.211	0.119	0.25	0.213	0.206
(V6) Availability of qualified personnel or skilled workforce/ experts	0.421	0.373	0.435	0.527	0.415	1	0.58	0.347	0.372	0.394	0.186	0.408	0.434	0.535
(V7) Education and training programs for UAV operators and workers	0.448	0.342	0.444	0.523	0.351	0.58	1	0.356	0.41	0.367	0.387	0.377	0.489	0.486
(V8) Project structure and type	0.366	0.319	0.186	0.404	0.154	0.347	0.356	1	0.343	0.493	0.503	0.538	0.583	0.446
(V9) Collaboration, communication and coordination among project stakeholders	0.201	0.292	0.288	0.483	0.329	0.372	0.41	0.343	1	0.323	0.392	0.335	0.316	0.445
(V10) Project cost and size	0.39	0.199	0.236	0.343	0.211	0.394	0.367	0.493	0.323	1	0.315	0.466	0.301	0.379
(V11) Advanced UAV technical characteristics	0.248	0.184	0.163	0.315	0.119	0.186	0.387	0.503	0.392	0.315	1	0.535	0.552	0.401
(V12) Easy-to-use, maintainable and controllable systems	0.307	0.252	0.258	0.438	0.25	0.408	0.377	0.538	0.335	0.466	0.535	1	0.725	0.66
(V13) Flight reliability and safety (obstacle-avoidance)	0.378	0.403	0.337	0.501	0.213	0.434	0.489	0.583	0.316	0.301	0.552	0.725	1	0.688
(V14) UAV technology interoperability	0.486	0.39	0.334	0.635	0.206	0.535	0.486	0.446	0.445	0.379	0.401	0.66	0.688	1
(V15) Technological advancements	0.408	0.484	0.266	0.437	0.184	0.318	0.485	0.438	0.326	0.362	0.499	0.57	0.549	0.594
(V16) Technology's cost effectiveness (ROI)	0.497	0.437	0.285	0.391	0.128	0.32	0.479	0.448	0.239	0.417	0.495	0.551	0.548	0.56
(V17) Proved effectiveness of the technology	0.299	0.397	0.35	0.383	0.237	0.323	0.391	0.35	0.296	0.37	0.301	0.331	0.424	0.426
(V18) Availability of multiple functional UAV platform types	0.211	0.365	0.278	0.411	0.338	0.391	0.284	0.43	0.257	0.317	0.297	0.497	0.42	0.421
(V19) Availability of required hardware and software	0.334	0.386	0.251	0.351	0.321	0.408	0.407	0.377	0.316	0.322	0.376	0.414	0.484	0.391
(V20) Attitude towards new technology adoption in the industry	0.361	0.449	0.462	0.459	0.307	0.551	0.463	0.313	0.292	0.281	0.287	0.362	0.442	0.379
(V21) Complexity of construction tasks/ Fragmented nature of the industry	0.339	0.348	0.1	0.452	0.302	0.458	0.25	0.449	0.378	0.344	0.271	0.377	0.48	0.478

Table C2. Correlation matrix of the 28 CSFs variables for UAVs (Part 1) (cont.).

Variables (V)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(V22) Society or users' awareness of drone technology	0.377	0.385	0.229	0.424	0.35	0.499	0.315	0.312	0.319	0.291	0.147	0.374	0.455	0.486
(V23) Competition	0.213	0.296	0.296	0.34	0.409	0.288	0.356	0.043	0.351	0.226	0.116	0.182	0.144	0.149
(V24) Market demand	0.309	0.284	0.279	0.322	0.249	0.264	0.27	0.205	0.238	0.234	0.215	0.141	0.234	0.238
(V25) Weather and site conditions	0.203	0.16	0.156	0.267	0.272	0.357	0.4	0.274	0.219	0.126	0.373	0.202	0.263	0.216
(V26) Proper licensure and certification requirement	0.323	0.217	0.315	0.364	0.301	0.438	0.415	0.351	0.316	0.179	0.443	0.421	0.417	0.476
(V27) Government regulations and support	0.339	0.321	0.114	0.318	0.183	0.265	0.263	0.357	0.164	0.183	0.181	0.192	0.32	0.296
(V28) R&D investments for UAV technology adoption	0.207	0.348	0.356	0.418	0.29	0.408	0.476	0.283	0.315	0.149	0.434	0.532	0.474	0.525

Table C2. Correlation matrix of the 28 CSFs variables for UAVs (Part 2).

Variables (V)	15	16	17	18	19	20	21	22	23	24	25	26	27	28
(V1) Technology Capital Cost (Availability of financial resources in the Organization)	0.408	0.497	0.299	0.211	0.334	0.361	0.339	0.377	0.213	0.309	0.203	0.323	0.339	0.207
(V2) Effective leadership and top management support	0.484	0.437	0.397	0.365	0.386	0.449	0.348	0.385	0.296	0.284	0.16	0.217	0.321	0.348
(V3) Organization's innovation culture and flexibility	0.266	0.285	0.35	0.278	0.251	0.462	0.1	0.229	0.296	0.279	0.156	0.315	0.114	0.356
(V4) Availability of ICT infrastructure support	0.437	0.391	0.383	0.411	0.351	0.459	0.452	0.424	0.34	0.322	0.267	0.364	0.318	0.418
(V5) Awareness of ethical, privacy and safety issues in the organization	0.184	0.128	0.237	0.338	0.321	0.307	0.302	0.35	0.409	0.249	0.272	0.301	0.183	0.29
(V6) Availability of qualified personnel or skilled workforce/ experts	0.318	0.32	0.323	0.391	0.408	0.551	0.458	0.499	0.288	0.264	0.357	0.438	0.265	0.408
(V7) Education and training programs for UAV operators and workers	0.485	0.479	0.391	0.284	0.407	0.463	0.25	0.315	0.356	0.27	0.4	0.415	0.263	0.476
(V8) Project structure and type	0.438	0.448	0.35	0.43	0.377	0.313	0.449	0.312	0.043	0.205	0.274	0.351	0.357	0.283
(V9) Collaboration, communication and coordination among project stakeholders	0.326	0.239	0.296	0.257	0.316	0.292	0.378	0.319	0.351	0.238	0.219	0.316	0.164	0.315
(V10) Project cost and size	0.362	0.417	0.37	0.317	0.322	0.281	0.344	0.291	0.226	0.234	0.126	0.179	0.183	0.149

Table C2. Correlation matrix of the 28 CSFs variables for UAVs (Part 2) (cont.).

Variables (V)	15	16	17	18	19	20	21	22	23	24	25	26	27	28
(V11) Advanced UAV technical characteristics (camera, payload, sensors, battery, autonomy)	0.499	0.495	0.301	0.297	0.376	0.287	0.271	0.147	0.116	0.215	0.373	0.443	0.181	0.434
(V12) Easy-to-use, maintainable and controllable systems (fits into operations)	0.57	0.551	0.331	0.497	0.414	0.362	0.377	0.374	0.182	0.141	0.202	0.421	0.192	0.532
(V13) Flight reliability and safety (obstacle-avoidance)	0.549	0.548	0.424	0.42	0.484	0.442	0.48	0.455	0.144	0.234	0.263	0.417	0.32	0.474
(V14) UAV technology interoperability	0.594	0.56	0.426	0.421	0.391	0.379	0.478	0.486	0.149	0.238	0.216	0.476	0.296	0.525
(V15) Technological advancements (Web, BIM, Wireless technology, AR/VR, LIDAR, RFID)	1	0.513	0.442	0.505	0.604	0.468	0.371	0.412	0.168	0.249	0.262	0.252	0.283	0.538
(V16) Technology's cost effectiveness (ROI)	0.513	1	0.559	0.405	0.38	0.457	0.319	0.366	0.257	0.274	0.317	0.356	0.231	0.469
(V17) Proved effectiveness of the technology	0.442	0.559	1	0.453	0.436	0.55	0.446	0.37	0.361	0.386	0.283	0.265	0.119	0.382
(V18) Availability of multiple functional UAV platform types for selection	0.505	0.405	0.453	1	0.569	0.507	0.415	0.417	0.214	0.308	0.371	0.421	0.353	0.615
(V19) Availability of required hardware and software	0.604	0.38	0.436	0.569	1	0.551	0.426	0.425	0.262	0.371	0.472	0.364	0.392	0.441
(V20) Attitude towards new technology adoption in the industry	0.468	0.457	0.55	0.507	0.551	1	0.504	0.528	0.39	0.422	0.369	0.265	0.153	0.449
(V21) Complexity of construction tasks/ Fragmented nature of the industry	0.371	0.319	0.446	0.415	0.426	0.504	1	0.584	0.19	0.233	0.323	0.475	0.334	0.373
(V22) Society or users' awareness of drone technology	0.412	0.366	0.37	0.417	0.425	0.528	0.584	1	0.432	0.416	0.221	0.254	0.247	0.445
(V23) Competition	0.168	0.257	0.361	0.214	0.262	0.39	0.19	0.432	1	0.572	0.175	0.053	0.07	0.174
(V24) Market demand	0.249	0.274	0.386	0.308	0.371	0.422	0.233	0.416	0.572	1	0.197	0.109	0.237	0.139
(V25) Weather and site conditions	0.262	0.317	0.283	0.371	0.472	0.369	0.323	0.221	0.175	0.197	1	0.578	0.329	0.383
(V26) Proper licensure and certification requirement	0.252	0.356	0.265	0.421	0.364	0.265	0.475	0.254	0.053	0.109	0.578	1	0.439	0.543
(V27) Government regulations and support	0.283	0.231	0.119	0.353	0.392	0.153	0.334	0.247	0.07	0.237	0.329	0.439	1	0.404
(V28) R&D investments for UAV technology adoption	0.538	0.469	0.382	0.615	0.441	0.449	0.373	0.445	0.174	0.139	0.383	0.543	0.404	1

Table C3. KMO and Bartletts's test (1).

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.856	
Bartlett's Test of Sphericity	Approx. Chi-Square	1429.902
	df	378
	Sig.	0

Table C4. Correlation matrix of the 20 CSFs variables for UAVs.

(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 C5. KMO and Bartletts's test (2).

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.837
Bartlett's Test of Sphericity	Approx. Chi-Square	874.861
	df	190
	Sig.	0

Table C6. Total variance explained of the critical success factors for UAVs.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.619	38.097	38.097	7.619	38.097	38.097	4.088	20.442	20.442
2	1.834	9.171	47.268	1.834	9.171	47.268	2.456	12.278	32.72
3	1.441	7.203	54.471	1.441	7.203	54.471	2.385	11.923	44.643
4	1.212	6.061	60.532	1.212	6.061	60.532	2.259	11.294	55.936
5	1.067	5.333	65.865	1.067	5.333	65.865	1.986	9.929	**65.865**
6	0.905	4.523	70.387						
7	0.746	3.731	74.118						
8	0.662	3.31	77.428						
9	0.628	3.142	80.57						
10	0.583	2.913	83.483						
11	0.573	2.863	86.345						
12	0.472	2.362	88.707						
13	0.431	2.154	90.861						
14	0.376	1.881	92.742						
15	0.324	1.621	94.364						
16	0.291	1.454	95.817						
17	0.28	1.398	97.216						
18	0.238	1.188	98.404						
19	0.197	0.984	99.388						
20	0.122	0.612	100						