Can drones build your house? - A research on heavy lifting drone applications in the construction industry

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ABSTRACT,
Unmanned Aerial Vehicles (UAVs), better known as drones, nurture the curiosity of more and more people, as their usability is enhancing the operations in every domain. The technology is already used in the construction industry for various applications, but are drones ready to lift and carry materials from one place of the construction site to another? And how prepared is the construction industry to implement heavy lifting drones in their processes? In this research, the readiness level of heavy lifting drones in construction industry operations is determined from five different perspectives: technical, business, social, ethical, and legal. A literature review about the current state of material lifting drones is presented as a starting point of this research. Next, the UAV readiness Quick Scan tool developed by Space53 is used to better analyze the five dimensions. The results are further discussed and interpreted together with an expert in aerial vehicles technology with additional knowledge of the construction field too. It is observed that construction companies are willing to use heavy lifting drones for their projects, but the readiness level of the drone itself needs improvements in all five domains. To attain a higher preparedness level, technical progress must be done first, because it will trigger the development of the other dimensions as well. This paper emphasizes the importance of the connection between technical, business, social, ethical and legal aspects when transforming a novel concept from prototype to a market-ready product.

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1. INTRODUCTION

1.1 Situation and Complication

In this contemporary era, fast advancement of technologies occurs in various industries. One of the well-known technologies is Unmanned Aerial Vehicles (UAVs), recognized globally as drones. The use of drones has become increasingly popular, as their application fields range from civilian use (disaster assessment, commercial, personal, or touristic) to military use (surveillance, aids, supply, or recording terrorist activities) (Yaacoub, Noura, Salman, & Chehab, 2020).

Even though drones may arouse the interest of many people, there are still some impediments regarding their full acceptance in the market. Technology feasibility of UVAs is an important aspect, but factors such as laws and regulations, data protection and business generation need to be considered as well to assess drone opportunities (CompTIA, 2019). Researching these aspects is crucial for companies and entrepreneurs who consider offering drone-based services. For instance, checking regional laws for the business use of drones must be done before converting drones into a profit-making opportunity (Joshi, 2021).

An interesting sector in which drones are being used is the construction industry. For example, since 2010, construction sites benefit from monitoring activities by UAVs which also simplify project planning (Kumarapu, Shashi, & Keesara, 2020). Other drone applications in this industry are aerial photography, surveying, inspections, safety/security monitoring (Tatum & Liu, 2017). The need of drones in constructions is increasing, as the aerial vehicles can approach dangerous and hard to access zones. Because of their usability and demand, the construction drone global market is forecasted to increase by 15,4% CAGR from 2019, to a total value of $11,968.6 million by 2027 (Chinchane, Singh, & Sumant, 2020). One intriguing application of drones that could enhance the efficiency of construction processes is lifting and carrying various materials and objects from one side of a construction zone to another. Regardless of their payload capacity, maximum altitude and flying time, these material lifting drones are referred to as heavy lifting drones in this research. These UAVs can be utilized for assembling buildings made of timber, concrete, steel, or masonry materials (Goessens, Mueller, & Latteur, 2018). Advancement of material lifting drone technology is progressing every day, as manufacturers are already designing drones that could carry a payload up to 220 kilograms (James, 2020), but also ensuring flying through harsh conditions and forming a multi-network system of drones. However, there are still some things that remain unexplored regarding the usability of unmanned aerial vehicles in the construction industry, such as legal requirements, social impact, business opportunities and ethical practices.

1.2 Research Objective

The purpose of this research is to assess the opportunities that heavy lifting drones bring to the construction industry, but also their limitations. The focus is placed on finding out the level of the drone preparedness for construction operations. For this, five different dimensions will be examined using an UAV readiness Quick Scan tool developed by Space53, addressed as Space53 tool/scan in this paper. A sub-objective of this research is to assess the scan for further improvements.

1.2.1 Research Question(s)

The main research question of this paper is presented below, as well as three additional sub-questions that will be helpful for answering the main one.

Research Question: *What is the potential of using heavy lifting drones in the construction industry and, if any, what are the implications for the development of this application?*

Research Sub-Questions:

- How prepared is the construction industry for heavy lifting drone applications?
- What is needed to further improve these applications in this field based on the level of preparedness?
- What parts of the UAV readiness Quick Scan tool developed by Space53 can be improved?

1.3 Theoretical Framework

It is already known that UAVs are being used in the construction industry and they bring many benefits to this sector. But the most researched applications of drones in this domain consider videography, surveying, inspections, and security monitoring operations (Tatum & Liu, 2017), thus there are limited studies that cover heavy lifting drone applications. Despite this fact, in a research made by Goessens, Mueller, and Latteur in 2018, the "feasibility of building real-scale structures" by using UAVs is explored. It is concluded that using drones for heavy lifting and assembling buildings is attainable and it is encouraged to be further researched.

However, when it comes to the adoption of a new sociotechnical structure on the larger market, "radically new technologies have a hard time to break through, because regulations, infrastructure, user practices, and maintenance networks are aligned to the existing technology" (Geels, 2002). The multi-level perspective proposed by Geels, shows how a radical innovation evolves, based on three different levels (Appendix A). The *landscape level* consists of external factors and trends and has the highest resistance to change. Though, when changes occur at this level, the *regimes level* is forced to adapt to the change. This level comprises rules and regulations imposed on social activities. At the *niche level*, or the "incubation room", technical innovations arise. UAV technology is a novel and feasible innovation for the construction industry and because of this, it can be positioned in the niche level. Moving on to the regimes and landscape levels, other important aspects such as legislation, society, codes of conduct, commercialization, need to be considered and this paper's aim is to research these dimensions.

To assess the *technical utility* of drones, the technology readiness level (TRL) model can be used. The TRL model classifies technology maturation according to nine different levels (Appendix B). The model was developed by The National Aeronautics and Space Administration (NASA) back in the 1970s to assess technology evolution, but later, the tool was adopted in various industries (Tomaschek, Eppinger, Joglekar, & Olechowski, 2016).

Even though drone technology is valuable, construction companies must be ready to embrace this technological change in their *business* models. Research shows that these companies are more willing to adopt new technologies if they can be used easily, are innovative, or bring competitive advantage (M., Sepasgozar, & Arbabi, 2017).

Drones seem like a promising innovation for the construction industry, but one of the main burdens that the UAV technology is facing is the absence of a clear regulatory framework regarding the safety and privacy of humans (Bassi, 2019). This issue is two folded: (1) the society might not be ready to accept drone usage for commercial purposes, due to security uncertainty and (2) drone technology must comply with specific safety laws and regulations. Since the construction industry is a dangerous one, unfortunately drone accidents occurred on some construction sites. With the increasing usage of UAVs, individuals are

becoming more and more concerned of the harm that drones might produce for this industry (DeCamara & McMillan, 2019). Because of this, in 2016, the Federal Aviation Administration (FAA) imposed regulations for the drone commercial utilization. At least 80% of 65 European countries had already imposed data protection regulations for UAVs (Molina & Campos, 2018) and some of the rules for the construction industry state that drones must be registered with the FAA, are allowed to fly only during daylight and must always have a remote pilot. Thus, *social readiness*, but also *legal readiness* needs to be considered when assessing heavy lifting drone applications in the construction industry.

After drone safety is ensured, its service purpose must be *ethical* as well. Individuals' safety raises ethical issues too, as cameras are mounted on drones to film processes and take pictures of the construction sites when needed. Thus, companies must act according to the best ethical practices of drones and to not use them in malicious ways.

Since all these five factors are important when assessing material lifting drone applications in the construction industry, the Space53 tool will be used for this research. The scan model comprises the following domains: technology, business, social, legal, ethical.

1.4 Academic Relevance

The first reason that classifies the academic relevance of this research as being highly important is that drone applications in the construction industry were researched until now only from a technical point of view. Building upon this, this research intends to show UAVs opportunities from five different dimensions: technical, business, social, ethical, and legal. In this way, the paper contributes to the expansion of the current knowledge about material lifting drone's capabilities in construction projects. Another reason is represented by the additional research that can be made further by other researchers or users of the Space53 tool. Improvements can be explored in terms of the assessment method, but also in terms of developing a multi-drone network to speed up the building process in the construction industry. In addition, this research contributes to the innovation process of the construction industry too, as new working methods on site can be further explored, but also unique building designs.

1.5 Practical Relevance

Every year, the global population is increasing, and residential buildings are needed to house people. This boosts the growth and development of the construction industry, as the demand for commercial buildings expands. Moreover, bridges contribute to maximizing traffic flow in urban areas and other architectural structures improve the cities' guises. These could be some of the reasons why the construction industry in Europe is expected to reach USD 2707.2 billion by 2024 (Yahoo! Finance, 2020). Thus, the practical relevance of this research can also be considered high, as there will always be a demand for buildings. In addition, some processes for building constructions are already automatized, but this industry is lacking modern technology that could improve labor efficiency (Sepasgozar & Bernold, 2012). The use of UAVs can solve this issue, but also one of the main concerns of the construction industry, namely the safeguard and health of construction workers. All these factors can be of interest for various stakeholders, such as drone manufacturer companies, architects driven by a strong interest for technology, constructions enterprises and even entrepreneurs passionate about UAVs applications, who can benefit from this research as a starting point for creating a profitable opportunity.

1.6 Research Design

To successfully answer the above-mentioned research question, along with the sub-questions, primary and secondary data will be gathered and analyzed. The research starts with collecting secondary data from a literature review about drone usage in the construction industry. Next, primary data consists of the Space53 tool and expert interview results. Companies and individuals with consistent knowledge of this domain will be asked to fill in the survey from Space53, and an expert interview will be conducted at the end, to discuss and analyze all the data gathered. Since multiple drone applications in the construction industry are already feasible, the focus of this research will be on heavy lifting drones for lifting and carrying materials across construction sites, but also for assembling structures. The targeted market for data collection is Europe, thus the people who will participate in this research have expertise in the European construction industry.

2. LITERATURE REVIEW

This section consists of two main parts. First, a literature review is done on heavy lifting equipment in the construction industry because it helps to collect information and form a knowledge foundation of the researched topic (Snyder, 2019). Once the current state of the lifting capabilities of drones from a technical point of view is understood, it is important to discern how social, ethical, business, and legal factors influence the readiness of the construction industry to adopt heavy lifting UAVs. Second, the theoretical background of the Space53 scan is presented, together with the scoring methods of the tool, for a better understanding of the data collection process.

2.1 Current State

It is already well-known that cranes are the main machines used for heavy lifting materials on construction sites. When using cranes, the space area needed for operating must be tremendous, thus the efficiency on site is affected. Workers are required to climb on top of the cranes to operate them and this procedure seriously endangers the safety of humans involved in construction projects, but also the nearby pedestrians. Consequently, from 1997 to 2015, 1259 fatalities were recorded due to crane accidents (Fang, Cho, Durso, & Seo, 2018). Because of this, construction companies need to find alternatives for safely lifting heavy materials and equipment on site, without affecting the work efficiency.

A good and possibly safer substitute for cranes is the heavy lifting drone, because it can be operated remotely, without exposing workers to accidents at heights. Unmanned aerial vehicles can be used for various purposes based on their design, weight, flying altitude, battery, engine type and other related components. Drones fosters the curiosity of many people, as their usability covers a large range of application domains, from cargo delivery, and agricultural use, to rescuing operations in emergency situations. But when it comes to the construction industry, the opportunities of heavy lifting drones for carrying and assembling materials need to be explored as the concept is still in the development phase. To determine how ready are the UAVs for carrying materials and assembling structures, various researched use cases are presented first. Next, the current state of the business, social, ethical, and legal readiness of this technology are introduced, together with the challenges faced when using these drones.

2.1.1 Use cases

Currently, there are numerous drone applications in the construction industry which mainly enhance the safety of workers, supervise the project development, and monitor the operations on sites. The use of heavy lifting drones in this sector for assembling structures is presently only a "proof-of-concept",

validated by various researchers (Choi & Dongbin, 2019). But according to a research on drone applications in constructions made by Tatum & Liu (2017), it is concluded that construction companies support further development of UAVs uses, as they consider adopting this technology for automated materials delivery and structural assembly operations. Until now, only a few use cases of lifting materials with drones in the construction industry were researched and tested. Some of these applications are presented and examined next.

- Modular construction

The modular construction technique implies transporting already mounted materials (modules) to a specific construction site for installation (Choi & Dongbin, 2019). For this experiment, drones were used to lift and transport cube boxes made of acrylic. At the end of the research paper, the authors concluded that the use of drones for heavy aerial lifting will solve many construction issues, such as access and congestion issues on site, and could also reduce the costs of construction companies.

The first modular construction project with drones was carried out in Orléans, France in 2012, by instructing a series of drones to carry and assemble bricks of a six-meter structure, over the course of four days (Augugliaro, et al., 2014). The building process starts when the drone lifts a brick from the pickup station with the use of a gripper installed on the UAVs bottom surface. Based on the instructions received from the software, the drone places the brick in the designated location (Appendix C).

- Masonry construction with a 3D model

The masonry construction using drones and a 3D model was researched by Goessens, Mueller, and Latteur in 2018. The UAVs need to be linked with a BIM (Building Information Modeling/Management) model, from which drones receive instructions for execution (Appendix D). The material lifting and air transportation can be done by one single UAV or by a synchronized pair of drones, depending on the object characteristics. Nonetheless, the researchers draw attention on two conditions for utilizing this process: (1) the maximum payload for a drone should not exceed 100 kilograms, and (2) different factors, such as weather conditions or wrong instructions can influence the drone's ability of accurate positioning (Goessens, Mueller, & Latteur, 2018). If the construction materials weigh more than 100 kilograms, a hybrid approach involving other types of robots can be implemented.

- Hybrid construction

A combination of UAVs and ground robots is an alternative solution for building different structures. According to Pereira da Silva & Eloy (2021), such a construction project was experimented in 2017 in Stuttgart, for the building process of an architectural structure made of carbon fiber and glass. In this case, a drone and two robotic arms were used to assemble a pavilion. The drone role was to supply the robotic arms with the necessary fiber for assembly.

2.1.2 Hybrid balloon drone prototype

Based on the research and experiments presented, the use of material lifting drones is already feasible from a technical point of view. Because of this, a concept of a hybrid balloon drone was researched and prototyped by a student team from University of Twente to fulfill the needs of the construction industry (Ruben, Jensema, van Ommeren, & Beene, 2021). Considering the recommendations of the construction companies and the relevant business, social, ethical, and legal aspects, the authors identified the best design for such an aerial vehicle. Thus, the final product was a balloon system crane combined with rotors. The balloon would be in the air the whole time, and it would carry a payload between 250 and 350 kilograms. The prototype was designed to be filled with helium, because this chemical element is less flammable than other gases. Besides exploring the feasibility of a technical prototype for heavy lifting drones in the construction industry, this report also provides an overview of the business, social, ethical, and legal aspects for implementing this type of drones in construction operations.

From a business point of view, it was found out that construction companies often need to transport materials and equipment over long distances to hard accessible areas. This is a challenge for the companies, as the materials vary in size and weight, thus workers or expensive machinery must be used for transportation. A cost-benefit analysis needs to be carried out to analyze if a drone system can replace the expensive machinery to carry any type of material, without exposing workers to possible accidents.

However, the most important social aspects when implementing such an aerial vehicle in the construction industry are safety, reliability, and trust in technology. Companies might be reluctant to adopt heavy lifting drones in constructions, as they could damage other buildings or hurt people inside and outside of the construction area. Due to all these factors, ethical issues can appear regarding drone's autonomy and moral concerns can hinder the diffusion of technology in the construction industry.

The legal dimension is also important when developing an UAV with lifting capabilities and the biggest concerns discovered were linked to public privacy. People are suspicious of the use of drones with cameras, as they might record every movement, thus data protection needs to be ensured. In addition, other legal requirements regarding the design of the drone were considered by the researchers when developing the prototype. Some of the aspects of the heavy lifting drone require the maximum noise produced to be below 80 decibels and the total weight of the system should not exceed 1000 kilograms.

2.1.3 Challenges

Although the use of drones for material lifting is feasible, these systems face some challenges when considering implementing them in the construction market. These challenges can be either product-related or market-related.

In the research of Choi and Dongbin (2019), it is concluded that different challenges have been identified for using heavy lifting drones – the payload and power supply are limited, the properties and characteristics of a UAV are also important as they contribute to the (in)stability of the drone and regulations must be imposed for safety and security reasons. Because of these, a rethinking of the whole construction process might be needed to benefit from the advantages of using UAVs in constructions (Goessens, Mueller, & Latteur, 2018). Furthermore, the most common market-related impediments that restrain construction companies from implementing drones or other robotic systems in their operations are the high implementation costs and the untrained workforce (Delgado, et al., 2019).

2.2 Analytical Framework

To determine the potential of heavy lifting drone applications in the construction industry, the UAV readiness Quick Scan tool developed by Space53 will be used. This tool was chosen because it comprises five different dimensions which are relevant for assessing the implications for drone development in this sector. The dimensions of the scan are technical, business, social, ethical, and legal. In principle, the Technology Readiness Levels (TRLs) model was used as a base for this tool, to construct a scale for assessing each dimension in this research. The model is composed of nine levels, from 1 to 9 (Appendix B), but for this research, the assessment scale starts from level 0 (not known/ not developed at all) to level 9 (fully implemented product available

on the market). By filling in all the questions for each dimension, an average score is automatically calculated at the end, which determines the readiness level of drones in a specific sector. For this research, the results will represent the overall readiness score of heavy lifting drones to be implemented in the construction industry processes. An elaboration on each dimension is presented next.

2.2.1 Technical dimension

The technical readiness of heavy lifting drones in the construction industry is assessed according to the ISO (International Organization for Standardization) standard 16290 presented by the European Cooperation for Space Standardization (ECSS, 2014). The questions formulated for this dimension cover four themes, namely the integrated system, drone management components or functions, flight components or functions, application components or functions and backend processing. For this tool, the TRLs are used as a scoring method (Appendix B). If the drone is already developed for heavy lifting applications and is fully integrated as a total system which can be bought already from the European market, the technical dimension will be assessed automatically with the maximum score (9).

2.2.2 Business dimension

The business readiness scan assesses if the use case is feasible, pragmatic, and if the benefits of using heavy lifting drones for assembling structures outweigh the costs. Thus, two aspects are relevant for this tool, namely feasibility and viability. These aspects can be examined by asking questions about the customer, the value proposition, business network, market forces, financial matters, and the value of the supply process. A five-point scale based on the TRLs is used for evaluating the business readiness of heavy lifting drones for assembling purposes. The options of the answers range from 1 (not at all), to 9 (to a very great extent), with 3, 5, and 7 as median scores.

2.2.3 Social dimension

The social dimension tool assesses three themes: stakeholders, design, and acceptance. These factors influence technology adoption on the market and ensure that social and privacy concerns are well addressed. To rank each theme, four Lab Levels derived from the TRLs are defined and used: *Lab Environment (TRL1)* – "the drone technology is developed in a closed laboratory setting, with only developers and researchers involved"; *Field Lab (TRL4)* – "the drone technology is developed and tested in a spatially restricted field lab with a restricted number of experts and/or end-users during a restricted amount of time"; *Living Lab (TRL6)* – "the drone technology is developed and tested in a living lab setting that is open to an undefined number of end-users within their own environment during a restricted amount of time"; *Public Space (TRL9)* – "the drone technology is market-ready and ready to be exposed in public space".

2.2.4 Ethical dimension

The ethical tool is used for understanding the moral acceptance of a new technology which influences various values, such as freedom, autonomy, justice, and privacy. The scan covers two themes: defining the goal of the drone and effects of the drone usage (regarding safety risks, ICT, distance and changing moral values). For this dimension, there is not a precise theory about ethical readiness levels, thus a Likert scale is used to answer the questions of this tool. The respondents will express their opinion about some statements, using scores from 1 (not at all applicable) to 5 (completely applicable).

2.2.5 Legal dimension

The legal readiness quick scan examines if the heavy lifting drones are suitable to be used in the construction industry, without breaking any legal requirement. For this tool, the themes assessed are public safety and security, environmental burden, privacy, and liability (civil & criminal). A 10-point scale was developed based on the TRLs to assess the legal readiness level of heavy lifting drones in constructions. The scale is divided in 4 subcategories: Awareness of possible legal aspects (scores 0, 1), Knowledge of/Considering legal aspects (scores 2, 3), Action taken (scores 4, 5, 6), Compliance (scores 7, 8, 9). A detailed explanation of the scores is provided in the survey, so the respondent can fill in the questionnaire accordingly.

3. METHODOLOGY

The scientific method used for this paper can be considered qualitative research, as the data collected is non-numerical and deduction, together with interpretation are pursued to answer the main research question (Sale & Thielke, 2018). This type of research was chosen because it is self-critical, as it allows researchers to collect and reflect upon all the information gathered in their own ways.

A hybrid approach of using both primary and secondary data is used for this research. Primary data includes the results collected from the Space53 tool and the answers from the interview, while secondary data represents the information gathered from desk research. For each question of this research presented in Section 1.2.1, the specific method used to gather data for answering it can be seen in the table below.

Research Questions	Methods
Main research question: What is the potential of using heavy lifting drones in the construction industry and, if any, what are the implications for the development of this application?	All primary data and secondary data
Sub-question 1: How prepared is the construction industry for heavy lifting drone applications?	Secondary data: literature review
Sub-question 2: What is needed to further improve these applications in this field based on the level of preparedness?	Primary data: Space53 tool results; expert interview
Sub-question 3: What parts of the UAV readiness Quick Scan tool developed by Space53 can be improved?	Primary data: Space53 tool feedback

Table 1 – Methods for answering the research questions

The activity flow for collecting and analyzing primary and secondary data is presented next.

First, a literature review is done on the current state of heavy lifting drones for construction purposes and their challenges regarding material lifting and assembling. A better understanding regarding the trend of the UAV technology development will be acquired, but also the barriers which heavy lifting drones might need to overcome to enter the construction industry. The information gathered from this literature study is presented in section 2 and will be useful for answering sub-question 1 of this research.

Second, the tool developed by Space53 is used for collecting additional data to formulate an answer for the second sub-question. The research is focused on the European market only, thus respondents can be from any European country. The typology of the individuals targeted to fill in the survey should meet one of the following criteria: the respondent must be (1) an employee in a drone manufacturer enterprise or (2) an employee in a construction company. The drone manufacturers must provide UAV solutions for the construction industry, while the respondents working in construction companies must have used drones already for different purposes (e.g., surveying, mapping, photogrammetry, etc.) or they might consider implementing them for lifting operations as well. Since it can be difficult to get in contact with such companies, the target is to convince at least three individuals to complete the survey. An existing network will be used, together with an internet search to find suitable companies which can take part in this research. Online channels, like LinkedIn and Email, will be used to reach employees from these companies. A message will be sent, asking for their willingness to take part in the research, by filling in the survey. When someone accepts the proposal and offers his help, a protocol with more information about the research is offered, along with instructions for filling in the survey will be sent to him (Appendix E). The language used for constructing the survey and protocol is English, thus it is possible to reach a wider range of respondents from Europe. But since a personal network of construction companies can be used, the survey along with the protocol were translated in Romanian as well. Both parts will be offered to the participants in accordance with their nationality or language preference. Once the survey is accessed, the respondent has a timeframe of seven days to complete it. All individuals will be asked to consider the whole construction sector when filling in the questionnaire, not only the company they work for. This will help in obtaining a better overview of the aerial lifting drone applications. The individuals need to assess the readiness level of heavy drone applications in constructions by themselves, with no additional help from the researcher, to ensure the correctness of the results. It is recommended to complete the whole questionnaire, but if a participant does not have enough knowledge about some of the domains, partial responses can be provided. Also, the individual has the freedom to choose the order in which he wishes to assess the domains. At the end of the survey, the participant is asked to rate the tool, by scoring each dimension on a scale from 1 to 5, in terms of helpfulness, further guidance provided, degree of relevant insights acquired and the ease of filling in the tool. Based on the feedback provided by the respondents, improvements will be proposed for further development of the scan and sub-question 3 of this research will be answered.

Third, after the results of the survey are available, an expert interview will be conducted to analyze and interpret the data collected. The expert must have knowledge of drones and construction operations. The interview will be semi-structured, because in this way additional information can be obtained from the conversation flow. Based on the answers provided, the second sub-question of this research will be answered.

Fourth, by putting all the data and information together, the main question will be answered. After presenting all the results, conclusions will be drawn together with the limitations encountered throughout the data collection phase.

4. RESULTS

In this section, the results of the Space53 scan are presented, along with the answers collected from the expert interview. All the data collected is elaborated upon and recommendations for the tool improvement are presented at the end. Also, the main research question, together with the sub-questions are answered by using the data specified in Table 1, Section 3.

4.1 Space53 Scan

To gather relevant data for this research, the respondents targeted to fill in the survey were drone manufacturers or construction companies which already use drones for some operations on sites. A total of 12 people started to fill in the tool, but only 4 answered enough questions to analyze them in this research. In all cases, the tool was not fully filled in by everyone, because the respondents had knowledge only about some of the domains. There were 3 respondents who completed the technical, business, social and ethical dimensions. They are working in construction companies which are using drones for one or more of the following operations: photogrammetry, GPS measurements, site inspections, 3D modelling. The legal tool was filled in by a single person from the Dutch Ministry of Infrastructure who has expertise in the aviation legislature. At the end, after all participants filled in the tool, the data was gathered, and the average score was calculated for each dimension. The results can be seen below, in Figure 1.

Figure 1 – The readiness of heavy lifting drones to be implemented in constructions based on 5 dimensions

According to the results of the scan, it is easily observed that the business dimension (6.3) is the most prepared when it comes to implementing heavy lifting drones in the construction industry. The least developed dimension is the legal one (4.13), with almost no evidence of regulation for material lifting operations with drones in constructions. The technical, social, and ethical dimensions results are similar, with scores ranging from 5 to 5.7. Overall, it can be stated that improvements are needed for all dimensions to increase the readiness of heavy lifting drones for construction operations.

4.1.1 Scan interview

There was also one person who works in a construction company and wanted to participate in this research, but instead of filling in the Space53 tool, he preferred to be interviewed. Since there were few respondents and any information about the potential of heavy lifting drones in the construction industry is valuable for this research, a short interview was conducted. The interview was structured based on the Space53 scan, hence it comprises five sections: technical, business, social, ethical, legal aspects (Appendix F). The questions for each section were formulated according to the subcategories covered by each domain, as presented in the analytical framework of this research. This

approach was chosen because in this way, it is easier to link the information gathered from the interview with the structure of this research. Therefore, in the end there were 5 people who provided information about the potential of heavy lifting drones in the construction industry. The data collected from the interview, together with the literature review presented in Section 2.1 are used for answering the first sub-question of the research. Next, all this information is presented and analyzed.

4.1.1.1 Technical dimension

In the literature review it was presented that construction companies support the further development of UAVs. This was also confirmed by the interview participant who stated that drones are expected to be able to move materials from a point A to a point B and to access dangerous zones in constructions. Additionally, the respondent said that heavy aerial lifting will decongest work on sites and a multi-network of drones with AI object detection is preferred for construction operations. He continued to explain that a crane can handle only one material at a time, but drones can carry multiple objects simultaneously. Thus, replacing a crane with a system of drones will increase efficiency on site by speeding up the building process. Various technical requirements such as maximum payload, flight components, drone management functions must be fulfilled when developing a heavy lifting drone. Some prototypes were already designed, but as shown in Figure 1, progress is still needed to reach a high level of technical readiness

4.1.1.2 Business dimension

From a business point of view, a multi-drone system can bring a competitive advantage for a construction company only when constructing high rise buildings, as the interviewed person stated. The advantage of replacing a crane with multiple drones is that more heavy materials are lifted in a shorter time, so the efficiency and quality of workers is improved. Regarding financial aspects, construction companies expect the cost of drones to be cheaper or at least as equal to the current construction costs.

4.1.1.3 Social dimension

According to the participant's answers, heavy lifting drones will be socially accepted in the construction market. But safety and reliability remain some of the most important aspects for adopting such a technology. Construction companies are willing to provide training regarding drone usage to the workers, with additional help from the other parties involved in the development of the aerial lifting technology. Therefore, other stakeholders' involvement and human-machine interaction must be further explored to enhance the social readiness of heavy lifting drones.

4.1.1.4 Ethical dimension

Ethical readiness is very important, as moral concerns can hinder the adoption of heavy lifting drones in the construction industry. The respondent stated that even though UAVs will partially replace human workforce, this cannot be considered an immoral act. When it comes to security on site, drones might create a feeling of unsafety among workers at the beginning, but once they get used to them, their presence will not be an issue anymore. Even though drones could be safer than cranes, concerns about other moral values, like autonomy and privacy can affect the ethical readiness level.

4.1.1.5 Legal dimension

Usually, drones use cameras to function, and many people are afraid of their recordings being misused. Heavy lifting drones' cameras might create new privacy issues but, as the participant answered, solutions can be found. For instance, the drone can start recording at the beginning of each operation, then the video is automatically erased once a new task is allocated to the drone. In this way, the video can be used only in real time, without storing the recordings. In addition, liability issues may arise too when using heavy lifting drones. The respondent explained that if any accident happens on the construction site, the stakeholders will blame each other. Therefore, to achieve a high level of legal readiness, new legislation is required to prevent a potential chain of liability.

Considering all the information presented above, an answer can be given to the first research sub-question *"How prepared is the construction industry for heavy lifting drone applications?"*. It can be assumed that the construction industry is willing to use heavy lifting drones, because their utility will speed up the operations on sites, while reducing the risks that the workers are exposed to every day. However, aerial lifting technology needs further improvements in all five domains to be ready to enter this market.

4.2 Expert Interview

The drone advancements needed for achieving a better readiness level in each domain is discussed together with an expert in aerial vehicles. This is done by interpreting the numerical results of the scan and further elaborating on the heavy lifting drone potential improvements and limitations in the construction industry. The expert who was contacted for this interview is a professor of unmanned robotic systems with knowledge about the use of drones in constructions as well. His expertise is helpful for assessing each single dimension and to better understand the heavy lifting drone readiness scores regarding constructions. The interview is a semi-structured one, as a discussion with an emphasis on the five dimensions (Appendix E). In the end, some additional questions are asked to link all the results of the scan. Interpretation of the scores, together with additional information about the use of heavy lifting drones in the construction industry obtained from the interview are presented next. For each dimension, the average readiness scores of the themes assessed in the Space53 scan are presented and further elaborated upon according to the expert interview answers. At the end of the section, based on the current level of material lifting UAVs preparedness, an answer will be given to the second sub-question of this research.

4.2.1 Technical scan

The technical readiness level can be considered low, as heavy lifting drone technology is not yet fully developed. According to the expert, the result is not so surprising because people know about manned heavy lifting drones (e.g., helicopters controlled by pilots), but not about unmanned drones as this technology is currently in the research level. There are just a few persons who have seen this type of drones in action, thus the awareness of heavy lifting UAVs is low. To increase their consciousness, the interviewee emphasized the importance of both software and hardware development. For the software, the payload control algorithm is important to ensure the reliability and robustness of the system. Regarding the hardware, the drone itself must be designed according to its payload, for instance the engine and propellers must generate enough thrust to keep the drone steady. Moreover, when the expert was asked about the low flight components score, he replied *"I believe that current flight components are mostly used for general drones, as unmanned technology has not been developed yet. Even if there are flight components specifically designed for heavy lifting, the risk associated with this drone is higher than the risk of a regular one, so people still doubt the flight functions."* To summarize, heavy lifting drones need to be tested in the construction sector, in an operational environment, to further develop this technology and to show the users their potential.

Technical readiness score	5.73
System integration	5.33
Drone management components/functions	7.10
Flight components/functions	4.83
Application components/functions	5.10
Backend processing	6.33

Table 2 – Technical readiness scan results

4.2.2 Business scan

The business readiness level was the highest one out of all dimensions. The expert stated that this score is the result of the business potential regarding heavy lifting drone applications - *"People see the opportunities. You should not only think about construction on land, but also about construction offshore. The risks are diminished, and the opportunities are higher for building projects offshore."* Moreover, during the interview it was explained that from a financial perspective, cranes are expensive and not very flexible, but heavy lifting drones would cost relatively low and would speed up the operations. Because of this, the financials category scored high, and the expert mentioned: *"Faster work means time saved, which results in money saved. As a company, you need to look at how fast you can use the drone and its flexibility."* The customer score was the same as the financial one, meaning that potential customers are really interested in this technology. But it can be easily observed that the market is not ready to implement heavy lifting drones, as the construction industry requires lots of security and safety aspects. Thus, the interviewee concluded: "*Until the legal part is solved, I am not sure that the construction market is ready for heavy lifting drones."*

Business readiness score	6.30
Customer	7.00
Value proposition	5.65
The market	5.80
Business network	6.50
The process	6.05
Financials	7.00

Table 3 – Business readiness scan results

4.2.3 Social scan

The readiness level of the social tool can be explained by a default association of high risk to something unknown. In general, people are afraid of drones and hardly accept them. But when it comes to heavy lifting drones, they correlate the *heavy* with *risk* first, not with the advantages. The expert explained: *"It is the people's perception, not the risk itself. The risk can be 1 and perceived as 10."* It might be surprising, but the social impediment that might prevent the use of heavy lifting drones in the construction industry is their design. A drone's design must transmit a feeling of safety and when people see big propellers, they unconsciously associate them with high risk. Obviously, there is a need to improve the design of the heavy lifting drone, but also to ensure that its sound is reduced, and it does not disturb the environment. To understand people's fears and concerns regarding drones, they should be involved in the technology development process, as their feedback will contribute to achieving a better social readiness score. Additionally, if awareness of the heavy lifting drones' advantages can be created, there will be a higher social acceptance level of this technology in the construction market.

Social readiness score	5.20
Stakeholders	5.65
Design	4.60
Acceptance	5.35

Table 4 – Social readiness scan results

4.2.4 Ethical scan

When it comes to the ethical readiness level obtained, it can be assumed that people's opinion is somewhere in the middle regarding the ethical use of heavy lifting drones in constructions. The score shows that people are not in favor or against drones, they are neutral because there is a lack of information about this technology. Because of this knowledge deficiency, people cannot decide if heavy lifting drones are good or bad. The expert said that the score is fair, as people do not usually see drones in constructions, especially heavy lifting ones. Thus, the score of the ethical scan reflects people's inability to make a decision due to not having enough information.

Ethical readiness score	5
Participants self-assessment	5

Table 5 – Ethical readiness scan results

4.2.5 Legal scan

Regarding the legal readiness level, the expert was surprised, as he personally expected a lower score. He explained that currently, there is almost no legal framework for heavy lifting drones. In fact, there are not so many activities with drones in the construction industry, so if a legal framework is required, the construction sector must take the first step to legalize the use of drones. The interviewee explained: "*Even for normal drones there is a lot of bureaucracy, so if there is something to do with heavy lifting, it is a completely different league. There should be an active market push to request the government to draft a legal framework."* This also explains why the legal dimension scored the lowest out of all five tools. Even though there is a high resistance to give permission for using heavy lifting drones in constructions, if the sector desires to implement this technology, a legal framework will be created eventually.

Legal readiness score	4.13
Public safety and security	4.50
Environmental burden	4.00
Privacy	4.00
Liability	4.00

Table 6 – Legal readiness scan results

4.2.6 Interpreting the results connection

It can be seen that the technical, social and ethical dimensions have similar scores. On the one hand, the expert explained that technically, there are some drone components which can be used for developing a heavy lifting drone, but the complete system level is not ready yet. On the other hand, the ethical dimension is linked with the social dimension to some extent. The social aspects are influenced by the information that people have about drones in general, while the ethical aspects represent their knowledge about heavy lifting operations in constructions.

When connecting all the results, it can be assumed that the five dimensions are interrelated. There is a chain reaction, as improvements in one dimension will trigger the further development of the other dimensions. According to the expert, the technical part is the most important aspect when it comes to implementing heavy lifting drones in the construction industry. Despite the fact that the business tool scored a bit higher than the

technical one, the technical dimension will pull the other domains further. If work is done on the technical aspects of the heavy lifting drone, challenges and limitations will be faced, which will result in technology improvements. Once a complete drone system is ready, it can be tested in operational environments, where a legal framework will be needed. Many people can be involved, thus social awareness will be created which will also impact the moral perception of people regarding heavy lifting drones. Thus, as the expert concluded, *"The business dimension is a bit ahead than the other ones, so some people already see the advantages of heavy lifting drones in constructions. But the technical part will bump the other dimensions too."*

Therefore, even though heavy lifting drones are not ready yet to be implemented in the construction industry, the technology will reach a higher readiness level in all domains if it is further developed. The expert interview results presented above give a complete answer to the second sub-question of this research – *"What is needed to further improve these applications in this field based on the level of preparedness? "*. To summarize the answer, improvements are needed in each domain, starting with the technical dimension. If the drone technology can be robust and reliable, heavy lifting UAVs will be accepted on the market and construction companies will benefit from their usability.

4.3 Quick Scan Tool Assessment

The sub-objective of this research was to assess the Space53 scan for further improvements. As mentioned in Section 3, the respondents of the survey can express their opinion about the tool by filling in some feedback questions before submitting their responses. Their impressions can be used to revise the survey and improve its quality for further research.

The feedback for the survey received from the participants of this research was negative in principle, with some good exceptions. The general impression of the respondents was that the survey is "too long" and "quite complex". Filling in all the tools by one single person requires approximately 40 minutes and not everybody is willing to allow so much time for this. Moreover, some of the questions are hard to follow, thus the respondents were not able to answer all of them. Few of the participants' impressions are cited below:

"Happy to help but I don't have the time to fill it out."

"I'm afraid I find most of the questions too complex to comment on."

"This is not a survey that you just click on, I find it quite complex."

Because of these two main negative aspects of the survey, some people who wanted to participate in this research asked for an easier way of providing information, stating *"I would rather like to be interviewed about this."* or *"I could offer you a 15-minute phone call to answer your questions."*.

Despite the pessimistic feelings towards the scan, some respondents also found good aspects of the survey. Each tool was assessed on a scale from 1 to 5 in terms of helpfulness, further guidance provided, degree of relevant insights acquired and the ease of filling in the tool. The overall average scores given for these aspects ranged from 2 to 4 per each dimension tool. Scores of 2 and 3 were given for the ease of completing the survey, while the scores for the other aspects reached 5 points in some cases. This shows that even though the scan is long and complex, its content is useful and insightful for the ones interested in this domain. The positive affirmation was also confirmed by a respondent who stated that *"the information of the tool is quite extensive and complete"*.

Therefore, to answer the third sub-question of this research - *What parts of the UAV readiness Quick Scan tool developed by Space53 can be improved?* - suggestions are provided next. The first recommendation for Space53 is to simplify the survey to gather more relevant data. Even though some people had knowledge about heavy lifting drones in constructions, they did not fully understand the questions and there were no answers provided. Replacing some academic words with more usual ones could make the tool accessible for everyone. Also, rephrasing some of the questions can improve the quality of the responses, as the participants will perceive the questions correctly. The second recommendation for improving the scan is to diminish the number of questions. For some dimension tools, the questions are repetitive, and this might cost the respondents additional time to answer all of them. Similar information can be deducted from multiple questions, thus the content of each tool needs to be examined and further improved to avoid repetition. The third suggestion is to shorten the assessment explanation of each tool. A brief overview of the scoring scale can be presented before starting to fill in the questions, without providing additional information about the structure of the dimension tool. By doing this, the response time rate will be visibly reduced, and more people would be willing to complete the survey. The fourth and the last recommendation is to make two separate versions of the survey, both with the same content, but with different lengths and vocabulary. One survey can be the current one with some changes based on the recommendations provided and academic terms, while the other one can be shorter, with more familiar terms. In this way, the respondents can choose which one they wish to fill in, based on their time availability and on the degree of content comprehension.

Finally, an answer is given to the main research question of this paper - *"What is the potential of using heavy lifting drones in the construction industry and, if any, what are the implications for the development of this application?"*. There is clearly a high potential of using UAVs for material lifting in construction projects, even though the technology is not fully developed yet. Construction companies are willing to use drones instead of cranes, as they would bring many advantages to their businesses and operations on sites would be faster and safer. But to further develop this system and to be fully accepted on the market, improvements are needed in all domains, especially in the technical, social, ethical and legal ones.

5. CONCLUSION AND DISCUSSION

In this section of the paper, a conclusion is drawn on the results and data collected throughout the research study. Next, a discussion on the practical relevance and implications of the study is presented. The end of the section is about the limitations occurred during the data collection phase and recommendations for further research.

5.1 Conclusion

The main objective of this paper was to find out the opportunities that heavy lifting UAVs bring to the construction industry and their level of preparedness for this sector. Five different domains were analyzed to determine the maturity of these drones. It can be concluded that the construction industry can benefit from this technology, especially for high rise buildings projects. A multi-drone system can be used to lift and carry materials across the construction site, and to access dangerous zones as well. Therefore, based on the interview conducted, construction companies already see the drone's potential in this sector. This is also confirmed by the scan results, as the business readiness level of heavy lifting drones in constructions is the highest one. The customers are aware of the benefits, but the market is not ready for this technology until a legal framework is set. Regarding

technical readiness, the drone system is not complete yet. Some of the regular drone's components can be used for the development of a heavy lifting one, but the flight functions need more adjustments. But to further develop and test this technology, a legal framework is needed to avoid a chain of liabilities in case unforeseeable accidents happen. To increase the social readiness of these drones, safety needs to be provided. The UAVs design must ensure that the machine interaction with other workers on site is secure and that the drone does not generate noise pollution with its propellers. The ethical readiness level is neutral, because people do not possess a lot of information about heavy lifting drones. So, there is a need to create awareness of the benefits that UAVs can bring in constructions. In conclusion, all five dimensions are interconnected, as they have similar readiness level scores. Construction companies are already aware of the heavy lifting drones' benefits, but further development of the technical aspects is needed to boost the readiness levels of the social, legal and ethical dimensions.

The sub-objective of this research was to examine the Space53 tool for improvements. It is concluded that the scan is complex and difficult to complete, so changes are needed to make it more accessible for people who are not familiar with technical academic terms. Moreover, it is recommended to develop another version of the scan, with fewer questions and less explanations.

5.2 Discussion

This paper reveals hitherto unexplored insights about the use of heavy lifting drones in the construction industry. During the literature study phase, published articles and papers about technical parts of heavy lifting drones were found, but none about the analysis of the other four dimensions. Thus, this paper contributes to the innovative opportunities that material lifting UAVs can bring to the construction industry. Moreover, the methodology used for collecting and analyzing data emphasizes the importance of potential customers' opinions when an innovative product is developed. By using the Space53 scan, different stakeholders were engaged in this research. The information provided in the survey or during the interview contributed to understanding the construction market better and its needs that heavy lifting drones must fulfil. The role of the expert interview was to link all the data collected to define improvements points for each dimension. In addition, if the recommendations for the survey are taken into consideration, more companies could be willing to participate in this kind of research.

The construction industry and other interested parties can benefit from this research by acknowledging the opportunities of heavy lifting drones. Since construction companies already see the usability of UAVs for lifting materials on site, drone manufacturers can focus on the technical dimension results to further develop the drone system. When this technology is ready to function, the matureness levels of the other dimensions will be enhanced too, as the dimensions are interrelated. Media could be involved to create awareness of the advantages of heavy lifting drones. Based on this research, construction companies can also take the initiative to request a legal framework for using these drones in their projects. As a result, the involvement of different parties in the continuous development of heavy lifting drone technology will increase the readiness levels of the technical, business, social, ethical and legal dimensions. Once these drones will be completely ready for the construction market, some processes can be automated to enhance labor efficiency on site, in a cheaper and more flexible way compared to cranes.

5.3 Limitations and Further Research

This research highlights the importance of technical, business, social, ethical and legal domains when developing a novel product. Although, some limitations occurred during the practical phase of this research. First, there were few respondents who filled in the Space53 scan. Due to the Covid-19 pandemic, people's willingness to participate in research studies decreased, because everybody is focusing on their most important tasks. Companies are even harder to contact during the pandemic period, because all their efforts are inclined towards maintaining high revenues, so little attention is paid to other external parties. Thus, contacting and convincing individuals to fill in the survey was one of the main impediments who resulted in a small number of respondents. Also, the time allocated for this research was an eleven-week frame and the respondents were allowed to answer the questions of the tool for one week only. Even though some people took their time to answer the survey questions, nobody filled in the entire scan, just some dimensions. This aspect leads to the second limitation of this study, which is the scan complexity. The length and the difficulty level of the survey prevented the respondents from answering all the questions. If everybody would have filled in the whole survey, the final results would have been more accurate.

Considering all these, further research is encouraged regarding the use of heavy lifting drones in the construction industry. The most important recommendation is to convince a higher number of respondents to fill in the scan. The focus in this research was on construction companies, but drone manufacturer companies can contribute significantly to this research too. The Space53 scan is more suitable for drone developers, so input from people with this expertise will enhance the accuracy of the scan results. Moreover, the second recommendation is to find participants who are able to fill in the whole scan, not just some parts of it. Drone manufacturers might be the most suitable respondents as the scan questions are very detailed for all five dimensions. Having a complete set of answers from multiple individuals will offer a better overview of the current state of heavy lifting drones in constructions. The last recommendation is to research the construction projects offshore as well. This research offers information about constructions on land, but more advantages of using heavy lifting drones can be discovered for the construction sector offshore. For this type of project, drones might be a faster and safer alternative to cranes than they are on the land.

6. ACKNOWLEDGEMENTS

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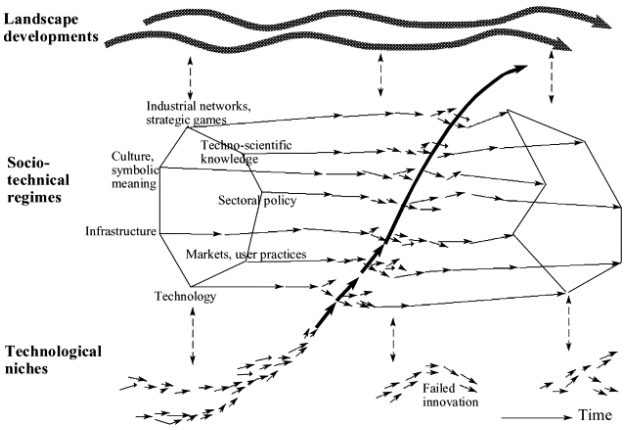
8. APPENDICES

Appendix A – "A dynamic multi-level perspective on TT."

Retrieved from: (Geels, F. W., "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study", 2002)



Appendix B – TRL Levels

Retrieved from: (Tomaschek, Eppinger, Joglekar, N., & Olechowski, "A Survey of Technology Readiness Level Users", 2016)

TRL	Definition
9	Actual system flight proven through successful mission operations
8	Actual system completed and "flight qualified" through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem model or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in relevant environment
4	Component and/or breadboard validation in laboratory environment
3	Analytical and experimental critical function and/or characteristic proof-of-concept
2	Technology concept and/or application formulated
1	Basic principles observed and reported

Appendix C – The process of pickup and place in modular construction.

Retrieved from: (Augugliaro, et al., "The Flight Assembled Architecture Installation: Cooperative construction with flying machines", 2014)

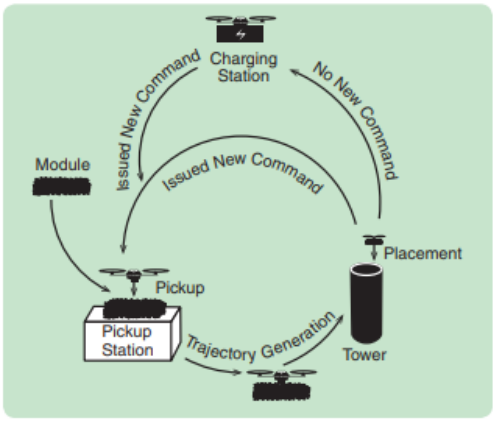
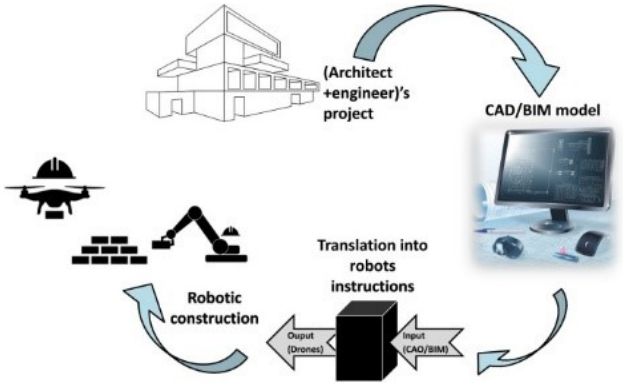


FIGURE 3 The pick-place state machine. The process of assembling a structure begins when a module is placed in the pickup station, which triggers a pick-place command to be issued to an idle quadrocopter, which then removes the module from the pickup station and places it at the desired location within the structure.

Appendix D – The process of sending instructions from BIM model to drones.

Retrieved from: (Goessens, Mueller, & Latteur, "Feasibility study for drone-based masonry construction of real-scale structures", 2018)



Appendix E – Survey Protocol

The purpose of this research is to determine how ready are the heavy lifting drones to be implemented in the construction industry. This will be done by analyzing 5 domains: ethical, business, social, ethical, and technical. Thus, the main question of this research is "What is the potential of using heavy lifting drones in the construction industry, and if any, what improvements can be made further?"

The survey developed by Space53 comprises questions about all those 5 domains. You, the participant, can choose yourself which domain you would like to assess first. When filling in the survey, please consider the whole construction industry, not just the company you work for. Also, keep in mind that your answers should reflect the use of drones for heavy lifting and assembling buildings/structures, not for other purposes. At the end of the survey some additional questions were added to provide feedback for the tool. Please grade each domain, so that the tool can be improved. When you are finished, you can download your provided answers. You can end the survey anytime, even if not all the questions were answered.

The purpose of this research is only academic, and it will help me finish my studies this summer. You may also benefit from this research's results, by improving your business services and position in the market.

If you have any other questions, please do not hesitate to contact me! Thank you for your time and good luck with filling in the survey!

Appendix F – Interview questions based on the Space53 scan

1. *Technical questions*
   - Is there currently a heavy lifting drone on the European market that can be bought which can be used in the construction industry for lifting all kinds of materials?
   - What are the technical limitations of such a drone?
   - Would drones with manual command be better than drones using AI object detection (no human assistance at all)?
   - Would a multi-network of drones work better than a single drone?
   - Instead of using cranes, would drones be able to lift modular constructions?

2. *Business questions*
- What would be the potential gains and losses of using heavy lifting drones?
- Would heavy lifting drones bring you a competitive advantage?
- How much do you think that such a drone should cost? Do you think they would be cheaper than cranes?

3. *Social questions*
- Who should teach the workers to use these drones, the drone manufacturer or the construction company?
- Do you think this technology would be accepted in the construction market?

4. *Ethical questions*
- Do you think that heavy lifting drones will replace the human workforce?
- Do you consider this being an immoral act? (replacing the human workforce)
- Do you think drones will create a feeling of unsafety among workers on site?

5. *Legal questions*
- Do you think drones would be an additional risk to workers or other pedestrians, compared to cranes?
- Would you be willing to take full liability if any accident would happen to workers while using drones for heavy lifting purposes?
- Do you think the use of heavy lifting drones will have a negative impact on the environment? (e.g., create noise pollution)
- Do you think they will create new privacy issues? (e.g., because of the cameras installed on the drones)

Appendix E – Expert interview questions

1. **Technical tool**
- How do you explain the score of the technical dimension?
- What technical aspects do you think are the most important when developing a heavy lifting drone?
- Why did the flight components score the lowest?

2. **Business tool**
- How do you explain the score of the business dimension?
- Why do you think this dimension scored the highest out of all five?
- What would prevent a construction company from using heavy lifting drones? (e.g., financial reasons)

3. **Social tool**
- How do you explain the score of the social dimension?
- What would be the most important social impediment that might prevent the use of heavy lifting drones in constructions?
- What needs to be done to achieve a better social readiness score?

4. **Ethical tool**
- How do you explain the score of the ethical dimension?
- Do you think this score is true?
- Do you think ethical readiness is influenced by social readiness?

5. **Legal tool**
- How do you explain the score of the legal dimension?
- Why do you think this dimension scored the lowest?
- Are there any regulations imposed on heavy lifting drones yet?
- What needs to be done to achieve a better legal score?

6. **Questions about the overall scan results**
- Why do you think technical, social, and ethical dimensions have similar scores?
- Which of the five dimensions is the most important when it comes to implementing heavy lifting drones in constructions?
- Do you think heavy lifting drones are ready to be implemented in the construction industry?