APPLICATIONS OF UNMANNED AERIAL VEHICLES IN THE AUTOMATED CONSTRUCTION INDUSTRY

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Abstract—*Over the years, many orthodox construction practices have become antiquated and inefficient in the scope of the modern world, yet they are still integrated in the development of current structures. Resultantly, traditional construction has remained a complex and messy process. The field of automated construction aims to change this by utilizing modern robotics to create a more efficient construction industry.*

This paper will focus specifically on unmanned aerial vehicles (UAVs), or "drones," and their applications within automated construction. Drones have been utilized by both the military and civilians for quite a long time, with many applications and enhancements arising as a result. The many years dedicated to drone development have made them relatively inexpensive in the grandeur of budgets dedicated to nearly any commercial construction project, while the technology that the drones are able to harness expedites many hindrances previously experienced by construction crews.

In this paper we will identify and investigate the types of drones currently being utilized in the construction industry, as well as their integral components and functionality. We will then evaluate the effectiveness of drone applications in a variety of construction contexts. In particular, we will analyze the effectiveness of UAVs in land surveying and mapping, physical masonry construction, and additional applications previously not possible with conventional construction methods such as aerial surveyance and speculation, expedited tool delivery, etc.

Key Words—Automated Construction, Construction, Drones, Surveying, Unmanned Aerial Vehicles

AUTOMATED CONSTRUCTION: THE PROGRESSION FROM THEN TO NOW

The construction of self-standing structures has been around since the beginning of time, with people seeking shelter from the world around them. Across the globe today, construction firms aim to design, pitch, model, and construct safe and efficient structures to be used by the public. These construction managers and engineers are tasked with the challenge of creating unique and eye-catching pieces of architecture that can serve citizens in a variety of different ways. Techniques of the construction of buildings and complex structures have stayed stagnant, with traditional construction methods taking precedence to new, untouched methods of construction. However, advancements in technology have caused doubt in the sustainable use of traditional construction techniques. Progress monitoring has proven to be time consuming and labor intensive, while methods of personalized data collection can be tedious when it comes to relaying certain information [1]. Similarly, these manual methods of construction always present a risk for on-site accidents or injuries to workers.

In recent years, a new and more efficient method of construction has taken the architecture industry by storm. Automated construction is defined as the use of machines and other operating equipment to aid in the construction of complex structures and development of commercial sites. One of the main applications of automated construction to the architecture industry is the use of unmanned aerial vehicles, commonly referred to as drones, to aid in simplifying the construction process. The term "drone" refers to the aircraft itself, along with the equipment that operates independent of human control. The use of various forms of drones dates back to around the time of the U.S. Civil War, when these military weapons were only used to cause harm. Now, these aerial tools can serve as an important reason for the safety of site designs [2]. One of the key attributes that construction clients look for in a team is their use of drone technology. Some of the main purposes of utilizing drones in construction include providing a remote view of a site, surveying, tracking day-to-day progress of a project, and counting the materials that are used to analyze a project's overall budget [3]. Not only that, but the use of these smaller drones can allow the exploration of more difficult spaces and bring forth new and improved data analysis.

DRONE COMPONENTS AND FUNCTIONALITY

With a recent increase in the use of technology in industry, such as drones, it is important to understand the internal structures of commonly used drones and their role in allowing these aerial machines to run at such a high level. Knowing the different parts of the drone that are being used allows the user to be more confident when flying. As for troubleshooting, the user will also be able to identify the source of any flight problem and know which parts call for more often inspections. This knowledge, which certain users may overlook, can allow caring users to be more efficient with their money when replacing or upgrading their parts.

Hundreds of different parts make up a typical drone used in automated construction, and every single one of them plays a role in allowing for a safe and efficient flight. Some of the most prominent parts of the drone, just to name a few, include the propellers, motors, landing gear, main body, receiver, controllers, and cameras. Many drones utilize four standard and pusher propellers to push the drone through the air, and the most powerful propellers are made out of carbon fiber to maximize strength [4]. One of the advantages of drones that utilize multiple carbon fiber propellers is that they offer more precise accuracy in calculations and, more importantly, added stability to the drone's base. In turn, building sector stakeholders are able to equip these powerful drones with features such as high-resolution cameras, laser-scanning rigs, and gyroscopic stabilization to acquire data like never before [5].

Practically all of the latest drones utilize brushless electric motors, which have been proven by use to be more efficient, more reliable, and quieter than traditional brushed motors. Drone manufacturers caution users to listen and get used to the sound that the motor makes inside the drone in order to detect possible damage or other problems quicker. Recent motor designs utilize these motors with a curved magnet that fits perfectly with the motor and allows more efficient runs. Properties of landing gear can differ greatly with various drones, as some adopt helicopter-like skids and others land perfectly on their body without other aid. For those that do use landing gear, retractable wings prove to be the most useful because they allow full 360 degree views in the air and refrain from interfering with the aerial photos being taken. [4]. The main body of the drone, typically crafted in a square or diamond pattern, houses the battery, main boards, processors, cameras, and sensors within the drone. A great amount of body pieces used for these drones are not waterproof, so it is important for users to be careful of their surroundings when flying near bodies of water. Two different controllers serve as the user's way to interact with the flight patterns of their drone. The Electronic Speed Controller (ESC) helps to vary an electric motor's speed, while the flight controller acquires input from the receiver and sensors and serves as the central of the functioning for the drone. Cameras used on board of drones are connected to pivoting mounts called gimbals to allow for rotating views of a site. Compact high definition video and picture units, such as GoPros, are commonly used with an option for real-time streaming to collect data as the drone flies [4]. These parts of the most commonly used drones work together in order to allow for simple user interaction and the power to collect aerial data unlike anything seen before.

One example of drone functionality in modern construction is through the practices of Skycatch. Skycatch is a company based in San Francisco that specializes in the design of drone systems and solutions for enterprise applications. Jacqueline Guilbault, marketing director for Skycatch, discusses in detail the rising importance of automated construction and how the company aids in simplifying the construction process. "There are millions of changes happening every day on a construction site, so capturing daily progress with daily drone data capture is the single best way to capitalize on drones. Some of our customers even fly multiple times a day because their sites evolve so quickly. Users can also go back and identify what was done on the project to the day, and having that historical archive has proven invaluable as customers use them for everything from verifying invoices to resolving claims" [3]. Guilbault explains that the drones the company produces are extremely popular for construction firms hoping to track their progress on a project. These drones can have numerous positive effects on the quality of data that is collected.

THE USE OF DRONES IN SURVEYING, MAPPING, AND SITE MONITORING

Arguably the most prominent utilization of unmanned aerial vehicles in the automated construction industry is in the area of surveyance, mapping, and site monitoring. Automated mapping is a prime example. This is where drones map construction sites while following a predetermined route that has been established by carefully placing control points on the ground [6]. The usage of ground control points is essential to this process because they establish scale, feature height, and cardinal orientation [7]. The images gathered from these automated flights can be used for both mapping and monitoring purposes, considering that unmanned aerial vehicles can be easily deployed with pre-programmed, site-specific procedures. Such programmable flight aspects include speeds, altitudes, hover times, and landing locations [2]. In theory, construction crews could carry out this automatic mapping procedure as often as they wish in order to monitor construction progress and site development.

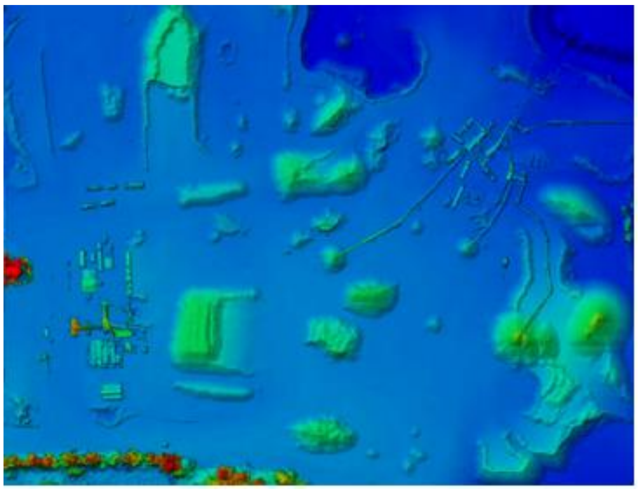

FIGURE 1 [7]
Digital Elevation Model of Material Stockpiles. Photogrammetry can be used on images such as these to determine remaining volumes of materials.

One of the main goals of construction crews is to capture an orthomosaic of an entire construction site. Orthomosaics are extremely detailed, to-scale compilations of many images stitched together to capture a much larger picture [8]. Many images and quite a bit of raw data must be gathered and processed before this can be obtained, however. While the drones are in the air, they collect many different types of data. Along with images, the drones can collect data pertaining to latitude, longitude, and altitude. Some drones are even equipped with LiDAR, which operates similarly to RADAR, except that it uses lasers instead of radio waves in order to gather extremely detailed representations of construction sites down to the smallest of details [7]. In traditional construction practices, construction drawings are used to create a Building Information Model (BIM) of the construction site, which is used for planning and monitoring. With the advent of drones, data collected from scaled images and scans such as point clouds can be used to render models that can be used alongside or even in place of BIMs [9]. Once a drone has automatically mapped a site and collected data pertaining to latitude, longitude, altitude, and LiDAR, different models can be generated such as two dimensional and three-dimensional renderings, as well as orthomosaics [7]. Techniques such as photogrammetry can be utilized to perform complex measurements and calculations in order to properly render and analyze these models. Photogrammetry is the practice of taking precise measurements from photographs taken at differing angles, allowing for the creation of point cloud maps as well as distance and volumetric calculations from digital elevation models [7]. In fact, by utilizing photogrammetry, large two dimensional and three-dimensional areas can be me measured within centimeters of true accuracy at very fast and cost effective rates [9]. This allows for construction crews to gain a more accurate understanding of their sites than ever before.

Drones can also be found in a variety of surveyance operations as well. Surveyors utilize the same methods as described above, but instead in the contexts of both cadastral and corridor surveying. Cadastral surveying is the most classical and well-known sub-field of surveying, and it focuses on the establishment and/or changing of property boundaries. Corridor surveyance involves the specific surveying and establishment of road, highway, and railway infrastructures [7]. Drones are especially good for this considering that they are a much more cost-effective alternative to other methods of this specific type of surveying such as aircraft, satellites, and road crews [7]. A prime example of just how cost-effective drones are in this context involves road paving. This is because without the accuracy and precision of properly surveyed roadways, it is very possible to add an extra quarter inch of pavement for miles, adding an extra few hundred thousand dollars to the cost of paving a roadway [10]. A remedy for this is to provide modern computer-enabled construction equipment with the data gathered by drones to prevent such a thing from occurring and to improve the overall efficiency of the paving process [10]. This application underscores just how perfectly modern technology allows automated construction to be a feasible, real world solution to previously unsolvable construction problems. Additionally, it shows just how useful unmanned aerial vehicles can be in the context of surveying and their ability to work in conjunction with a variety of other technologies in order to accomplish complex construction tasks in an efficient manner.

PHYSICAL MASONRY CONSTRUCTION WITH DRONES

While drones alleviate a plethora of limitations by providing aerial views to construction projects, they can also prove helpful in the physical work as well. Recent adaptations to the programmability of unmanned vehicles and the materials they can use has opened a floodgate of possibilities for building structures from the sky down.

One of the first grandeur displays of the potential of this kind of construction was put on display Fonds Régional d'Art Contemporain in Orleans, France, in 2014. The installation, titled “Flight Assembled Architecture”, spotlighted a 6 meter-tall, foam block structure erected by four quadrocopters throughout the week [11]. While many architects and designers had been working for years to implement more technology into their work, this exhibit branched into an unexplored dimension. Automated tactics like 3D printers and CNC machines are able to narrow down the inaccuracies and looked-over mistakes that arise from human-produced construction, but are still limited to operating in impractical conditions. The warehouses and labs that are needed to support these machines are often far away from the active construction site, leading to massive time investments of transporting pieces from where they were fabricated to where they need to be implemented. The separation of where a part of a structure is created and where it is needed also means that more time must be allotted for transportation delays if there are any errors with the structure or changes in the plans. Drones surpass these drawbacks by being able to do their work on the construction site.

Automated aerial vehicles are resilient to unpredicted circumstance while being able to operate in many conditions that other machines can’t. More mobile and practically transported than their counterparts, drones are also able to build unlike any other construction method. Able to follow highly technical, precise programs, machines have the ability to execute exact commands that demand accurate movements. Aerial drones, however, are able to follow these commands on a job site, giving a foreman the ability to alter the design plan and then implement the desired changes instantaneously. On-the-job adjustments are very common due to unexpected changes that arise because of a multitude of factors like issues with the location or demands from superiors. The flexible nature of drones makes them a formidable component of future construction tactics.

As there are multiple upsides to implementing unmanned aerial vehicles into the workforce, engineers have put in incredible amounts of research and development into making drones valuable to masonry. The most important aspect to creating automated construction would be the development of the automation itself. For other types of machinery, programming has existed for several decades, making the designed and calculated movements of a stationary object relatively simple. However, drones presented the challenge of needing software capable of projecting pathways in three-dimensional space, being able to adjust for obstacles, such as other drones, and then to be able to actively judge the status of the structure the drone is working on to maintain appropriate precision.

Over the past decade, improvements to robotic technology have worked towards making the demands of construction for drones realistic. The fruits of these advancements can be seen by the Flight Assembled Architecture Project, based on the research of ETH’s Flight Machine Arena [11]. Showcasing their potential in a scaled down fashion, this display highlighted the incredibly careful and cohesive method of physical construction with drones. The Flight Machine Arena model focuses on a synergistic compilation of multiple drones working at once to efficiently complete a structure. Relying on an “overhead motion capture system” which implements a series of software focused on controlling the flight patterns of the vehicles, the model is able to adjust for incurred errors [11]. Each physical zone of the “construction site” of this representation is marked with reflective tape, implementing the landscape into a digital system that allows for the program to lead the drones relative to the surroundings. With the topography of the site mapped out by the controlling software, real-time feeds of movements and actions of the drones in the site are fed back to the main system, and then adjusted orders are sent back to the fleet of drones. The constant management of the drones means that the system can function seamlessly if any complications arise. Because the system is designed to have two drones operate at once, if a drone varies in its flight pattern, the overlying software can adjust the motion of the other drone operating with it. If a placement of a material is off from where it was supposed to be, instructions are given to account for the error. The incredibly well thought through design of the Flight Machine Arena led to an incredibly successful display in the Flight Assembled Architecture showcase.

Implementing pickup stations, charging stations, and placement platforms, the Flight Assembled Architecture Project was able to effectively construct a 1500-piece, cylindrical tower [11]. The building material was a light-weight, foam block thirty centimeters in width and ten centimeters in height and depth that could be easily transported by smaller drones. The Flight Machine Arena model that was used by the Flight Assembled Architecture was simplified to the designations of a “blueprint”, “foreman”, and “crew system” [11]. Here, the blueprint is the overall programmed design, the foreman is the monitoring software that gives commands and receives data from the drones, and the crew is the two pairs of drones that operate alternately to build the structure. When put to work, the blueprint would pass the placement information to the foreman, defining the overall order of the process. The foreman would then give these instructions to the crew for action. One pair of the crew would act on the commands from the foreman, travelling to the pick-up station and then executing the placement. The other pair of drones would remain at the charging station until they were called when placement had gone successfully. At the pickup station, the drones were highly regulated in their motion to ensure a well-placed grab. The designers of the software used in this system found it most important to control the lateral movement of the drone when approaching a block so that it could grab it as close to the center of mass as possible. If the drones were unable to obtain the blocks at a controlled, central location, too much variation would occur in the placement process to make a viable product. Before taking off with the block, the travel of the drone was precalculated to maintain a safe separation of space between the pair. While one pair of drones were going through the placement process, the foreman relied on its graphical knowledge of the environment to give intermediate instructions. While a drone descended to set a block, if there was too much variation in its real-world path, the foreman aborted the action and the drone would reset to a safe height above the structure to make another attempt. Adjusting flight patterns and supervising the placement, the system was able to obtain a mean lateral placement error of about nine millimeters with a standard deviation of about six millimeters [11]. The six-meter-tall structure was completed in under eighteen hours.

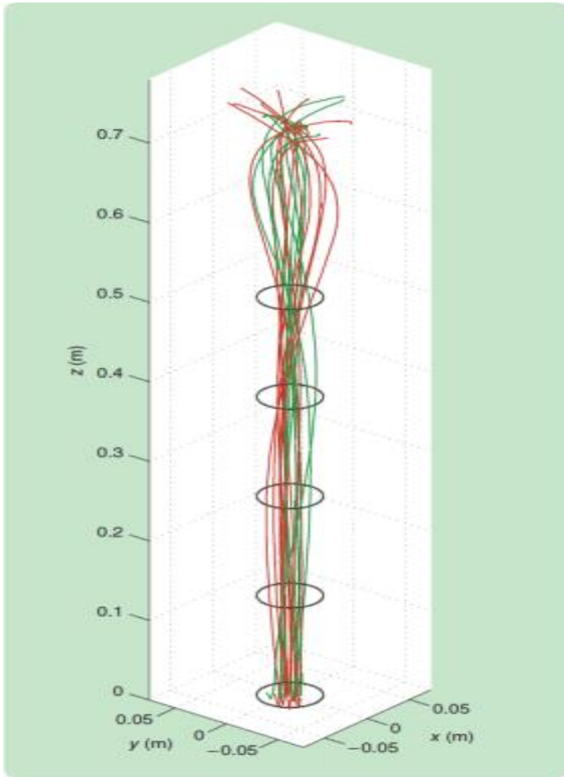

FIGURE 2 [11]
Placement Projections from the Flight Assembled Architecture.
The colored lines represent actual trajectories of the drones placing blocks while remaining in a precision of twenty-five millimeters as indicated by the black rings.

Along with programming that has been developed for drone systems, there have been remarkable improvements to drone compatible masonry. A type of material utilized by drones has been dubbed “drick”, a combination of the words “drone” and “brick”, and the development of these objects was displayed in the 2016 IASS (International Association for Shell and Spatial Structures) Annual Symposium by a team composed of member of the Universite cathlique de Lovain (UCL) and the Building Technology Program from the Massachusetts Institute of Technology [9].

The focus of the research that was presented at the IASS symposium looked to create a drick that was less than thirty kilograms and be able to form corners when placed together while maintaining the integrity of traditional brick-laying practices. Accordingly, they tested styles of a “Drick60” that had block shaped based with protruding trapezoidal features on the top. The bottom on the brick had a female juncture so that the brick below could be inserted to join the two and form an interconnected structure.

However, construction with the Drick60 showed that the flat sides produced too many weak spots, as the culminating weight of the concrete could not be dispersed well.

Redesigning the drick, the team took another approach to make a piece that could effectively displace weight throughout a structure. Their result was the "Drick60i", which has two shapes: an m-shaped trapezoidal base which would be placed alternatingly with a drick with a w-shaped trapezoidal base, both retaining the joints on top and junctures on their bottoms to connect to others [9]. The team found that this model created much more sound constructions that supported itself with less weak spots.

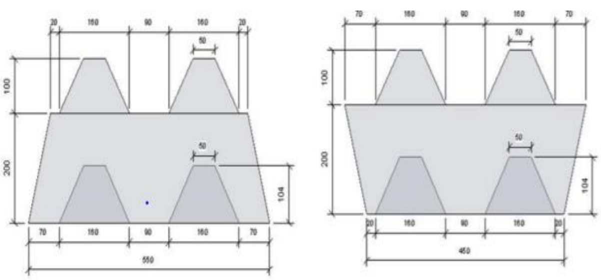

FIGURE 3 [9]
"Drick60i" from the IASS 2016 Annual Symposium The m-shaped drick (left) and the w-shaped drick (right) were used to create formidable structures while utilizing drones.

ETHICAL IMPLICATIONS OF UTILIZING DRONES IN CONSTRUCTION

As with many other recent technological innovations, there are a multitude of ethical considerations that must be made by those implementing new technologies. Utilizing unmanned aerial vehicles in the automated construction industry is no exception. In fact, drones alone have raised many ethical questions in recent years due to their incredible capability to document their surroundings while also being incredibly free to move practically anywhere. Additionally, there have been many recent concerns regarding the capability of unmanned aerial vehicles to pose a possible threat to aircraft and air space in general. In order to alleviate many of these concerns, in 2015 the Civil Aviation Act was amended to ensure that drones operated by civilians do not exceed four hundred feet of altitude while in flight, and that all drones being utilized for commercial purposes must be operated by a licensed pilot [1]. This is a beneficial solution because it ensures the safety of American airways while also making sure that all commercial drone pilots are properly educated and are capable of operating the equipment that many people are concerned about.

Generally, the main ethical concern regarding the usage of unmanned aerial vehicles in almost any commercial or private context, however, is individual privacy. This is true considering especially that drones collect so much data in commercial construction applications by taking images and scanning their surroundings constantly [1]. This can be very concerning to most people who live near construction sites or anywhere else where these commercial drones are being utilized, considering that much of the area surrounding where they reside is subject to constant scrutiny by construction crews and commercial drone pilots. In order to address this issue, those whose privacy may be affected by the usage of drones in construction applications should be notified ahead of time about the information being collected and should be made aware of their options. Additionally, those using UAVs to collect information should treat the data they gather in a sensitive and respectful manner as to ensure that the privacy of those around them is not infringed or degraded in any way.

Although individual privacy is a large concern among the general population when it comes to drone usage, it is generally a secondary concern to those operating them, as crews and pilots are usually more concerned with the possibility of damaging the drone equipment, or injuring someone with the drone [2]. These are all valid ethical concerns and should be taken into a great amount of consideration when embarking on a construction or surveying project of any magnitude in order to ensure the safest and most efficient use of unmanned aerial vehicles in the automated construction industry.

The Status of Unmanned Aerial Vehicle Use Today

Limitations

Unmanned aerial vehicles provide a plethora of benefits to all sorts of industry, but, like with all great advancements, come with several problems in practicality. Some of the issues that face the usefulness of drones today are the strict regulations imposed by the Federal Aviation Administration, size of current models, and the overall price [7]. The laws set in place to monitor drone use restrict the airspace where drones could be used. One of the biggest problems arises in the tight restrictions of using aerial vehicles around airports. Most of the urban hot spots of the world have an airport in or around it by necessity of today's global connectivity. Concurrently, these areas are the most likely to have construction projects arise by way of renovation or expansion for population shifts. While more projects would promote the need for drone use, the barriers set in place by the government make them difficult or impossible to use.

Beyond government limitations, the current status of most commercially available drones leaves more to be desired for commonplace usage in construction. Most quadcopters developed today are designed to be compact rather than hardy, leaving battery times that last for only about thirty minutes [7]. While it is feasible to land a drone and replace its battery or charge it, as seen in the Flight Assembled Architecture exhibit, it is impractical to have to stop working so frequently on a job that has strict deadlines. Unable to continuously work for extended periods of time, construction crews have to alot time for bringing the drone down and getting it back to a battery level to continue its work, creating frustrating stoppages. As alternative to rejuvenating a single drone, crews would have to invest in a fleet of drones to keep them on a rotating schedule to continue to work throughout the day with minimal breaks.

While it appears that the lackluster-battery life can be combated by keeping more drones in stock, another realistic barrier to the regular use of drones is the price tag associated with making them usable on a construction site. Several companies have been able to create commercial-grade drones for a couple thousand dollars, but if the drone is wanted for surveyance, the additional hardware that it needs could cost up to tens of thousands of dollars [7]. In the scope of a construction-site budget this may not seem like much for a single unit, but it is only really beneficial to have multiple drones, making drone fleets a serious investment that smaller operations would be deterred from.

Current Usage

Despite the drawbacks of using drones, the combination of companies DJI, Skycatch, and construction giant Komatsu have made headlines for a large-scale contract that could implement drone use by this year [12]. DJI and Skycatch are working at the technical level, DJI designing the drones that are then able to utilize Skycatch's surveyance technology. Landing a contract with Komatsu, a company capable of taking on the risk of integrating drones to their tactics, makes unprecedented progress towards assimilation of drones into the construction world. Now drones and their developers will have the opportunity to showcase their potential on a real construction site. Therefore, the success of Komatsu with their newly acquired technology could prove drones to be incredibly valuable beyond their current limitations. Likewise, if drones prove effective now, the demand for drone development will heighten as more companies seek to compete with Komatsu's practices. Concurrently, federal administrations might be swayed by expedited construction practices with drones, leading to legal reform on the restrictions of unmanned aerial vehicles in industry. The use of drones now has the potential to make an impact on the future of construction as we know it.

Conclusion and Findings

The world constantly changes with the technology developed in an age of unprecedented knowledge and expansion. However, construction, the field that develops the landscapes that we inhabit, has been timid to adjust to modern tactics. Tradition has held the industry inert with recurrent problems in safety for its workers, sustainable practice, and long and draught out projects. The evolution of automation, however provides a bright future that significantly reduces the issues seen in contemporary construction methods. The implementation of unmanned aerial vehicles specifically could be an industry shifting adjustment because of their technological dexterity and capabilities in surveying and physical masonry. Drones themselves are composed of hundreds of fine-tuned pieces that make them incredibly useful in many parts of industry. Their lightweight, but powerful propulsion systems give them access to massive areas of space above and around landscapes. By harnessing brushless electric motors, drones are quiet and reliably efficient compared to other aerial vehicles. The landing gear equipped to today's drones makes taking flight and landing a seamless process that doesn't require complexities with designated departure and landing areas. On top of their practicality, drones can be modified to support other technologies like high-resolution or thermographic cameras. With these modifications, drones have proven to be highly effective for use in surveying, digital mapping, and site monitoring. Relying on control points on the ground, programmed routes can be developed to allow drones to easily oversee an entire site. Utilizing LiDAR, up-to-date, accurate graphical representations can be created to keep track of progress and develop improved models. With the accuracy and effectiveness of drones, construction teams can experience remarkable levels of efficiency adjusting for previously unpredictable changes and complications. Besides surveyance, drones could prove to be impactful in the physical labor associated with any construction project involving masonry. Able to work on-site without the need of specific, factory like conditions as seen with other forms of automation, drones shine in being resilient to unforeseen changes in the progress of a job. Developments with research like the Flight Machine Arena bestow astonishingly thorough and accurate programs that drone fleets can employ to create viable structures without putting human laborers at risk as seen in traditional methods. The Flight Assembled Architecture exhibits the effectiveness of this system, and did so with a remarkably precise result. Furthermore, developments from the IASS have worked to make materials catered to drone usage that allow them to make robust structures with little need for painstaking adjustments for construction sites. Despite the current dilemmas that drones currently face with regulation and functional limits, construction companies are already investing into using drones in their projects. With big names in the industry already taking on the current risk associated with drones, it is likely that the attention drones are receiving will lead to a future void of their downfalls today.

SOURCES

[1] N. Mkansi. "Drones in Construction: A tool to measure progress." University of the Witwatersrand, Johannesburg. Accessed 1.27.19. http://wiredspace.wits.ac.za/bitstream/handle/10539/25408/Group%205_DR2_researchreport.pdf?sequence=1&isAllowed=y.

[2] M. Tatum. "Unmanned Aerial Vehicles in the Construction Industry." Associated Schools of Construction. Accessed 1.27.19. http://ascpro.ascweb.org/chair/paper/CPGT198002017.pdf.

[3] N. Heydenburg. "Drone Technology Evolves for the Construction Industry." Design News: Serving the 21st Century Design Engineer. Accessed 1.17.19. https://www.designnews.com/automation-motion-control/drone-technology-evolves-construction-industry/157782070359814

[4] F. Corrigan. "Quick Drone Parts Overview Along With Handy DIY Tips." Dronezon. Accessed 1.16.19. https://www.dronezon.com/learn-about-drones-quadcopters/drone-components-parts-overview-with-tips/

[5] A. Sullivan. "Robots, Drones, and Printed Buildings: The Promise of Automated Construction." Building Design and Construction. Accessed 1.16.19. https://www.bdcnetwork.com/robots-drones-and-printed-buildings-promise-automated-construction.

[6] T. Rakkha. "Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones." Elsevier. Accessed 1.27.19. https://static1.squarespace.com/static/53d65c30e4b0d86829f32e6f/t/5b08663c1ae6cf8d38a67223/1527277122120/1-s2.0-S0926580518300165-main.pdf.

[7] C. Snow. "The Truth About Drones in Mapping and Surveying." Skylogic Research. Accessed 1.27.19. http://www.abovenv.com/wp-content/uploads/2016/08/TheTruthAboutDrones_mapping-1.pdf.

[8] J. Patterson. "An Aerial View of the Future – Drones in Construction." Geospatial World. Accessed 1.16.19. https://www.geospatialworld.net/blogs/an-aerial-view-of-the-future-drones-in-construction/.

[9] N. Anwar. "Construction Monitoring and Reporting using Drones and Unmanned Aerial Vehicles (UAVs)." The Tenth International Conference on Construction in the 21st Century. Accessed 1.27.19. https://www.researchgate.net/publication/326264559_Construction_Monitoring_and_Reporting_using_Drones_and_Unmanned_Aerial_Vehicles_UAVs.

[10] C. Choi. "Drone Surveys Improve Automated Road Construction." Inside Unmanned Systems. Accessed 1.17.2019. http://insideunmannedsystems.com/drone-surveys-improve-automated-road-construction/

[11] F. Augugliaro. "The Flight Assembled Architecture Installation: Cooperative Construction with Flying Machines." IEEE Control Systems Magazine. 11.07.2014. Accessed 19.02.2019. https://ieeexplore.ieee.org/document/6853477

[12] J. Hrenak, "Komatsu to use DJI Drones to help Automate Construction Industry." Poc Network. Accessed 1.17.18. https://www.pocnetwork.net/technology-news/komatsu-to-use-dji-drones-to-help-automate-construction-industry/.

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