Using Unmanned Aerial Vehicles for Automated BIM-based Construction Progress & Reporting [1]

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ABSTRACT

The use of Unmanned Aerial Vehicles (UAV) and drones has increased in recent years in the construction industry. The progress in technology in the design and navigation of low-weight and autonomous drones and UAVs allowed for a cost-effective and more practical operation in construction management and monitoring [1].

An innovative automated construction monitoring and reporting framework, based on real-time data obtained from UAVs are developed, the data will be collected from multiple locations and point clouds used to construct a 3D model using photogrammetry techniques [2].

This new model obtained from drone images can be compared to the BIM model at various construction stages to monitor the construction progress. Besides construction scheduling and costing, this comparison can include real-time recording, reporting, billing, verification, and planning.

With the obtained automated system, a significant reduction of the effort required can be observed compared to more traditional methods, resulting in better operations, planning and effective on-site adjustments.

Keywords - Drones, UAVs, progress measurement, GIS, 3D mapping, monitoring, aerial monitoring, BIM model, unmanned service devices, USDs, Smart Construction Monitoring

INTRODUCTION

"You have probably seen them buzzing around above you: drones."[2] Year after year they are becoming a typical sight and people, also non-professionals, are using them for all sorts of purposes. UAVs are increasingly becoming part of our lives, but why? [3]

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[2] (n.d.). PwC Belgium: audit, tax and consulting services. https://www.pwc.be/en/documents/20180801-drones-eye-view-v2

The first recorded UAV dates back to 1849, "when the Austrian attacked the Italian city of Venice using unmanned balloons that were loaded with explosives”[3][4]. “The first drone was the 1918 Kettering Bug, developed for defence in World War I. It was used as an aerial torpedo to reduce the need for manned flights over hostile territory.”[4]

Between WW1 and WW2, the “Reginald Denny series from Reginald Denny industries were the first drones produced on a large scale, around 15.000, and Northrop bought the company in 1936.”[5]

“In 1946, B-17 Flying Fortresses were transformed into drones for collecting radioactivity data during nuclear tests”[6]. “Decoy drones, such as the ADM-20 Quail, were developed during the Cold War to help manned planes fly safely into defended airspace.”[7] “The use of reconnaissance drones in the Vietnam War highlighted the main purpose of drones, then and now: to gather information.”[8]

It does not matter which type of drone we choose, they all have a common denominator: they accomplish a task that would prove time-consuming, costly, confusing, or even impossible for a human. We need to be sure to choose the correct type of drone for the selected task. When people talk about drones, they usually think of vehicles that are flown remotely (RPV). New apps/technology development is growing to allow communications of the many new unmanned service devices (USDs).

"We can divide into three main groups types of aerial drones:

1. Multi-rotor
2. Fixed-wing
3. Lighter-than-air

The most common drone configuration is multirotor that have four to eight rotors. The multi-rotor (a rotary wing) has been available for almost ten years, in part thanks to the development

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[3] Rshaffer. (2020, June 10). A short history of unmanned aerial vehicles (UAV). Consortiq. https://consortiq.com/short-history-unmanned-aerial-vehicles-uavs/
[4]Stamp, J. (2013, February 12). Unmanned drones have been around since World War I. Smithsonian Magazine. https://www.smithsonianmag.com/arts-culture/unmanned-drones-have-been-around-since-world-war-i-16055939
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[6] B-17 Flying Fortress. (2019, March 25). AIRMAN Magazine. https://airman.dodlive.mil/2019/03/25/b-17-flying-fortress/
[7] ADM-20 quail. (n.d.). Federation Of American Scientists – Science for a safer, more informed world. https://fas.org/nuke/guide/usa/bomber/adm-20.htm
[8] A brief history of drones. (n.d.). Imperial War Museums. https://www.iwm.org.uk/history/a-brief-history-of-drones

of always smaller, more powerful and affordable electronic components, also used in smartphones."[9]

It is an unstable and energy inefficient configuration, but it can take off and land vertically. The aeroplane (fixed-wing) configuration is much more efficient with greater endurance and range, but it needs space to take off and land. Airships (lighter-than-air) do not need airspeed to generate lift so they can fly almost indefinitely, but they are very weather dependent.

When we have a problem, there is a need for a particular technology, like many different technology markets, the drone industry is highly problem-driven. It has a significant advantage that it needs minor, relatively, adjustments to modify or forward the technology, compared to the classic development cycle, which can take years.

The computational power is miniaturised and is now less expensive as days go by. We can buy and connect pieces that already exist in the market. As the technology applied to drones and UAVs is becoming more and more accessible, is the reason for the fast-expanding market, and explains why we see drones now used in multiple industries like the use of drones in media, advertising, police work, firefighting, agriculture, construction, energy, transport, and more.

While drones are growing in multiple industries, as per this paper, we will focus on the construction that, like 2018, is seeing a 239% growth YOY. [5]

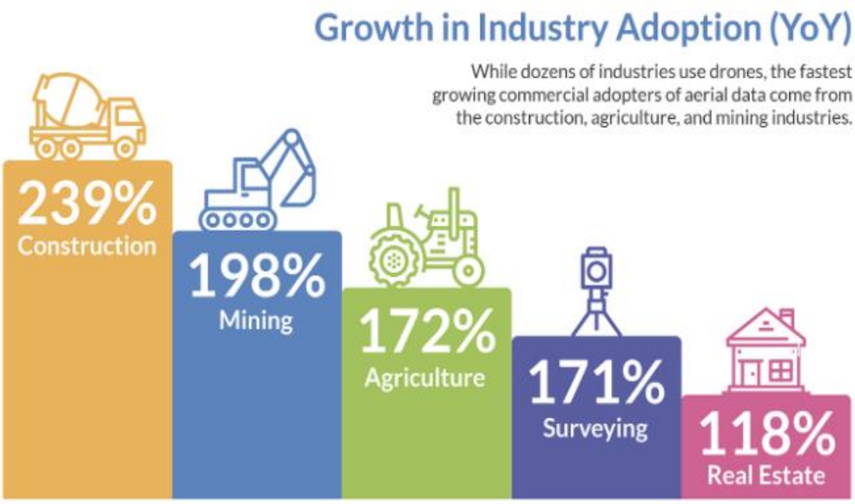

Figure 01: Drones growth in industry adoption YOY.[10]

[9] Types of drones: Multi-rotor vs fixed-wing vs single rotor vs hybrid VTOL. (2019, December 18). UAV. https://www.auav.com.au/articles/drone-types/

[10] Drones in construction: What does it mean for the industry? (n.d.). 27 Advisory – 27 Group are strategic nation-building consultants with a shared vision of rebuilding humanity. https://27.group/drones-in-construction-what-does-it-mean-for-the-industry/

As of today, still many construction companies consider the measurement of work in progress to be a complicated problem faced by project management. In construction projects, site managers usually spend a significant amount of time measuring, recording and analysing the progress of work. Is essential for many business and project management functions such as cost and schedule control, financial reporting, claims, and productivity measurement. For these functions to be reliable and valid, regular and accurate analysis is required.

However, there is often a lack of accurate and up to date as-built information due to the time consuming and expensive practice of manual data collection. In building construction, the average duration of activities is typically in the range of days or a few weeks [6], and the natural frequency of manual data collection and reporting is weekly and monthly. The absence of accurate and real-time as-built information handicaps the managers' ability to monitor schedule, cost, and other performance indicators. In turn, it reduces their ability to detect or manage the variability and uncertainty inherent in project activities.

Unmanned Aerial Vehicles (UAV) and drone usage have increased in recent years for surveying, facility management, and other relevant fields. The images obtained from drones and other imaging tools can be used for more practical and cost-effective operations in the areas of architectural engineering and construction management and monitoring. The critical challenge is to interpret the images and obtain relevant information.

Among the many applications, as per the below image [6], we will focus on the construction site management.

Figure 02: 20 possible usages of Drones.[11]

[11] 6 commercial drones 2019 application | UAV application today. (2019, September 22). Study Material Online. https://studymaterialonline.com/6-commercial-drones-2019-application-uav-applications-list/

Furthermore, what is BIM [4]?

Building Information Modelling (BIM) is a fully integrated model which follows the creation of a physical asset through its entire lifespan, from concept through design, construction, operations & maintenance through renovation and eventual demolition or repurposing. BIM is going to have a profound impact on the practice of project controls as the design databases are "hot-linked" to the CPM scheduling and cost estimating databases which means as the structure is designed and built in three dimensions, the CPM schedule, and cost estimate generated at the same time. While this will unlikely reduce the role the project control professional has played in terms of quantity take-offs and creating CPM schedules, it will open opportunities to create, update and manage the cost and productivity databases that are necessary to make 4D and 5D BIM work.[4]

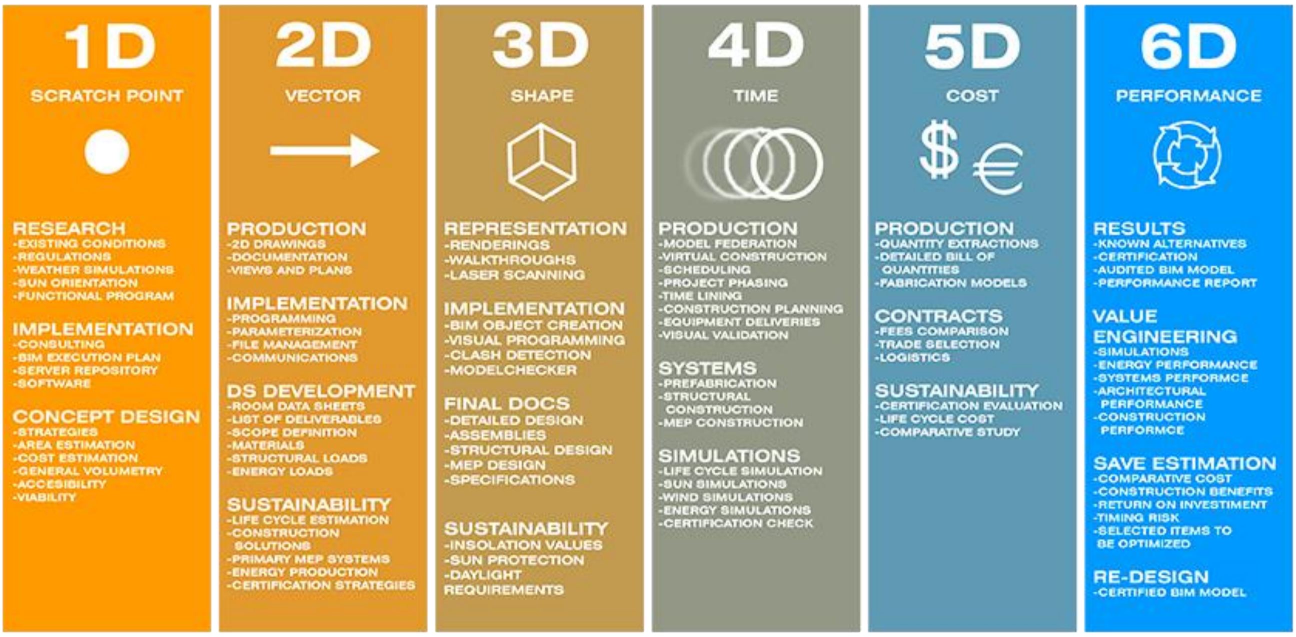

Figure 03: From 1D to 6D and impact on Project Controls.[12]

The objectives are to explore how this so-called "drone model" can be compared to the BIM model at various construction stages, to allow us to respond to the following questions:

A. What data can we capture with the drones to compare with our 3D/4D/5D/6D model?

B. What are the current limitations or constraints of using drones to capture data?

METHODOLOGY

Traditionally the approach for monitoring construction projects involves a strict execution of plans without the possibility of any last-minute modifications. The availability of accurate real-

[12] Scope of services. (2016, March 6). BIM6D. https://bim6d.es/en/scope/

time data, in this approach, (showing the construction progress) is limited. However, a smart monitoring system based on harmonised real-time data that is gathered with various innovative tools, e.g., UAV and drone-mounted sensors (photo/video camera, thermal imaging camera, and IR sensors, and others). This data is then analysed by using software that allows for better operations, planning, and adjustments (Figure 4). Some of the crucial applications of drones and UAVs in construction monitoring include the following.

A. 3D Map Creation [7]: Aerial monitoring provides data for 3D object creation and the area's orthophotography map. Continuous update of the data can be executed and archived as an online map for interactive viewing of the objects. Investors and clients can be provided more significant control over the work ongoing on-site with the latest information.

B. Aerial Photogrammetry & 3D Scanning of Construction Projects [8]: Aerial photo and video provide clients/companies with stunning visuals, such as look-ahead at the first stages of construction. All details of the 3D model can be easily accessed online by all parties.

C. Routing Construction Progress Monitoring [9]: even before the development of construction phases, we can agree on pre-set flight paths in the construction sites providing almost real-time visual progress reporting for site professionals, developers, stakeholders.

D. Volumetric Measurement: By utilising precise aerial photogrammetry over vast areas (both 2D and 3D), we can measure with an accuracy of a few centimetres, and can be done quickly and with cost efficiency, without creating disruption to the construction activities.

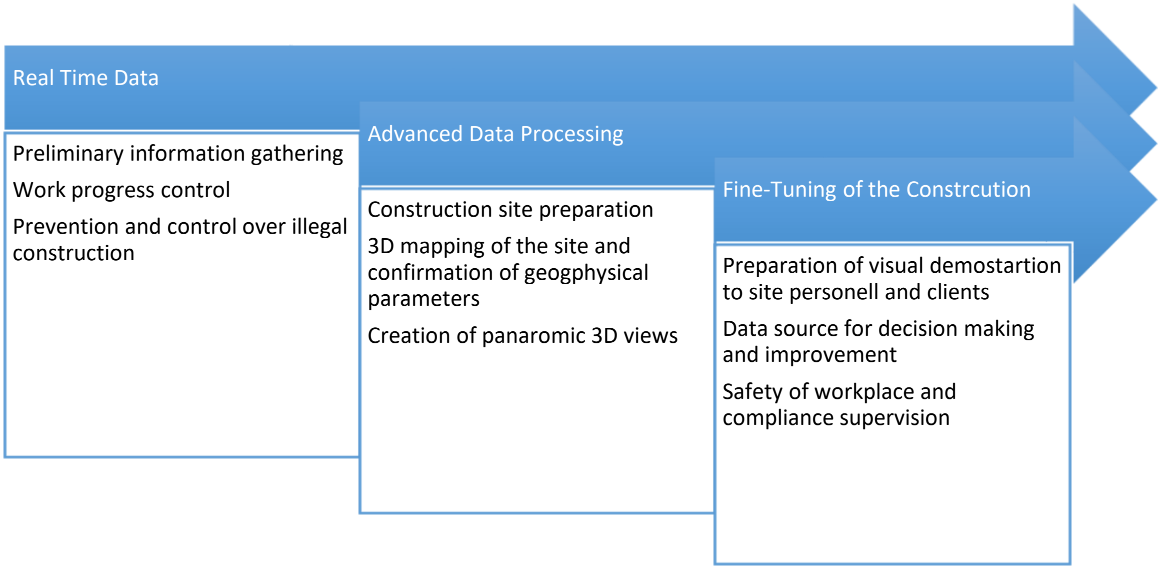

Figure 04: The main elements of a smart construction monitoring system using drones and UAVs.[13]

In figure 5, the detailed proposed framework of construction monitoring/reporting using drones and unmanned aerial vehicles (UAV). The high-resolution images and videos obtained with weekly, bi-weekly or monthly site visits allowing the engineers "to be always on-site". Only days are needed using UAVs, compared to weeks that it used to take. The images and videos done with drones can be done even before we start actually start construction and allow for better planning and optimisation, including safety measures.

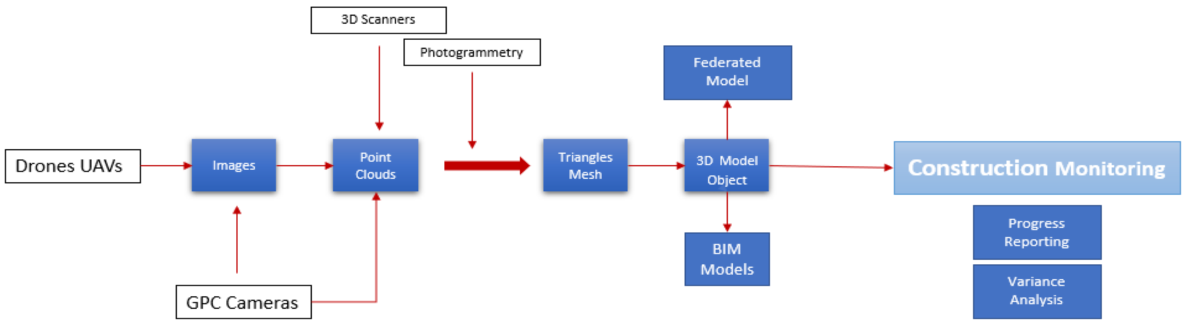

Figure 05: The overall concept of construction monitoring/reporting using drones and unmanned aerial vehicles (UAV).[14]

[13] Critical Elements of the intelligent construction monitoring system using drones and UAV's, by Author.
[14] The whole idea of construction monitoring/reporting using drones and unmanned aerial vehicles (UAV), by Author.

Once we obtained the data both from drones and UAVs, the data can then be analysed with different software to extract useful information for decision-making. The analysis of data has remained an exciting subject of research for more than a decade (Ham et al., 2016). In recent years, several image processing, computer vision, and geometrical processing techniques are developed which can generate semantically-rich 3D models by collecting overlaying images, or they can be applied to manually or semi-automatically conduct progress monitoring, surveying, safety inspection, quality monitoring, and activity analysis during the construction. Several of the presented techniques can be used to streamline the condition assessment in existing buildings and infrastructure systems [5].

Creating a 3D model of an object from the images is called 3D reconstruction. This process captures the 3D shape and appearance of real objects. We can use different on the market software that is capable of automatically extracting thousands of common points between images. Each specific point found in an image is called a critical point. Visual points are considered when two crucial points on two different models are found to be the same. Also, when we match a group of key points, we can generate one 3D point. The more we are able to have significant overlap between the two images, the common area captured is more meaningful, and therefore, we can establish a higher number of key points and match them together. The larger the number of crucial points, the higher is the accuracy of the 3D reconstruction, this requires to have a high overlap between the images. To prepare a 3D model of a structure, e.g., an under-construction building, the overhead images are not capable enough to capture the details on sides of the building. For this reason, orbital flights around the structure, capturing oblique imagery recommended improving the quality of the 3D model.

To have better managerial decision making and cost control tool, the 3D model can be utilised to provide on-time relevant information about the construction progress and process, see, for example, to monitor earthmoving activities. Comparing the volume between our BIM federated model and the model created with the drones images can be done at different stages of the project to better track progress, and this images can also be used for concrete quantities and to assess the accuracy of structural elements.

The comparison can be extended to include real-time recording, reporting, verification, billing, planning besides scheduling and costing. A fully automated system reduces in a significant way the effort required compared to a more traditional approach in progress monitoring and reporting in construction sites. The computerised system provides useful and smart ways of site management and supervision that also results in improved operations, planning, and active on-site adjustments.

FINDINGS

The presented approach of smart construction monitoring applied to a case study construction project of large retail construction in Europe, with the limitations of flight altitude due to the proximity of Linate Airport (LIN). The construction activities were continuously monitored using drones.

At several stages of construction, the drone flew a minimum of four times to capture various data with different height and camera angle settings. The data set is collected as follows:

- For the first data set, images are acquired with a camera angle at 0 degrees with a height of approximately 35 meters above the case study building height.
- The second data set obtained by flying the drone at approximately 25 meters from building height with the camera angle of 80 degrees.
- The third data set, the drone is flown again at the height of 35 meters from building height with an angle of 45 degrees.
- The fourth data set obtained flying the drone at a height of approximately 45 meters at an angle of 30 degrees.

After the completion of aerial photography, the collected data analysed to construct the 3D models. A software named "3DF Zephyr"[15] is used for 3D reconstruction. Once the 3D model is generated, it is exported in .obj (Wavefront) format[16]. This data is afterwards imported into REVIT[17] and overlaid with the actual REVIT models to compare different dimension of the buildings.

With this overlay, a variety of comparisons at different stages of the construction project were carried out. The below fig.06 shows the benefits obtained from the presented drone-based construction monitoring approach.

[15] 3DF Zephyr - la soluzione fotogrammetrica completa - Da fotografie a modelli 3D - 3Dflow. (2020, March 4). 3Dflow. https://www.3dflow.net/it/

[16] Chakravorty, D. (2020, March 6). OBJ file format – Simply explained. All3DP. https://all3dp.com/1/obj-file-format-3d-printing-cad/

[17] Revit | Software BIM | Autodesk Negozio online. (n.d.). Autodesk | Software per progettazione 3D, Ingegneria e intrattenimento. https://www.autodesk.it/products/revit

- Cost Savings
- Schedule Compression
- High Quality Design and Construction
- Completed Projects much more closely aligned with design intent
- Elimination of need for separate as-built drawings

Fig.06: Range of results obtained from the drone-based construction monitoring approach[18]

The volumetric comparison between construction plan/schedule and on-site progress for the selected case study project can be seen in fig.07, 08 and 09. The correlation between the BIM model (red colour) and drone model (green colour) shows the project progress. Various benchmarks and targets can be set, and the project can be routinely monitored with reasonable accuracy. Similar comparisons can also be made at different stages of the project.

As an example, Figure 8 shows an example quantity comparison for the placement of bathrooms. The comparison indicates that all bathrooms are on schedule. Similarly, Figure 9 shows an example schedule comparison for the installation of windows in the case study project. The comparison shows that the placement is delayed by schedule. This case study application reflects the effectiveness of the presented approach for smart monitoring of construction projects.

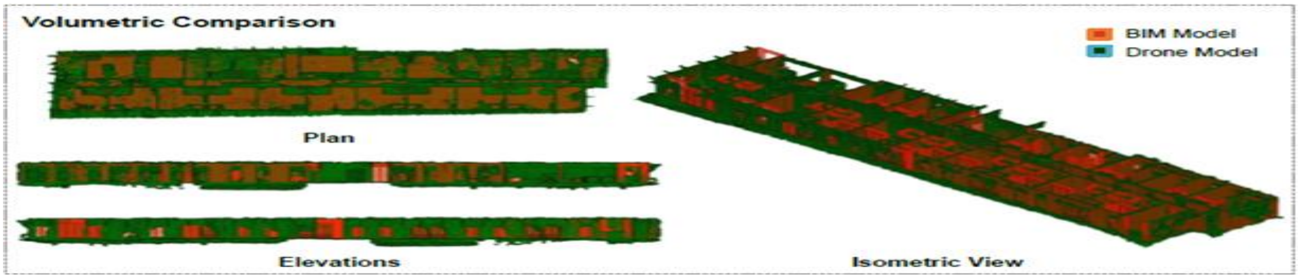

Fig.07: The volumetric comparison between construction plan/schedule and on-site progress[19]

[18] Range of results obtained from the drone-based construction monitoring approach, Author
[19] The volumetric correlation between construction plan/schedule and on-site progress, example

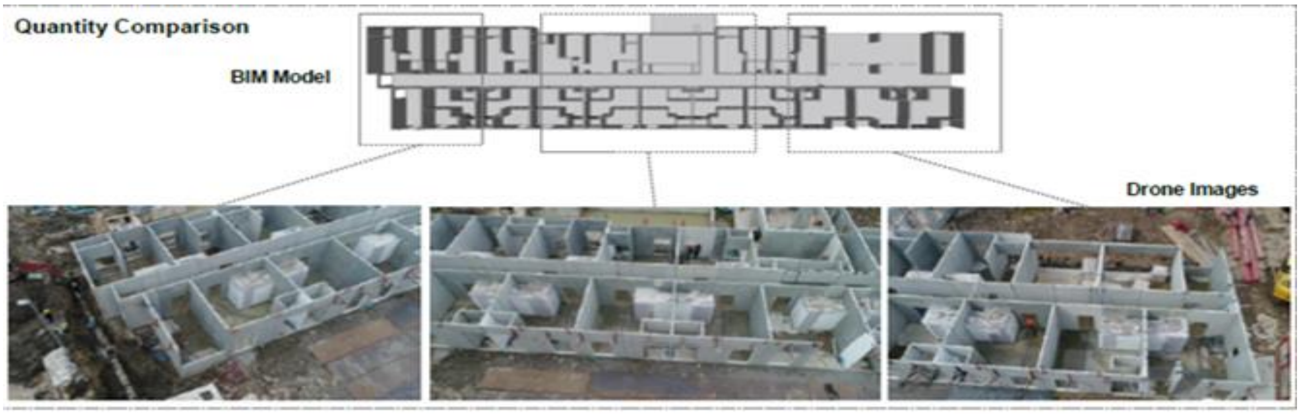

Fig.08: An example quantity comparison for the placement of toilets[20]

Fig.09: An example schedule comparison for the case study project – The placement of windows is delayed by schedule[21]

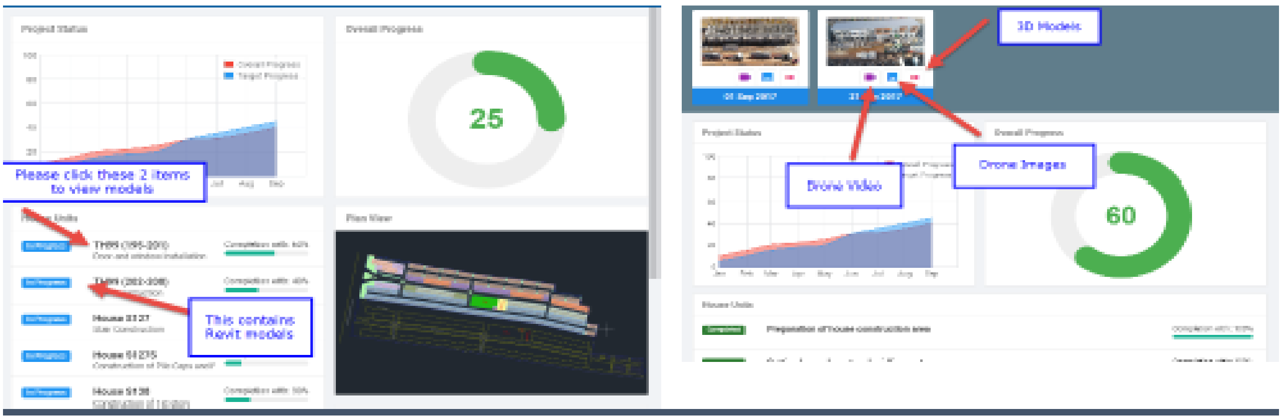

Fig.10: An example of automatic reporting[22]

[20] An example quantity comparison for the placement of toilets, example
[21] An example schedule comparison for the case study project – The installation of windows, example
[22] for the case study project, example

To compare the accuracy and reliability of the presented technique, it was applied to four other case studies of similar nature, and the results were compared with actual data. The dimensions of case study buildings were measured and then compared with the 3D drone models. It is observed that the drone 3D models are reasonably consistent in shape and geometry of the actual buildings.

Due to limitation if the operation of drones, see weather conditions, obstacles and others, in some cases, there can be certain types of errors due to data source, quality of data, the height of the drone, the angle of the camera while capturing the images and the construction methods. In this real project, the mean error in the control point measurements for four tested cases was found to be less than 0.08 meters.

CONCLUSIONS

The framework development presented in this paper for a fully automated smart construction reporting and monitoring system based on real-time data obtained from UAVs and drones. The current progress in technology both in navigation and design of autonomous and low-weight UAVs and drones can be efficiently used in a dynamic manner to result in more practical and cost-effective operation in the fields of construction management and monitoring. In the presented approach, the data in terms of drone images from multiple locations and point clouds (from 3D scanning of the construction site) can be used to construct 3D models using the photogrammetry techniques. The models created with drones can then be compared to the original BIM model at various construction stages to monitor the construction progress. This comparison can be extended to include real-time recording, reporting, billing, verification, and planning, besides construction scheduling and costing

We used the example of a retail construction project; the effective use of drone data is demonstrated in terms of smart construction monitoring and comparisons between drone model and BIM model. A fully automated system reduces the effort significantly compared to more traditional construction and reporting procedures. The obtained system provides useful and smart ways of site supervision and management but also results in better operations, planning and effective on-site adjustments.

FOLLOW ON RESEARCH

Further research is ongoing to expand the field of applications to billing, verification and planning.

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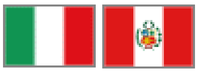

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