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CONSTRUCTION PROJECT CONTROL AND MONITORING WITH THE INTEGRATION OF UNMANNED AERIAL SYSTEMS WITH VIRTUAL DESIGN AND CONSTRUCTION MODELS

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Abstract: This research investigates the process of integrating the use of Unmanned Aerial Systems (UAS) and BIM 3D models in construction project management control.
This project was conducted on a recreation facility construction site for progress monitoring and reporting. Data and information was first captured using UAS. Aside from the visuals illustrating construction progress report, a model integrating the "as planned" 3D model with the captured data is being developed to regenerate the "As Built" model to ultimately enable construction progress monitoring. This paper introduces the processes used and demonstrates some of the models being generated.
The impacts and value and current limitations of integrated innovative systems UAS-BIM on construction management project will finally be discussed.

1. INTRODUCTION

One of the challenges for the construction industry is the fact that it remains one of the least efficient industries in the world. The reasons are numerous but primarily almost every building that we build is still a one off design, constructed piece by piece on site. Inefficiencies can also be measured throughout the construction project from the initial procurement and bidding through to design and construction. In Canada, overall productivity across industries has increased on yearly basis over the past 10 years, whilst construction productivity in accordance with the definition by Statistics Canada has declined. One of the key factors that were identified for the construction sector was the limited investment (input) in innovation and technology (Oudjehane 2014). The $8.5 trillion global construction industry isn't exactly known for its efficiency. The U.K. Green Building Council estimates that 15% of materials delivered to construction sites end up in landfills, the result of mismanaged scheduling and purchasing. The American Institute of Architects believes building-related waste makes up anywhere from 25% to 40% of America's solid-waste stream. With construction spending in the U.S. totaling $1.13 trillion in 2016 those losses add up to more than $160 billion in waste—and that's just in America.(Dillow 2016).

Current trends in construction indicate what may be considered disruptive technology being adopted and implemented by the construction industry (Higgins 2015). In 2016, the top ten trends for construction in (The Kore Company 2016) included Building Information Modeling 3D and 5D as the top 2 cutting edge technologies to innovative construction, decision making and project management.

Automated robotics and UAVs were respectively ranked 7th and 8th amongst the top 10 innovative trends that were to disrupt the construction sector.

Building Information modelling also known as BIM and often also referred to as Virtual Design and

Construction VDC, was introduced as a conceptual model in the mid-60s (Kimmel 2008). The concept (Engelbart 1965) suggested object based design, parametric manipulation and a relational database; which was developed much later into a visual display of conceptual design. Integration of BIM in construction has significantly grown over the last 10 to 15 years. BIM has firstly extended the traditional 2D (planar) technical drawings (plans, elevations, sections, etc.) to a 3D design and furthermore adding time to the three primary spatial dimensions (width, height and depth) to what is defined as a BIM fourth dimension (4D). With cost as the fifth dimension, BIM 5D thereby provides the key attributes of a construction project. Often BIM 4D is what allows for the visual animation of projects, but fundamentally it enables progress tracking of construction projects.

For the construction industry, the case for return on investment is straightforward when it comes down to drones. Unmanned Aerial Systems or UAS also called drones are cheaper to fly than manned aircraft and faster than human surveyors, and they collect data far more frequently than either, letting construction workers track a site's progress with a degree of accuracy previously unknown in the industry. With the right computing tools, captured data using UAS can be converted into 3D structural models, topographical maps, and volumetric measurements (useful for monitoring stockpiles of costly resources like sand and gravel). Collectively, that intelligence allows construction companies to more efficiently deploy resources around a construction site, control and trim costs, and delays.

Adoption of UAS just like using BIM in construction projects has a direct impact on productivity as described above. The purpose of this paper is an introduction to the integration of a BIM 3D model with Unmanned Aerial System (drone) technology in order to provide a comprehensive real time tool for project monitoring and control.

2. THE CONSTRUCTION PROJECT

The construction project used for the testing of the integration of Unmanned Aerial Systems with a 3D BIM model was the Rocky Ridge Recreation Facility in the Northwest part of Calgary. The construction of the facility is well under way with completion expected by the end of 2017 and for an opening in 2018. The proposed Rocky Ridge Recreation Centre will have 3000 sq ft of library space, gallery and art making space, 300 seat theatre, outside nature trails, three full size gyms, pool, ice rinks, gym, running track, and a skateboarding park. The project is contracted to PCL Inc. and to be operated by YMCA is expected to cost $191Million.

Figure 1. The Rocky Ridge Facility in Calgary (The City of Calgary)

The uniqueness of the project design added to some of the innovation adopted for this construction project.

3. THE PROCESS

For the purpose of this study, monitoring of the construction site was initiated in the fall of 2015. Although the project was initiated as an applied research, and validation for the multiple applications of UAS in construction, the delivery and execution of our on-site test and data capturing was planned and designed to simulate progress reporting around tangible milestones rather than schedule driven work progress reports.

The flight operations were used to capture data that was afterwards processed using PI4D software to generate a 3D model of the “As Built”. A 3D BIM design model was also used for the purpose of validation and comparison. The flowchart below describes the main framework for the process used to carry out the integration of BIM with UAS.

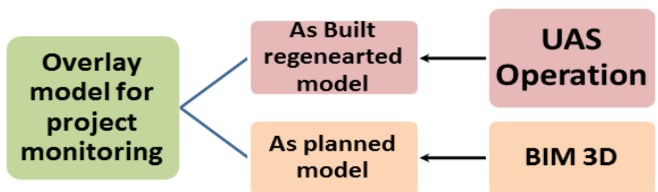

Figure 2. Process of BIM and UAS Integration

The following is a description of the process used to capture data using an Unmanned Aerial Vehicle. .

3.1. The Unmanned Aerial System

The classification of UAS is based on the military standards. The same has been adopted for civilian UASs. Civilian UAVs are hence classified into: a) fixed wing, and b) multirotor or multicopter. Each UAs class has its unique design, operability and advantages and disadvantages which are briefly presented below. (Arain and Moeini, 2016)

Like most weather dependent and sensitive outdoor operations the use of UAS can be challenged by extreme weather conditions. At the initial phase of the project an assessment of the most suitable UAS was conducted. The pros and cons of cons of both fixed wings and multi rotor were weighed.

Based on the fleet of drones available at the UAS Lab within the Southern Alberta Institute of Technology, the following types were considered.

3.1.1 Fixed wing

Three fixed wing UASs have been first considered and shortly tested: a) Modified long range Skywalker X8; b) Modified long range Talon ; c) Modified long range Skywalker X6

Fixed wing UASs have a simple and aerodynamics structure consisting of different type of wings such high wing, mid wing, low wing and flying wing, connected to the main fuselage. Fixed wing UASs have long flight time capacity(depend on the type of UAS) within both visual and beyond visual line-of-sight (VLOS & BVLOS) to cover long distances and large operational areas such as road and pipeline construction sites in a single flight. Fixed wing UASs are suitable for the rapid creation of aerial orthomosaic and visual monitoring of the project site. These UAS platforms offer a perfect platform for real-time accurate visual assessments of the linear project site and enable the construction managers to monitor and capture the large project sites in a timely manner (Arain and Moeini, 2016).

3.1.2 Multirotor or multicopter

Three types of multi rotor UASs were also explored and these were: a) Modified DJI 1000 multirotor UAV: b) Modified DJI Inspire 1 multirotor UAV; c) Modified DJI Pahnotm 4 multirotor UAV .

In spite of the non-aerodynamic complex structure of multirotor UAss, the ease of operation and control of the systems renders the multi rotor UAS as the most suitable platforms for non-linear construction sites. Multirotors have a lower speed and much shorter flight time (maximum 30-40 minutes) than fixed wing UASs. As a result, the quality and accuracy of the images captured by multirotor UASs are much higher.

The main advantages of multirotor UASs are the Vertical Takeoff and Landing (VTOL) and capability to hover and perform agile maneuvering in small spaces. Multirotor UASs are suitable platforms to monitor and inspect urban facilities construction sites such as bridges, power plants (fossil or nuclear fuel based), municipal buildings, hospitals and emergency centers (Arain and Moeini, 2016). These types of UAVs are also able to carry different types of sensors as multi spectral, LIDAR, and FLIR for more advanced analysis, modeling and monitoring of the construction sites. Multirotor UAVs enable the building inspectors to assess the building situation and define the possible damages with high level of accuracy and in a timely manner (Arain and Moeini, 2016).

The picture below illustrates the platform that was used following a preliminary assessment of the various of UAS platforms currently available..

Figure 3. Modified DJI Phantom 4 multirotor UAV

The Phantom 4 UAS platform has the following characteristics: Type of motor: Electrical motor: Diameter : 0.4 meters; Maximum flight time : 30 minutes; Maximum coverage distance: 3 to 4 km; Payload: Only can carry the built-in camera; Control: Remote Control and Autopilot; Required operational skill: Moderat

Itis on the basis of these key characteristics and the advantages of multirotors, in conjunction with the site constraints, location and size of the project that the multirotor UAS platform, as shown in Figure 3, was chosen as the suitable platforms for this project to capture and create the aerial orthomosaic of the site.

3.2. Data Capturing

On a monthly basis the research team used UAS to take aerial photos of the construction site. The UAS consists of a Multirotor drone with a high definition camera installed on a gimble. The flight path and frequency of photo capturing was determined on the basis of 80% overlap between adjacent captured photos. Global Positioning System (GPS) was used to geolocate the captured images. The camera orientation was also recorded for each image. Part of the optimization processed included for data capturing included testing for various camera orientations.

3.3. Data Processing

The captured photos were imported into Pix4D, a photogrammetry software. The software was used to generate 3D point cloud model from the captured photos. The geolocation and camera orientation of each picture and camera specifications was used to calibrate the photos inside the software. The image below shows the calibrated camera positions in green and the initial camera positions (GPS coordinates) in blue. Depending on the number of images used the time to generate the 3D point cloud model varies. It took about two days to generate the model in the images shown below.

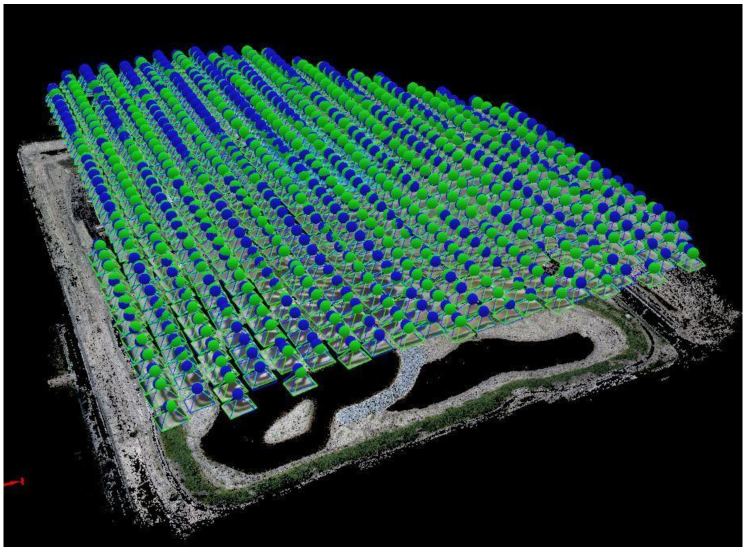

Figure 4 Image coordinates calibration

The images from Figures 5 and 6 respectively illustrate:

- the state of the construction as captured;
- the point cloud model generated

Figure 5. As built image

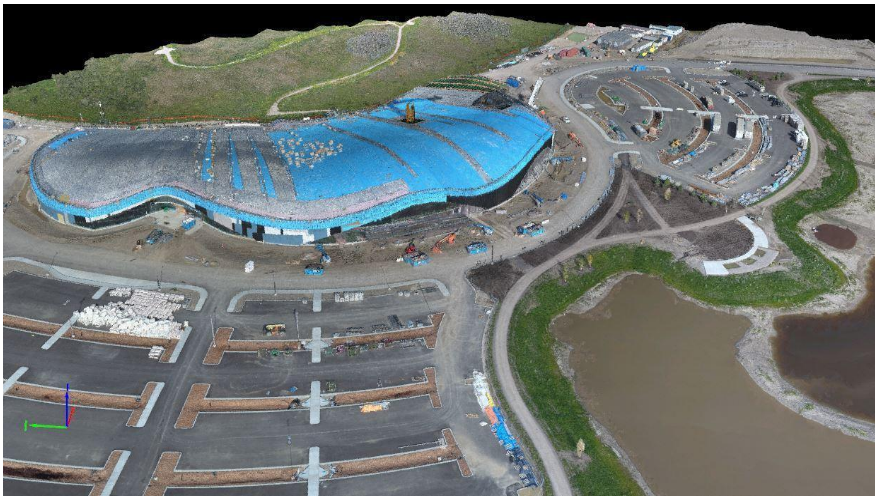

Figure 6. Point cloud and regenerated image

3.4. The BIM Model

The BIM model used included all substructure, superstructure and building envelope components. The components are located in the exact as-built position.

4. Model overlay

The as-built Point Cloud model was manually overlaid over the BIM Model using Autodesk Naviswork, a 5D BIM simulation and analysis software. The point cloud and BIM models were compared visually. The comparison showed a good match. The image below compare in green the completed beams to the beams in the BIM model as shown in yellow.

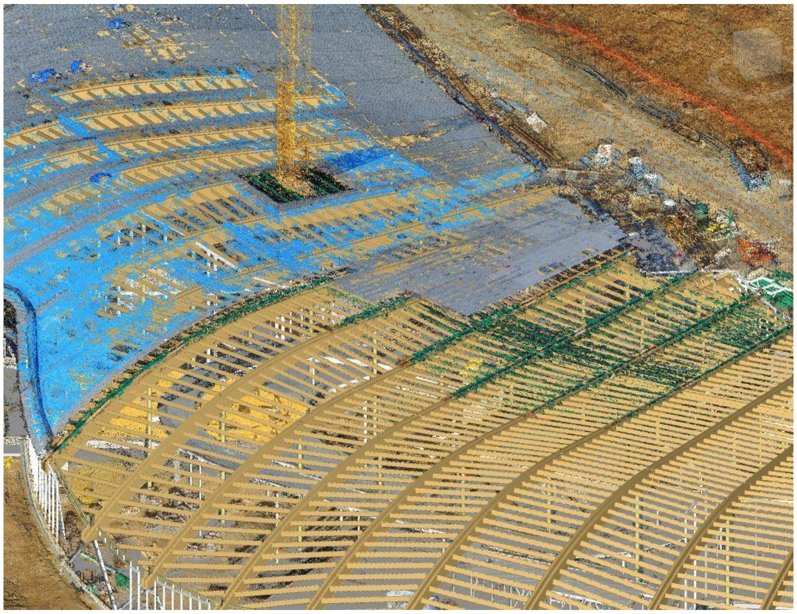

Figure 7. Overlay between “as built” and “as planned” model

5. DISCUSSION

Photogrammetry can be used to generate a relatively accurate 3D Cloud Point Models that can be used in construction monitoring.
In this context, the process used to compare the as-built Point Cloud Model to as planned BIM model was manually conducted on a step by step and thereby lengthy. There is hence a need to automate it to allow for an optimized and real time project monitoring and control.

Recently developed software introduced the option to automatically overlay photo based on as-built cloud point model to 3D BIM or CAD Models. While the software can help minimize the time and effort to overlay the models, visual inspection and comparison is still manual.
In order to maximize the benefits of using UAS system in monitoring construction progress the comparison process should become automated. To achieve this automation the BIM should be used to classify the point cloud model. in most cases, the as-built cloud model is imported as a background in a 3D modeling or BIM software, and the user manually traces 3D geometries over the scanned model. While this process is suitable for developing accurate as-built 3D models, using it for construction project monitoring is cumbersome and inefficient.

It is however possible to use BIM models and compare the geometry of each components in a BIM model to the as-built cloud point model. If a group of points fall within a defined distance from a component (e.g. beam), these points can be classified to be this competent.
If schedule is linked to the BIM model (4D) it is possible to automatically identify which components of the project are completed since the as-built model will have these components. Missing components in the as-built model that are expected to be completed according to the schedule can be identified as an incomplete task.
If cost is also added to the BIM model elements (5D) it is possible to calculate the cost of completed components.

Opportunities to integrate BIM with UAS for project monitoring do exist and have been demonstrated in this paper. However, using a 3D model to compare planned BIM model to as-built cloud point model limits the validation of the effectiveness of such process.
An automated process or algorithm for comparing the 2 models should enable effective integration of captured data into construction project monitoring.

6. ACKNOWLEDGMENTS

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