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APPLICATIONS OF BIM AND UAV TO CONSTRUCTION SAFETY

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Abstract: Building information modeling (BIM) and unmanned aerial vehicle (UAV) have shown a potential to improve construction safety performance. As new technologies, they are in an early adoption stage in the construction industry. It is still not clear what is the application status of UAV to construction safety or how BIM and UAV are working together to serve as a safety inspection tool. Therefore, this paper conducted a preliminary literature review to identify the current research and application status of BIM and UAV to construction safety. It was found that there are two approaches in the literature in terms of using UAV and BIM for construction safety. In approach 1, UAVs are used to collect geometric data of construction sites to visualize current site conditions in BIM, based upon which potential safety issues can be identified. In approach 2, BIM with the aid of experienced safety experts can provide potential safety hazard locations, and then flight routes of UAVs can be generated accordingly. In the end, this paper proposed a loop system integrating approach 1 and 2.

1. INTRODUCTION

Construction safety performance has improved substantially in the past four decades. For example, the fatality rate in the US construction industry decreased from 23 per 100,000 workers to 10 per 100,000 workers between 1980 and 2016 (BEA 2017, BLS 2017). However, a plateau in the reduction of safety incidents has recently been reported in several countries, such as US and Canada. An example of this plateau is shown in Figure 1, where the fatality rates of the US construction industry have been stable in the past decade (Mean ± SD: 9.21 ± 0.61).

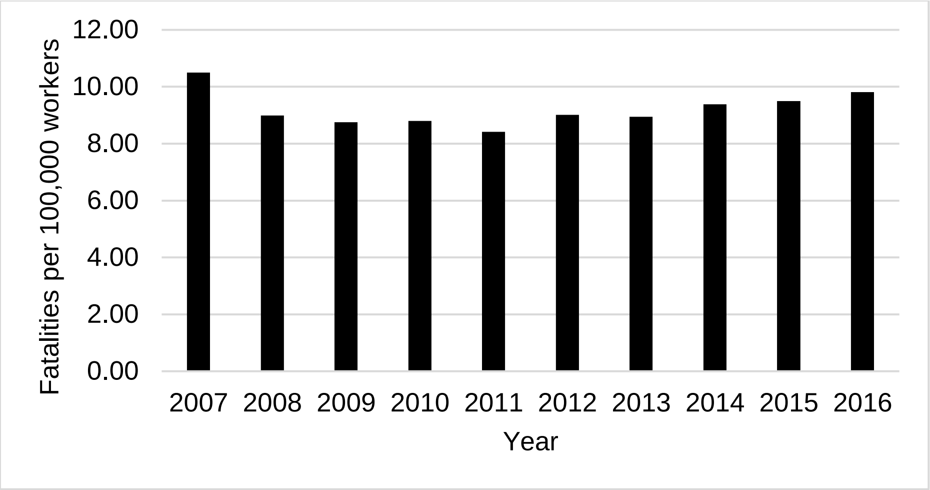

Figure 1: Traumatic fatality rate per 100,000 workers of the US construction industry 2007 to 2016[1,2]

[1] (BEA 2017)
[2] (BLS 2017)

To overcome this plateau, it is necessary to find new approaches. Building information modeling (BIM) and unmanned aerial vehicle (UAV) have shown a potential to improve construction safety performance. As new technologies, they are in an early adoption stage in the construction industry. Some researchers already did a review on the BIM applications to safety (Martínez-Aires et al. 2018). However, it is still not clear what is the application status of UAV to construction safety or how BIM and UAV are working together to serve as a safety inspection tool. Therefore, this paper conducted a preliminary literature review to identify the current research and application status of BIM and UAV to construction safety.

The paper is organized as follows. Section 2 introduced BIM and briefly discussed its application to construction safety. Section 3 introduced UAV and briefly discussed its application to construction safety. Section 4 discussed the existing research studies applying both BIM and UAV to construction safety. Section 5 proposed some future directions.

2. BIM AND CONSTRUCTION SAFETY

2.1. BIM

Building information modeling (BIM) is playing a significant role in the architecture, engineering, and construction (AEC) industry. BIM simulates the construction project in a virtual environment which results in an accurate virtual model of a building, i.e., building information model (Azhar 2011). A building information model is “the digital representation of physical and functional characteristics of a facility” (Natuonal Institute of Building Sciences 2015). It characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedule (Azhar 2011). BIM is also extended to 4D BIM that is a process of intelligently linking a 3D digital model with the schedule related information; or a 5D BIM that has additional cost information compared to 4D BIM.

2.2. BIM Applications to Construction Safety

BIM can serve in many areas of the entire life cycle of a facility. For example, the collision issues between existing underground utilities and new buildings can be avoided in the project planning stage by applying BIM and laser scanning techniques; in the preconstruction stage, building information models enable contractors to perform a fairly accurate quantity takeoff and prepare detailed estimates (Azhar et al. 2015). For safety management, although BIM has shown a great potential to improve construction safety performance, it is still a new area. Zhang et al. (2013) have done a pioneer work by applying BIM to the construction safety area. In their work, a rule-based checking system that automatically analyze a building model to detect fall related safety hazards was developed, and corresponding preventive measures based on Occupational Safety and Health Administration (OSHA) requirements were applied in an automated approach.

However, there are several challenges in implementing BIM to safety. First, construction sites are dynamically changing. How can we retrieve the dynamically changing job site information and update 3D models in a real-time manner (Martínez-Aires et al. 2018)? What kind of cost-effective techniques can we reply on? Second, how to automatically identify potential safety hazards? Current practices are manual focused, which is based on construction workers' previous experience. Third, safety regulations vary across countries. OSHA in the U.S. has strict definitions of items and corresponding safety requirements. For example, OSHA defines a hole as "a gap or void 2 inches (5.1cm) or more in its least dimension, in a floor, roof, or other walking/working surface" (OSHA's construction fall protection rule, 29 CFR Subpart M §1926.500), and "Each employee on a walking/working surface (horizontal and vertical surface) with an unprotected side or edge which is 6 feet (1.8 m) or more above a lower level shall be protected from falling by the use of guardrail systems, safety net systems, or personal fall arrest systems. (OSHA's construction fall protection rule, 29 CFR Subpart M §1926.501(b)(1)). On the contrary, UK, Australia and New Zealand have performance-based safety regulations, which means that contractors themselves determine construction methods and safety actions as long as they meet the safety goals of the government. Considering these challenges, Zhang et al. (2013)'s work has two major limits, i.e. only applicable to static construction sites and only applicable to the U.S.

3. UAV AND CONSTRUCTION SAFETY

3.1. UAV

An unmanned aerial vehicle (UAV) refers to a pilotless aircraft, a flying machine without an onboard human pilot or passengers (Valavanis and Vachtsevanos 2015). It is often used interchangeably with unmanned aerial system (UAS). Drone is another common name of UAV. Generally, a UAV has two physical parts: aircraft and remote controller. For example, the aircraft of DJI Phantom 4 Pro has GPS, propellers, motors, and front LEDs, etc.; and its remote controller has display screen, control stick, and return home button, etc. (DJI 2017). Other systems can also be mounted onto drones, e.g., laser scanners with Light Detection and Ranging (LiDAR) system.

3.2. Application of UAV to Construction Safety

UAVs have been applied to many areas, e.g. military defense, survey and mapping in urban planning, and conservation of endangered spices, etc. The application of UAVs to the construction industry has been slow (Mosly 2017). It just started to become a hot topic in the past 7 or 8 years. Potential applications of UAVs in the construction industry include monitoring construction activities, site surveying, visual inspection of hard-to-reach locations, safety inspection, interactions with workers, and defect and damage detection, etc. (Asnafi and Dastgheibifard 2018, Ham et al. 2016, Li and Liu 2018, Mosly 2017). In addition, a recent study by Opincar (2017) tried to answer a question, i.e., whether general contractors can benefit from the use of UAVs in the construction process, especially for data acquisition. But Opincar (2017)'s results seem hard to answer the proposed question, given that one of his conclusions is "there does seem to be an interest, and a curiosity to see if the industry will latch itself onto the UAV as a main player of data acquisition."

Regarding safety applications, Irizarry et al. (2012) conducted a usability assessment study of UAVs as safety inspection tools, and they proposed that an ideal UAV for construction safety inspection needs to have the following features: autonomous navigation, vocal interaction, high-resolution cameras, and collaborative user-interface environment. UAVs were also used to count the number of hardhats in different images of the site (Irizarry and Costa 2016).

In a more recent work, Melo et al. (2017) developed a three-stage approach to adopting UAVs for safety inspection on site. These three stages are target planning focused on identifying potential safety hazard areas based on workers' experience, image collection by UAVs, and image Analysis focused on qualities of images and safety rules checking. Their work showed that the application of UAVs for safety inspection on site was useful, especially from the perspective of the increase of transparency of unsafe conditions.

4. THE INCORPORATION OF UAV TO BIM

This section discusses several pioneer works conducted to incorporate UAVs into BIM for construction safety management. Generally, the existing research studies can be categorized into two groups depending on the approaches. In approach 1, as shown in

Figure **2** A), UAVs are used to collect geometric data of construction sites to visualize current site conditions in BIM, based upon which potential safety issues can be identified. In approach 2, BIM with the aid of experienced safety experts can provide potential safety hazard locations, and then flight routes of UAVs can be generated accordingly (

Figure **2** B). Since both of these two technologies are relatively new for the construction industry, there are only a few papers that mentioned one of these two approaches. The following subsections discusses the research studies using approach 1 and 2, respectively.

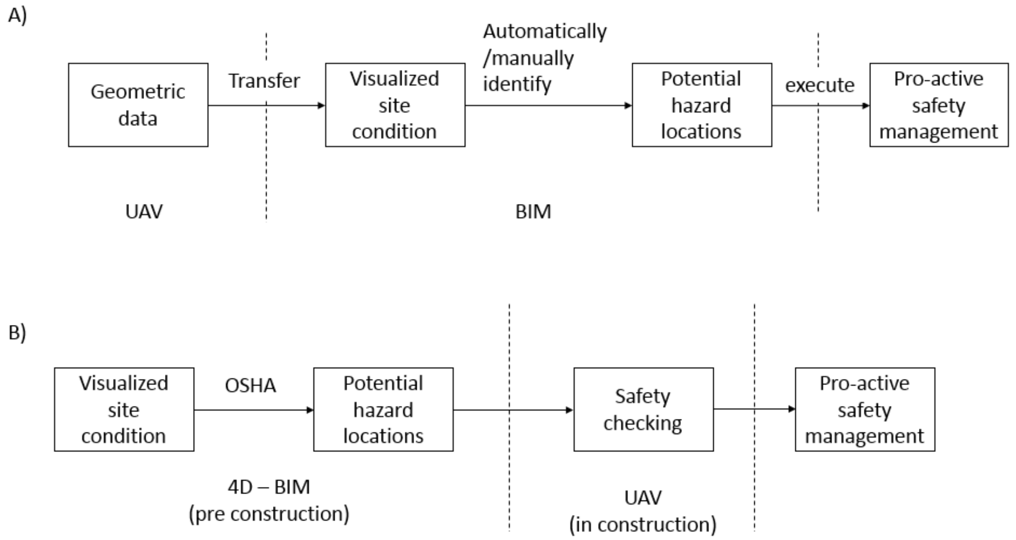

Figure 2: Schematic architecture of the existing BIM/UAV systems: A) approach 1, UAV is used to collect images for geometric data (adapted from (Zhang et al. 2015) and (Melo et al. 2017)); B) approach 2, UAV is used to collect image for safety checking (adapted from (Asnafi 2016))

4.1. Approach 1

With the development of UAVs and digital camera systems, the accuracy of geometric measurement of UAVs has become robust. For example, Siebert and Teizer (2014) used an automated UAV to survey three earth piles and compared the obtained data with GPS data. The average area error is approximately 10%. Therefore, some research studies have been conducted to use geometric data collected by UAV systems to visualize current site conditions in BIM.

In 2015, Wang et al. (2015) proposed a semi-automated method to detect potential fall and cave-in hazards at the excavation stage. A building information model was established in three steps based on the 3D data and related safety regulations. First, based on safety rules and regulations from OSHA, they summarized fall risk criteria. Second, they used laser scanning to generate 3D point cloud data of excavation pits. In the end, an algorithm was employed to determine the excavation depth (i.e. whether it is greater than 1.83 m) from the 3D data, and to identify potential hazard location. In this paper, the authors reported that UAVs can also be used to collect geometric information and to generate 3D point cloud data with mounted systems, such as LiDAR system.

In the same year, Zhang et al. (2015) firstly reported to use geometric data collected by a UAV system to visualize current site conditions in BIM for the construction safety management. They developed a building information model that aims to proactively enhance construction safety by construction site planning. A UAV as one of the remote sensing technologies was used to obtain the geometric information of the construction site. The UAV is also used to correlate the worker's position (acquired by GPS) with the structure position generated by the building information model. After that, the geometric information was automatically analyzed by workspace modeling technologies to visualize workspace on a building information model platform. As a result, the BIM platform can be used to identify potential workspace conflicts, and corresponding adjusted strategy was proposed to avoid these conflicts. In addition, the high-resolution image taken by the UAV was used to correct the data collected on site in the BIM, and to manually identify potential safety issues.

Later, Melo et al. (2017) reported a similar research. They used images acquired from a UAV to generate a BIM that shows the present stage of construction, and then the BIM can be used to design safety planning and establish a safety system. They used a UAV to survey an educational building under construction. Based on the data acquired from the UAV, a good quality and level of detail of BIM was established. Then, the corresponding safety analysis was performed. The authors pointed out that the detail of BIM highly depends on image quality of UAV.

4.2. Approach 2

The advantages of UAVs, e.g., small size, make it possible to perform safety inspection in dangerous locations which are difficult for safety professionals to access. At the same time, 4D BIM (3D BIM model enhanced by scheduling information) can provide a more direct view of potential hazard locations in each construction stage. Hence, the second approach has been proposed by several researchers.

For example, Asnafi (2016) and Alizadehsalehi et al. (2017, 2018) firstly reported to use UAVs to monitor the potential hazard locations identified with the aid of BIM. They developed a framework, which involved 4D BIM based model, safety regulations, UAV-based safety inspection, dynamic data and the analysis of project safety. Their safety framework consisted of two parts: pre-construction and construction stage. At the pre-construction stage, the framework used the 4D BIM to simulate hazards on the site. At the same time, the safety rules extracted from OSHA were employed to the 4D BIM. So that, the potential hazards and their location can be identified and then eliminated by prevention methods. At the construction stage, the UAV can be used to monitor and control construction safety rules. The safety managers can compare the UAV images with the 4D model developed at the preconstruction stage to verify that the potential hazards locations are under control and the prevention methods are effective.

In addition, BIM can be used to design the flight path of UAVs in safety inspection. For example, in 2015, Freimuth and König proposed a system to survey construction sites using a semi-autonomous UAV, where 3D buildings and site models were generated using aerial images. In their system, a UAV was employed to take images which were used to generate dense point cloud data for the 3D model. The waypoints of the UAV were determined by the locations of survey jobs, survey purpose and building element types, which can be generated from BIM. The UAV then took necessary images based on the generated waypoints. Although the authors did not mention in their work, this system could be used to the normal safety inspection. The safety issues of UAVs on construction sites is also essential. Freimuth and König (2015) used the BIM to automatically calculate the safety distance between the UAV and all objects in the operation.

To summarize, UAVs can benefit BIM in all the three stages of construction, i.e., pre-construction, construction and post-construction stages. The fundamental function of UAVs is surveying in these stages, but the applied targets are different. In the pre-construction stage, the targets are focused on the site and surrounding buildings. UAVs can collect the site and surrounding buildings' information. This information can be used to generate a 3D model that can be used for pre-construction safety planning. During construction, the targets are focused on the potential safety hazard sources or locations. Based on pre-construction safety planning, UAVs can inspect the potential hazard sources. If there are safety incidents happening, UAVs can be used as early warning systems. In addition, images taken by UAVs can be used to correct the BIM with real site safety condition. By updating 3D building model and conducting safety rules checking, a new safety planning can be proposed. For the post construction stage, the targets are focused on the finished buildings. For example, to assess the conditions of buildings, UAVs can take the images of the dangerous parts of building. In this progress, the BIM is an ideal approach to design the waypoints of UAV.

Meanwhile, UAV can be assisted by BIM from the design of safety waypoints, which results in the semi-autonomous and fully autonomous UAV safety inspection.

5. LIMITATIONS AND FUTURE DEVELOPMENT

Yang et al. (2018) summarized some potential issues of applying UAVs to sites, including camera functioning, performance, battery power, implementation cost, cost effectiveness, compensation, distracting workers, accidents, issues in adapting to the system and privacy issues. In addition to these common issues, there are some limitations of the existing UAV/BIM systems.

The most important issue is that there is not a system integrating the functions of geometric survey, potential hazards identification, and potential hazard locations' inspection. As mentioned in the previous section, some research studies focused on the functions of geometric survey and potential hazards identification, while some research studies focused on the functions of potential hazards identification and potential hazard locations' inspection. However, there is not a UAV/BIM framework integrating these three functions. Figure 3 shows a loop system integrating approach 1 and 2. It works similarly as the approach 2. The difference is that once inspection is done, the geometric data collected by UAVs may be used to correct the 4D BIM model to get an accurate model for the next construction stage.

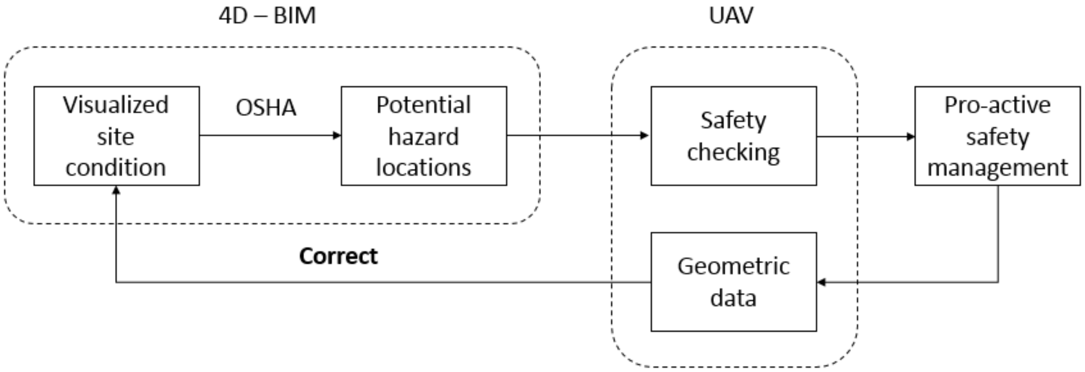

Figure 3: Schematic architecture of a BIM/UAV system in combined with approach 1 and 2

Another issue is the automated recognition of UAV images and autonomously flying UAV. Some literatures used the BIM in combined with safety rules (e.g. OSHA) to automatically identify the falling zone. However, many works were done by manually, e.g., the work by (Melo et al. 2017). With the development of artificial intelligent technologies, there is a potential to build a fully automated UAV/BIM safety inspection system in the future.

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