A Systematic Method of Integrating BIM and Sensor Technology for Sustainable Construction Design

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Abstract. Building Information Modeling (BIM) has received lots of attention of construction field, and sensor technology was applied in construction data collection. This paper developed a method to integrate BIM and sensor technology for sustainable construction design. A brief literature review was conducted to clarify the current development of BIM and sensor technology; then a systematic method for integrating BIM and sensor technology to realize sustainable construction design was put forward; finally a brief discussion and conclusion was given.

1. Introduction
Building Information Modeling (BIM) has received lots of attention of construction field, and has been used in assisting construction management. The application of BIM for construction design mainly focus on construction site layout and construction progress management. There is still grate space for applying BIM in building examine, monitoring, and restructuring, expanding and continued constructions (He et al., 2012). Collecting data from building is an important basis for BIM application in other aspects, and sensor technology is very powerful for acquiring data.

This paper is aimed to develop a method to integrate BIM and sensor technology for sustainable construction design. A brief literature review was conducted to clarify the current development of BIM and sensor technology; then a systematic method for integrating BIM and sensor technology to realize sustainable construction design was put forward; finally a brief discussion and conclusion was given.

2. Literature Review
Various types of sensor can be used in construction field. For structural maintenance and monitoring, Yang et al. (2012) put forward a sensor network to collect the temperature data of the enclosure of buildings [1].

For the selection of sensor types, many researchers developed several of methods to collect different data from buildings. Wu et al. (2001) [2], Gao et al. (2007) [3], and Connolly et al. (2006) [4] put forward that fiber-optic sensors could be used to monitor structure’s stress, strain, crack, vibration and corrosion situations. Wang et al. (2015) developed a method to monitor the structure using Light Detection and Ranging (LiDAR) devices carried by a quadcopter [5]. In other aspects of the combination of sensor and BIM, Fodil et al. (2016) proposed the 3D capture technology combined with BIM, for conduct the life cycle management (LCM) of building [6], the research focuses on...
photogrammetry and laser scanning technology. Similarly, Costin et al. (2012) proposed that using radio frequency identification (RFID) to carry out the path tracking of objects in the building [7].

For the layout of the sensors, there are many researchers conducted related studies. Ma (2012) proposed that optimizing the sensor arrangement in high-rise building structural health monitoring using complex mathematical method [8]. Papadopoulou (2016) uses a multi-model system identification method to optimize the sensor distribution for monitoring the wind flow around the structure [9].

For the researches about the technical frame of sensor networks, Isikdag (2015) explained in detail about the methods of integrating BIM and information provided by Internet of Things (IoT) and sensors [10]. Jafer et al. (2011) [11] and Huang et al. (2011) [12] proposed that using WSN to monitor indoor environment management; Dorvash et al. (2014) used WSN to monitor the vibration of high rise buildings [13].

At last, for the management and utilization of the data collected by sensors, and the integration of BIM and the data collected by sensors. Deng et al. (2014) raised that using sensor network to collect building big data, and raised several examples of the values of building big data [14].

The integration of sensor technology and BIM to realize sustainable construction design has efficient research basis, and a systematic method can be established according to above methods.

3. A Systematic Method of Integrating BIM and Sensor Technology in Sustainable Construction Design

In above part, a brief review has been conducted to figure out the application status of the integration of BIM and sensor technology in many aspects. This part is aimed to sort out a systematic method of integrating BIM and sensor technology to push forward sustainable construction design, using the methods introduced in above part. The over view of the method is showed in Table 3.1, and the details is described in the follow parts.

**Table 1. Overview of the Integrating Method**

| Sensor Selection | Construction Phase/Requirements | Selection |
|------------------|---------------------------------|-----------|
|                  | Construction plan and design    | Laser scanning (Integrating VR) |
|                  | Construction safety management  | RFID Fiber-optic sensors Others |
|                  | Site facilities and materials management | RFID/BLE Others |
|                  | Site environment protection     | Various site data collection sensors |
|                  | Construction progress management| Laser scanning |
|                  | Restructure, expansion, and continued construction management | Laser scanning Fiber-optic sensors Others |

| Integrating method | Sensor Spatial Layout | No general method, differs according to different goals |

| Data Integration Frame | Aspect | Selection |
|------------------------|--------|-----------|
| Data base selection    | NoSQL base |
| Data transfer format   | JSON   |
| Graphic presentation   | Unity 3D Engine |
3.1 Construction Field Management

3.1.1 Construction Plan and Design. In construction plan and design phase, the most practical sensor technology is 3D scanning. Usually laser scanning and photogrammetry will be used to collect the terrain of construction site. This data can integrate in GIS and BIM system to assist managers deploying construction facilities and materials. In BIM integrated with the data collected by 3D scanning facilities, operators could easily recognize and clarify the special relationship among facilities and structural elements. Meanwhile, VR technology can also be integrated into the above system, managers could using VR facilities to directly watch the relationship among completed parts and structural elements needs to be built. Through this system managers can make construction schedules more conveniently, improve the efficiency of facilities and materials’ deployment, and reduce the probability of doing wrong works.

According to above parts, a comparison between laser scanning and photogrammetry has been conducted by Fadli et al. and the result shows that laser scanning is better in resolution, precision, range, and data and operation complexity, but photogrammetry is relatively safer and cheap. So it is recommended that photogrammetry could be used to do work which with low accurate requirements, while 3D scanning could be used to acquire mass of accurate points data.

3.1.2 Construction Safety Management. Construction safety management includes 3 aspects: the safety of people, the safety of facilities, and the safety of materials. Among them, the safety of facilities includes the safety of completed structure and the safety of equipment, which will be discussed in restructure, expansion, and continued construction management, and construction facilities & materials management, respectively. This part will focus on the safety management of people.

In construction safety management, positioning and tracing technologies will be essential because it is important to know the real-time positions of workers. RFID is widely used in this aspect. Besides, BLE also belongs to radio frequency technology, and it is also popular in positioning and tracing. By deploying RFID readers in the construction site, implanting RFID tags to workers and combining with the geometry information in BIM, proceeding through a geometry algorithm, workers’ position can be located with a relatively high accuracy (about 1.5m). Besides positioning and tracing technology, many other types of sensor can also be used in construction safety management. Some specified examples could still be raised: pressure sensor can be used in underwater construction to detect whether the air pressure is exceed the acceptable range of human; PM 2.5 sensor can be used in a relatively close construction spaces (e.g. underground) with pollution construction machines.

3.1.3 Site Facilities and Materials management. Various sensors could take part in site facilities and materials management. One of them is positioning and tracing technology, in which RFID is most popular. Like positioning and tracing workers in construction site, RFID tags can also planted in facilities and near materials to locate and trace them, with the assist of the structural geometry information from BIM, managers could directly know the position of facilities and materials, and can make deployment schedules, so that a lot of time and labor wasting could be avoid.

In site facilities management, the operation and management of facilities is also an important part and the integration of BIM and sensors can also assist the operation and management of facilities. As an example and case researched by Lee et al, various of sensors were used (e.g. slewing sensors, cable length sensors, boom angle sensors, camera and laser scanning devices) to collect the operation data of a crane, and BIM will provide building and context’s 3D information and the detail position of objects need to be lifted, this system is proved to be useful for those cranes have blind spots.

3.1.4 Site Environment Protection. In modern construction managements, environment protection is also an important aspect that managers need to consider about. Air pollution and noise pollution are common pollution types in construction site. In order to control the air pollution caused by dust, dustproof cloth is often used to block the diffusion of dust, while PM 2.5 sensors could also be used to collect air quality data from the construction site, with the building information provided by BIM,
managers can figure out the diffusion source and reduce the dust emission. Similarly, noise sensors can also detect the noise intensity and make noise reduction measures.

3.1.5 Construction Progress Management. BIM is a practical tool for construction progress management, and it is not strange to use sensors to conduct progress management. With the assist of 3D capture devices (e.g. laser scanning & photogrammetry), the machine can scan the completed structure automatically and compare the scanned model with BIM to assist progress control.

Sensors can also assist construction quality management; it will be introduced in the next part.

3.2 Restructure, Expansion, and Continued Construction Management
Restructure, expansion and continued construction is conducted after the building was finished and be used for a time. Usually designers will check the structural manually to decide whether it is appropriate to be restructured and make construction plan. This method is risky because it is hard to check the inner situation of structures, and some buildings were not used as they were planned. So it is essential for designers to get accurate data of the situation about the structure’s health and how did it work.

Using sensors to conduct structure health monitoring is plain and simple. Usually 3D scanning devices were used to examine the surface quality of the structure to check: i) its crack situation, and ii) its deformation, automatically; the stress and strain sensors were planted into or affixed on the concrete to check the inner mechanical situations, also some other mechanical sensors (e.g. velocity sensors, acceleration sensors and seismic sensors) could also be planted into structure; and the temperature sensors could be used to detect the temperature diversifications, which is particularly useful for big volume concrete structures such as dams.

For building mechanical situation detection, optic fiber sensor is recommended for its significant advantages in property (e.g. high sensitivity, small volume, wide range and safety), and extensive usages. A case study of Wuhu Yangtze River Railway Bridge shows that the optical fiber sensors can accurately measure strain and they are suitable for the long-term and automatic monitoring.

For sensor deployment, there is no widely accepted method to deploy various types of sensor, there are only suitable ways to deploy several kinds of sensors. Deploy plan of sensors is still to be determined according to actual situation; a comprehensive deploy method which is suitable for layout various types of sensor is still to be developed.

It is nature that the structural health monitoring system could be used in construction quality management and operation & maintenance phase.

Meanwhile, through the data collected by these sensors, a knowledge base could be found to record the real time operation and usage data of the building, which is useful for scientific research and future design works.

3.3 The Technical Frame of Integrating Sensor Network and BIM
Actually sensor network is a special case of IoT (Internet of Things). And it is a technical problem to realize the communication among sensors, found a database to store those data, integrating sensor data with BIM, and realize the interaction between users and the system. Isikdag et al. has developed a frame, including basic publish-subscribe method for exchanging information among large amounts of IoT nodes; and a message-based cloud update for solving the problems about information updating and saving, etc.

From the research of Khalid et al. (2017) [15], for the selection of database, NoSQL database was recommended for its high scalability, and it was more agility and dynamic for situations that data updates frequently; and in aspect of data transfer format, compared with XML, JSON was recommended because it can be better understood by NoSQL database; Besides, for graphic presentation, Unity 3D game engine was proved to be efficiency in dealing with scenes having lots of vertices.
4. Discussions
This paper developed a method to integrate BIM and sensor technology for sustainable construction design. The method raised above is technically feasible, but without the consideration of economy feasibility, peoples’ concept, current management level and enterprises’ willing to apply it, which hinted that the cost of applying sensor networks will be high, and current management awareness is lagging in construction field. So the future researches could focus on economic property of sensor networks and promoting information technologies in construction field.

5. Conclusion
This paper developed a method to integrate BIM and sensor technology for sustainable construction design. The current publications shows there are sufficient research about the integration of BIM and sensor technology, the function of sensors can basically meet various of requirements in construction field, the selection of sensor types and the spatial layout is differ according to different goals, and the technical frame for integrating BIM and data collected by sensors is mature.

For policy suggestions, government shall promote BIM applications and applying sensor technologies in construction field; and interdisciplinary research should be encouraged, too.

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