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To cite this article: Zhenping Zhao *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **371** 022034

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Integrating BIM and IoT for smart bridge management

Zhenping Zhao¹, Yu Gao¹, Xingyi Hu², Yin Zhou², Lidu Zhao², Guocheng Qin², Jieming Guo², Yachao Liu¹, Chenchen Yu¹ and Daguang Han^{3*}

¹The Seventh Engineering Co., LTD. of CFHEC, Zhengzhou, Henan, 451450, China;

²School of Civil Engineering, Chongqing Jiaotong University, Chongqing, 400074, China

³Faculty of Technology, Art and Design, Oslo Metropolitan University, Oslo, 0130, Norway

*Corresponding author's e-mail: daguang.han@scsda.com.cn

Abstract. Considering high risk, long construction period, high construction and maintenance costs, bridge management is asynchronous, unintelligent and inefficient. The purpose of this research is to investigate a new approach with its supporting building information modelling (BIM) and Internet of Things (IoT) tool to enhance the smart management in bridge life cycle. BIM provides detailed geometric and semantic information and IoT contains the management and analysis of the actual condition of the bridge. An example of a super bridge under construction in Xinjiang is used to illustrate the developed system. Results show that the developed system can significantly grasp the quality of the bridge in time, reduce the construction risk and construction period. The developed BIM/IoT-based system is also effective and practical in the quality and risk management among multiple locations, such as smart buildings, smart tunnels, and even smart cities.

1. Introduction

Bridges are vital elements of modern transport system. As critical infrastructure components their long-term safety and service ability must be ensured. The mechanical damage leads to a degradation of structure, raising the need for a regular structural assessment to ensure the safety of bridge. Conventional inspections of bridge are mostly based on visual investigations. Due to the difficult access of bridges, inspections are time-consuming, costly and dangerous. Today, bridge assessment is also asynchronous, unintelligent and inefficient.

Digital methods based on emerging technologies may pave the way to such new paradigms. Sensor-based bridge safety monitoring has already been widely accepted. Recent breakthroughs with Unmanned Aircraft Systems (UAS), equipped with high definition photo camera technologies and Internet of Things (IoT) have generated a significant interest as a source of information about the bridge safety information. Digital imaging in combination with photogrammetry and analysis methods may generate new solution. However, the potential can only be exploited through the development and combination of assessment methods that allow an efficient acquisition of data as well as an automated processing and interpretation. Only when powerful algorithmic methods can be integrated into completely automatic workflows, an innovative change in practical bridge assessment can be achieved.



This paper proposes a framework and applies it to a bridge in construction, thus providing a new approach to image data acquisition, sensor data acquisition, processing and interpretation in bridge construction.

2. Literature review

In this section, the relevant literature is divided into two sections: BIM and IoT applications.

BIM (Building Information Modelling) is a 3D digital information model that integrates engineering information, processes and resources at different stages of the project life cycle. The Internet of Things is an important part of the new generation of information technology and an important stage of development in the era of "informatization." The core and foundation of the Internet of Things is still the Internet, which is an extended network based on the Internet.

BIM has the following problems in the application of bridge engineering: (1) the positioning of BIM is not allowed; (2) the standard specification problem. Chen Xiaofei et al. placed the bridge monitoring points in the BIM model to make the construction process more coordinated, thus improving the efficiency of construction monitoring[1]. Geng Renhui and others combined the BIM technology with the construction phase of the bridge project to realize the 3D visualization and the management of the construction site[2]. Wang Huan and others proposed a BIM-based bridge operation and maintenance management model, which basically realized a unified and standardized implementation process as well as application of complex maintenance data[3]. Liu Zuxiong and others summed up a feasible BIM-based bridge construction material refinement management plan, which overcomes many shortcomings in the traditional material management. It is conducive to control the cost of materials during bridge construction[4]. Li Hongxue et al. proposed a BIM-based bridge engineering design and construction optimization solution, which provides a reference for the application of BIM in complex bridge engineering to improve the efficiency of design and construction[5]. Liu Zhimin and others used BIM technology to simulate and construct bridges, and implemented the feasibility and practicability in the design stage[6]. Tian Yunfeng et al. used 3D laser scanning and BIM model in their construction quality management, which presents a reference to 3D laser scanning and BIM model in other quality management[7]. Shen Haihua et al. combined the characteristics of bridge information model, in order to realize BIM-based bridge life cycle management[8].

In general, more and more researchers are now using BIM technology and IoT technology in engineering construction, but this is still a long way to go. Only when we find the demand points on the construction site and use the strengths of new technologies can we solve engineering problems accurately.

3. Integrating BIM and IoT for smart bridge management

The methodological framework presented here allows to automatically acquire, analyse data and interpretation. Critical artificial intelligence algorithm is selected and developed into an analysis method which is designed to generate an automatic bridge assessment. The flow of the proposed framework is introduced below.

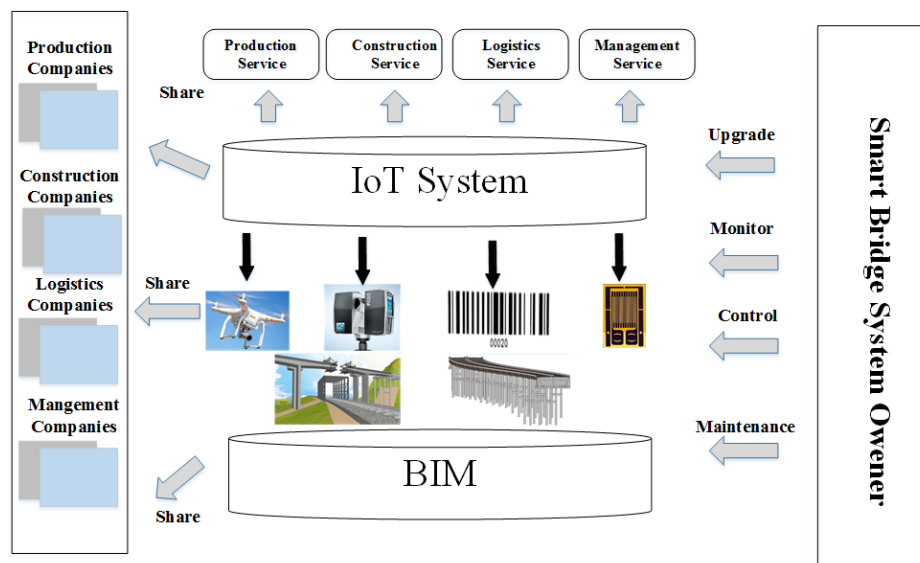


Figure.1 BIM+IoT System

An overview of the general framework is shown in Figure.1. The development framework of the proposed BIM and IoT for smart bridge management contains (1) BIM model. It contains detailed dimensions, locations, and semantic information of bridge in construction. BIM model is a better suited visual representation of the actual state of bridge. (2) IoT. The IoT facility contains UAV equipped with camera and 3D laser, as well as sensors and QR codes installed on the component, which can timely grasp the quality status of the physical bridge including its visual appearance, geometric size, stress and strain (Figure.2). The information obtained by the IoT technology is processed and transmitted to the BIM model for unified management. The combination of the described method is leading to a profound bridge quality assessment based on a large number of images, sensor data and automatic analyses.

The BIM platform is used to analyse, integrate the large data, in order to discover and adjust the quality problems of bridge construction in time under harsh environment, which reduces the risk and construction cycle. Additionally, the RFID and 2D barcode technology is introduced to record details owing to it can read and write information according to the demands, which realizes the digital construction and maintenance of intelligent bridge. The flow chart is shown in Figure.3. When the bridge components begin to install in the construction site, the engineers can obtain the installation method by scanning and reading the RFID card and QR code. After serving for several years, the IoT equipment can also record the condition data, which is beneficial for bridge maintaining.

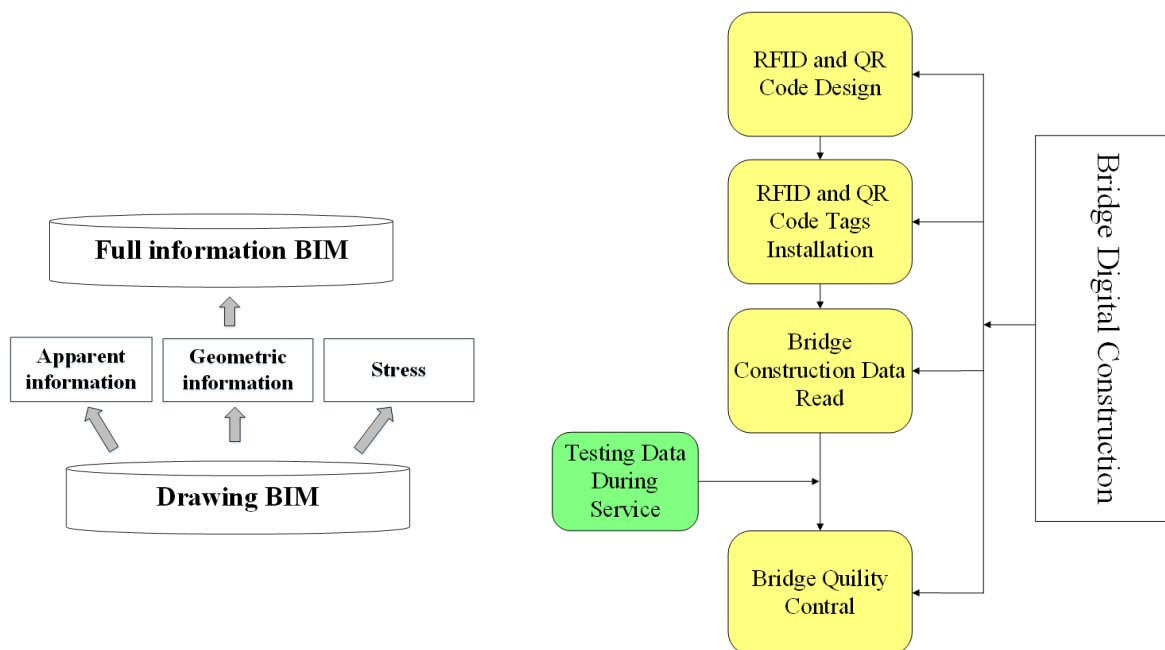


Figure.2 Full information BIM model

Figure.3 Bridge digital construction and maintenance

4. Framework for BIM/IoT-Based monitoring and sample application

This section presents the detailed framework proposed in this paper. The detailed description of integration of BIM and IoT is presented in section 4.1. A reference bridge structure that will be used for demonstration and application purposes is presented in section 4.2. A detailed explanation of the key components is contained in section 4.3 to 4.6 alongside the sample applications.

4.1. Detailed description of the proposed framework

The main components are 3D laser scanning, 3D photogrammetry, sensing and interpretation. These are combined with the aim of automatically extracting information about the structural condition as the basis for structural healthy assessment. The complete framework including processes and algorithmic is shown in Figure.4.

Regarding the prefabricated component, it will be scanned and photographed to detect fabrication size and apparent damage; As far as the cast-in-place component is concerned, many advanced sensors will be lay on the key position for the stress and strain. After these the big data will be transmitted to the BIM model platform for analysis and decision making. This process contains a lot of important algorithmic that is used to analyse the point cloud and photogrammetry model.

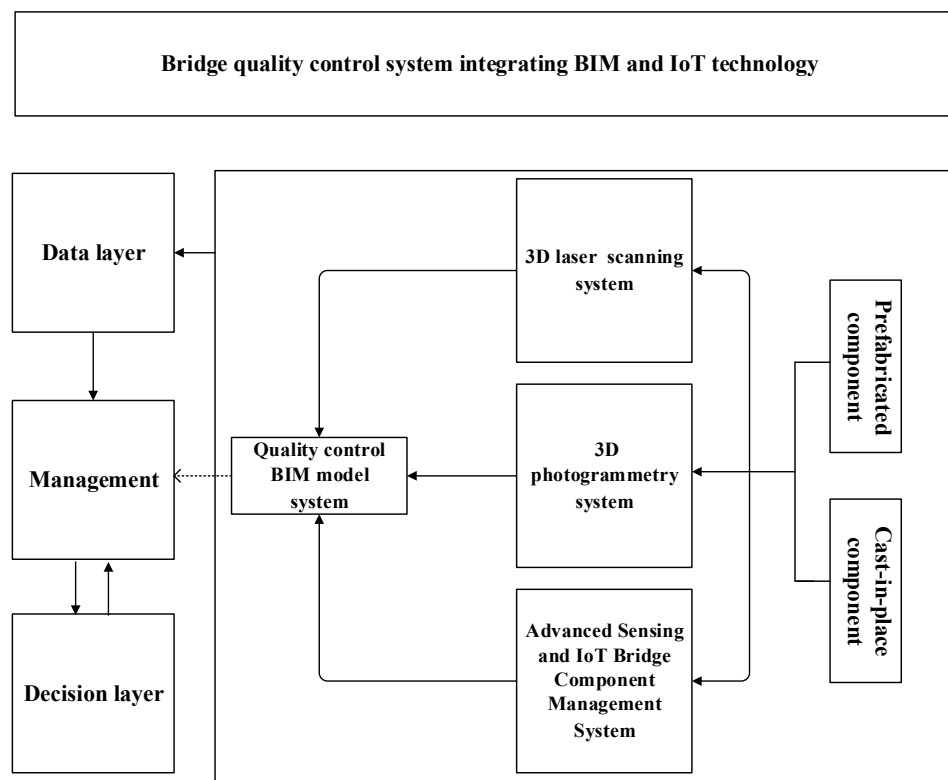


Figure.4 Bridge quality control system integrates BIM and IoT technologies

4.2. Application projection

The project is located in the eastern part of the Xinjiang Uygur Autonomous Region, at the eastern of Tianshan Mountains. The overall characteristics of the terrain are high in the north and low in the south. In this section of the route, a total of 2,563 meters / 1 bridge, 4,100 meters / 15 bridges, 630 meters / 9 bridges, and 29 meters / 1 bridge. In order to facilitate construction, reduce cost and shorten the construction period, the main line bridge adopts standardized prefabricated assembly superstructure. The bridges located in the same section should adopt the same span as much as possible. As a result of the large undulated project site and the vertical valleys, the height of the bridge piers from designer exceeds 20m. Combined with the harsh climatic environment, the situation are challenging with the quality control of the prefabricated components, the maintenance of the bridge, the accuracy of the assembly construction, the deformation monitoring of the high pier section. In order to solve the above problems, this paper builds a smart bridge management system suitable for the project by means of sensing, BIM and IoT technology.

4.3. Bridge quality control BIM model

For the BIM+ IoT bridge quality control requirements, the BIM model of the bridge is the data carrier of the information. Therefore, the detailed BIM model is established according to the construction drawing scheme [9-11]. The details and granularity of the model depends on the project requirements. At the same time, a theoretical finite element model (FEM) is established according to the plan and design documents so that we can obtain the expected force state of the structure, and analyse the risk of the bridge construction process initially. Thus, the data carrier for bridge construction quality control and post-operational maintenance is completed.



Figure.5 Bridge quality control BIM model

4.4. 3D laser scanning system

Using 3D laser scanning technology, a 3D laser scanning platform was built in the prefabricated beam factory and the construction site [12]. The FARO Focus 330 scanner is erected on the prefabricated beam field and the construction site to completely scan the three-dimensional geometry of the prefabricated and construction components.

As is showed in the Figure.6, it is a prefabricated beam in the factory. In order to acquire the component point cloud data fully, the scanning is performed at both side of the beam, and three common feature points are selected to ensure that they are within the two different fields of view. Based on the three feature points, the two-site point cloud registration is performed (Figure.7(a)) in the case where the horizontal and vertical intervals are both set to 2 mm using KD tree-ICP algorithmic[13-15].

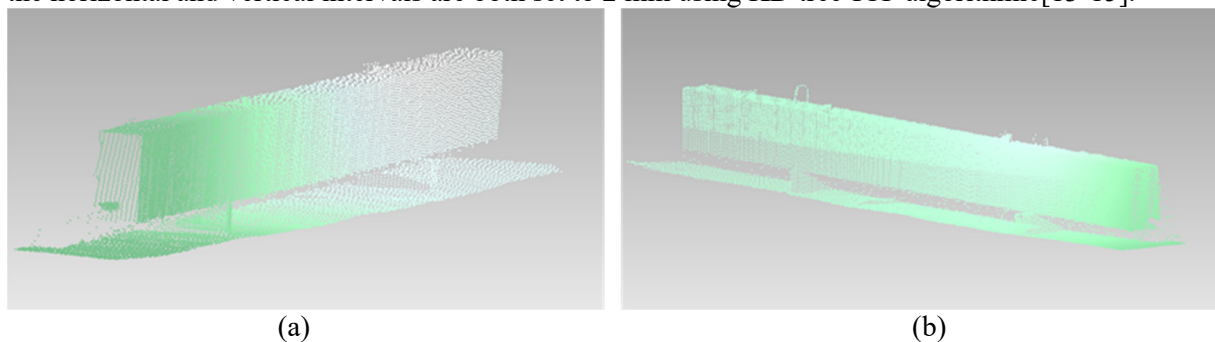


Figure.6 Point cloud of a prefabricated beam:(a) First stop, left view;(b) Second stop, right view

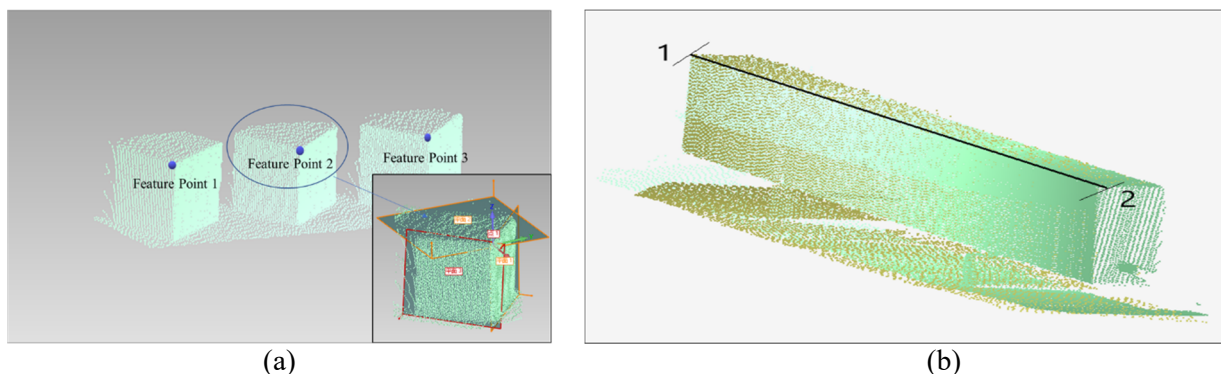


Figure 7 (a)Point cloud plane fitting and feature point matching;(b) 3D point cloud model of beam

After noise reduction, adjustment, and volume reduction[16-19], the point cloud is transmitted to the platform processing centre from wireless local area in the construction site. Finally, the point cloud model after registration is used for quality inspection, measuring its dimensions and comparing it with the design information to verify compliance with design requirements. As is showed in the Figure.8 and Figure.9, the manufacturing size has been measured according to the point cloud model to test the quality of beam. The result shows that the deviation is 0.0015m(relative error is 0.0289%), meets the design requirements.

Table 1 Point cloud quality test results of beam

Point number	Coordinate (m)			Design length (m)	Point cloud length (m)	Deviation (m)
	X	Y	Z			
1	12.2411	2.6428	0.2579	4.5000	4.5013	0.0013(0.0289%)
2	8.2397	4.6785	-0.0688			

4.5. Three-dimensional photogrammetry system

For the prefabricated beam and the other components of the construction site, the UAV equipped with a high-definition camera is used to obtain multi-angle [20] image data of bridge components. With the photogrammetry technology, a three-dimensional real-time model of the bridge is established. Based on the model, it can carry out the construction quality acceptance combined with the image processing algorithm. At the same time, it can achieve the bridge damage identification and location, as well as realize the bridge construction quality assessment, operation and maintenance periodic inspection. Its technical architecture is shown in the Figure.8.

In this case, we also took a set of photos of a beam and established a photogrammetry model. Before the apparent damage detection using image processing algorithm, we corrected the coordinate system and scale of the model by selecting 4 feature points as the Figure.9 shows: the geometry of photogrammetric model has been corrected using the point cloud geometry after manufacturing inspection.

Due to space limitations, this paper selects several typical defects identified for analysis. Figure.10 shows the marking and measurement results of the longitudinal crack of a concrete beam based on the model. While marking the crack, the system automatically calculates its spatial localization and length and width, and generates corresponding codes into the bridge operation and maintenance database; At the same time, it automatically measures the coordinate values of the inflection points at the crack mark to locate the start and end of the crack, which is important for damage tracking and development trend prediction based on detection data.

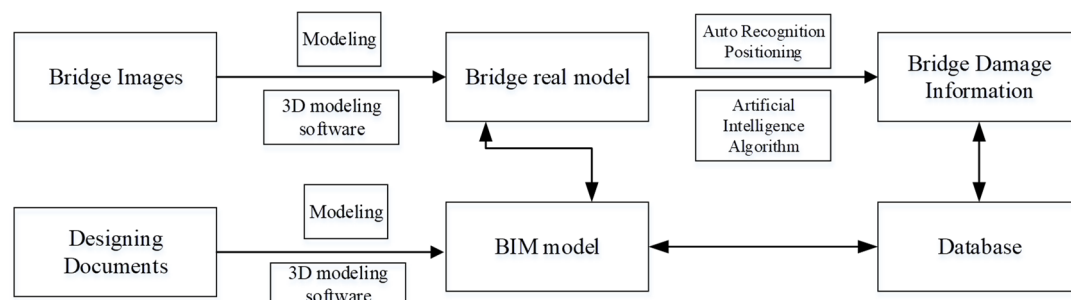


Figure. 8 Construction of three-dimensional holographic photogrammetry system

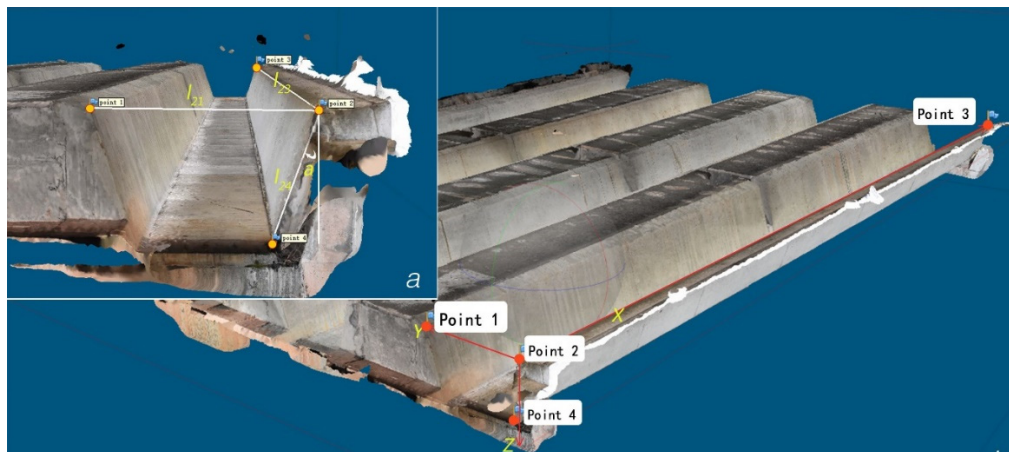


Figure. 9 Display of three-dimensional real-scene photogrammetry model of beam

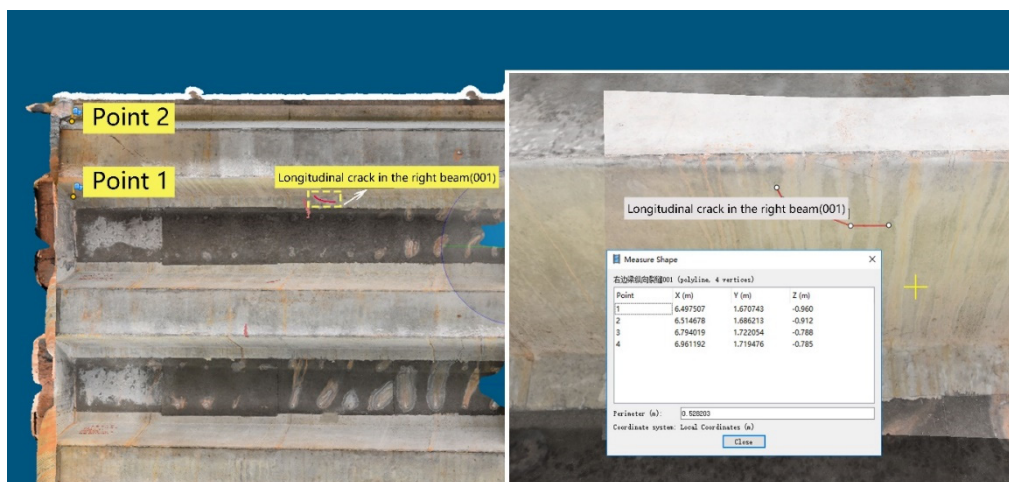


Figure. 10 Concrete beam damage detection and record

4.6. Advanced Sensing and IoT Bridge Components Management System

The strain sensor and the QR code are arranged on the components of the prefabricated beam factory, to monitor the internal force state of the strain gauges in each component in real time; the QR code label of the package and RFID card is implanted in the production process of the prefabricated beam, which contains the production quality parameters such as manufacturing equipment, manufacturer. Combined with the BIM model, each prefabricated beam has been given a unique label with its installation location and conditions of the prefab for construction as well as post-monitoring and maintenance.

As the Figure.12 shows, there are a lot of information contained in the QR code, including project description, component manufacturing equipment, manufacturer, construction process and material. This information can be updated depends on the demand, which will play an important role in the management of the bridge life cycle.

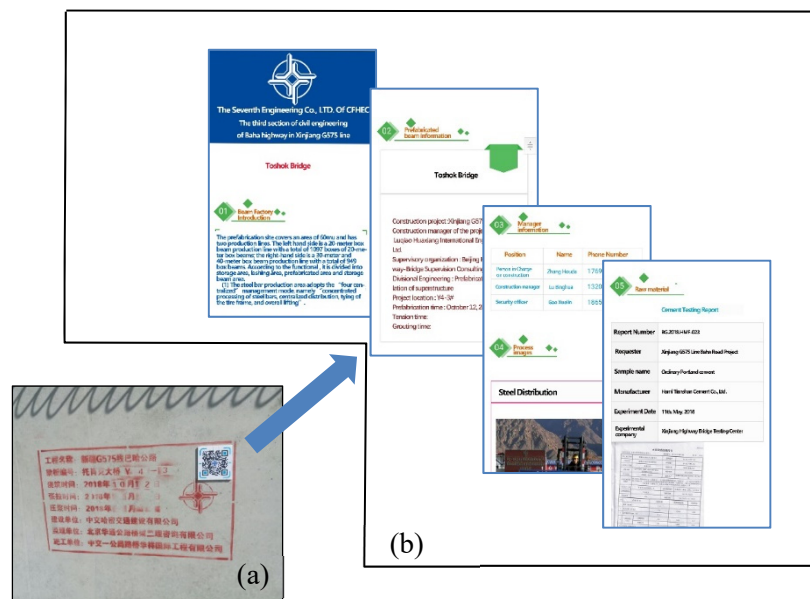


Figure.11 (a)QR code label for beam;(b) Projection information contained in the QR code

5. Conclusion

The main contributions of this research are to investigate a new approach with the supporting of Building Information Modelling (BIM) and Internet of Things (IoT) tool to enhance the smart management in bridge life cycle. BIM provides detailed geometric and semantic information and IoT contains the management and analysis of the actual condition of the bridge. An example of a super building bridge spanning 2017-2020 in Xinjiang G575 is used to illustrate the developed system. Results show that the developed system can significantly grasp the quality of the bridge in time, reduce the construction risk and construction period.

To conclude, BIM and IoT technology combined with data analysis methods have the potential to revolute bridge structural assessment. In the future, this work can be improved and extended. The developed BIM/IoT-based system is also effective and practical in the quality and risk management among multiple locations, such as smart buildings, smart tunnels, and even smart cities.

Acknowledgement

This research has obtained the financial support of: The Seventh Engineering Co., LTD. of CFHEC, and Chongqing-Leuven Academy of Smart City and Sustainable Development. The authors would like to express sincere gratitude to them.

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