# Vision-based Precast Concrete Management Plan in Off-Site Construction Site : Using PC Member Quality Grades

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**Abstract –**

**As a product of commercialization in prefabricated buildings, the information of the whole life cycle of Precast Concrete (PC) is an important basis for product quality traceability and progress control. During the stage of production, transportation, storage and installation, some quality problems inevitably appear on PC, and according to the degree of damage, there are different procedures to handle the PC. In case of a PC is slightly damaged, it can still be used in the subsequent installation and will not produce quality impact on the building structure; While if the damage is serious, then the PC is needed to be repaired before using in construction. Therefore, the tracking of status information of PC becomes particularly important.**

**This paper presents a status information management method for PC from production in the factory, loading and transportation to temporary storage and installation on the construction site. The system model of PC information management in the installation stage of the construction site is established by giving each component an identity and then using the image recognition based on Quick Response Code (QR code), so as to achieve the purpose of prior quality inspection and information traceability. In the future research, PC will have visible changes of stage and traceable historical information, just like commodities on the market.**

**Keywords –**

**Precast Concrete; Off-Site Construction; Status Information; Tracking Information Management**

## 1 Introduction

### 1.1 Research Background and Purpose

Prefabricated building generally refers to the building where the components and units processed and manufactured in the factory, are transported to the construction site and assembled on site through reliable connection. Due to the advantages of prefabricated building, such as short construction period, high production efficiency, high resource utilization rate, environmental protection, in line with the concept of sustainable development and so on, multiple countries have issued relevant regulations and policies to vigorously develop strategic emerging prefabricated buildings. For example, the China State Council proposed that by 2020, the proportion of prefabricated buildings in new buildings must reach more than 15%, and more than 500 prefabricated building demonstration projects should be cultivated[1]. This has greatly stimulated the development of construction industrialization, also gradually reduced the dependence on labor force.

However, some features which are difficult to manage also exist. For example, a large number of components and complex processes need to be systematically managed; as well as the information dynamic change, which means members may be damaged or have other quality problems at any stage of the project. Some of them can still be used after repair measures are proceeded, while some have to be discarded. In the process of prefabricated construction, due to the lack of effective means of communication and the low level of information sharing between on-site process and off-site management, an increase in unnecessary waste of resources and engineering costs can be expected.

Inevitably, in the actual construction process, it is complicated to transfer the status information of component and locate the component. Besides, it takes a long time to manually check one by one according to the drawings[2]. Thus, the real-time status and historical traceability information of each prefabricated component that can be shared with all required participants is very necessary for project planning and schedule.

In addition, Building Information Modeling (BIM) provides scientific and feasible technical support for prefabricated building construction with its dynamic information, visualization, intercommunication, simulation, coordination, optimization and other characteristics.

The aim of this study mainly concentrates on the tracking of the status of prefabricated components, which are divided into different degree of damage and have corresponding on-site diversion processes in the construction site, and the visualization of project progress. Through the mobile intelligent device, the construction status of all components can be viewed, and the precautions can be confirmed on electronic equipment before installation, which help to get rid of the paper data filling. Finally, the information of each component is integrated and displayed in the model, and the project progress can be seen intuitively. The result should make the information exchange and transmission between on-site and off-site more immediate and effective.

### 1.2 The Scope and Methods of Research

Therefore, this paper proposes a framework of PC traceability management system. PC may be damaged, cracked and other quality problems during transportation and storage. Therefore, a platform was established to help on-site staff and off-site managers communicate effectively. QR code was used to identify each PC member and manage the information through mobile intelligent devices.

The method and process of this research is:

(1) research trend

- preceding research analysis
- analysis of OSC workers' needs

(2) a whole-process approach to traceability and information management of PCs

- components identification
- tracking management of production and delivery process
- information management during the installation stage of PCs

(3) combination of image recognition and PC information check

- experimental hardware and software
- build database for image target
- build information management platform during the installation phase.

## 2 Research Trend

### 2.1 Literature Review

In order to eliminate the shortage of manual identification in positioning components, Ergen, E., Akinci, B., and Sacks, R.[3] proposed an automatic system which combines Radio Frequency Identification (RFID) technology with Global Position System (GPS) technology, so that the system needs the least labor input.

The precast production management system which has been developed by Yin and Tserng[4], using Personal Digital Assistants (PDA) and the application of RFID for preform production management, including incoming material inspection, production process inspection, mold inspection, specimen strength feedback, logistics and receipt management.

Wang Z and Zhang Q[5] proposed a framework integrated with the computer vision methods to monitor the construction process of prefabricated walls automatically. The framework combines target detection, instance segmentation and multi-target tracking to obtain the location and time information of the prefabricated wall from surveillance video. The identified and collected state information is stored in JavaScript Object Representation (JSON) format and then sent to the appropriate BIM to add a timestamp to the wall component.

Li and Xue[6] designed an IoT platform, which used RFID technology to collect data for the on-site installation process of prefabricated components. The captured data is synchronously uploaded to the cloud to provide decision support for relevant site managers and staff. It also uses BIM and virtual reality (VR) technology to develop the functions of visualization for construction process and traceability for PC, which enable managers to monitor on site construction and approximate cost information faster and more accurate.

Li and Lu[7] designed the Proactive Construction Management System (PCMS). It uses real-time positioning technology based on Chirp-Spread-Spectrum (CSS) and data visualization technology based on Unity3D to track on-site construction matters, such as equipment and workers. Real-time feedback and postoperative visual analysis can be obtained.

Kiziltas and Akinci[8] believed that data capture technology, such as smart tags, laser scanners, and embedded sensors, can simplify related processes, and its performance is different from the manufacturer's specifications when used in the construction site due to interference, data reading range, data transmission and other problems such as accuracy, hardware and software interoperability, and memory limitations.

BIM is a very useful tool to help facilitate on-site assembly services (OAS) of prefabricated construction as it can effectively manage physical and model data. However, the advantages of using BIM in prefabricated construction OAS cannot be cultivated due to incomplete and untimely data exchange, as well as the lack of real-time visibility and traceability. To address these challenges, Lee and Xue[9] Designed the Internet of Things (IoT) platform and integrated BIM and IoT into prefabricated public housing projects in Hong Kong. The data captured on site is transported to the cloud in real time for decision support of relevant site managers and workers. Visualization and traceability features using BIM and virtual reality technologies allow managers to monitor construction progress and approximate cost information in real time.

The table below shows some of the existing studies on PC information management.

Table 1. Research topics and existing methods

| Research topics | Relevant Method |
|---|---|
| PC tracking | Optimization of supply chain; Locating components using Global Position System (GPS); radio frequency identification technology(RFID); global navigation satellite system (GNSS); |
| PC identity | Identity number; QR code; Barcode; RFID |
| PC information management | Formalization of the information flow; 4D building information model (BIM); Cyclic operation network (CYCLONE) simulation model |

Because this study only needs to read the identity information of each PC, and no need to achieve the effect of data exchange, it is unnecessary to adopt RFID technology which is more expensive and complex to develop. And the development of QR code has been very mature. Furthermore, the data forms after reading QR could be various directly, not limited to data in the form of dozens of bytes. While RFID technology need a data processing system to transform the byte data into a visualized form . So by comparing the general methods, the most feasible QR code representing component identity is selected.

## 2.2 Analysis of OSC workers' needs

Based on the discovery and observation of the on-site assembly process, Lee and Xue lists the requirements analysis in the installation stage as shown in table 2[9] . Discover that the managers need real-time assembly management services, like the project process, 3D BIM models and components tracing service; and on-site workers need handling service to record emergent condition of on-site PCs.

Table 2. Requirement analysis of on-site assembly by Lee et. al

| Requirement | Priority |
|---|---|
| System needs to keep a record of pending prefabricated elements (with or without ID) for current working day | Preferred |
| Be aware of prefabrication are safely | Must have |
| Be aware of prefabrication are erected | Must have |
| Be aware of place where prefabricated components are held | Optional |
| Batch upload of photos synchronized or synchronized with hand-held scan data upload | Optional |

Also, an interview with a company's employees was done by Moon[10]. The result shows that workers need intelligent applications to help construction, data validation, inspection and guidance, especially in communication support and schedule management. Moreover, it is necessary for on-site workers to have an intelligent system on mobile devices to share information in the process of implementation. Among these, "data confirmation and check" was identified as the most important requirement as shown in Figure 1.

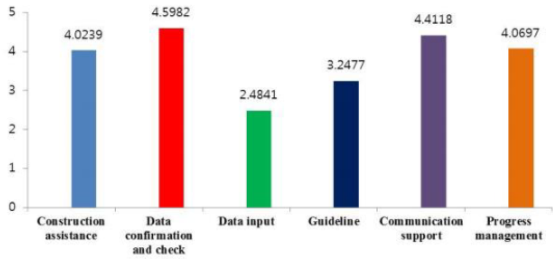



Figure 1. Result of interview by Moon et. al

Therefore, it is very necessary to update the status information of PCs at the construction site for the control and management of installation progress. Meanwhile, in the installation process, it is also important to confirm the quality of each component and check the safety of the installation environment, which can be displayed on the smart mobile device.

# 3 A whole-process approach to traceability and information management of PCs

Information expression of PCs is expressed through BIM 3D model. As the information carrier in the project, BIM model tracks the model components and manages the whole process of PC from production, transportation, lifting and installation, and records the operator, time, specific location and on-site working pictures in detail. And through the platform to reflect information in the BIM model, so as to achieve information management.

The information traceability of PCs requires the cooperation of multiple parties. The specific process allocation is shown in Figure 2.

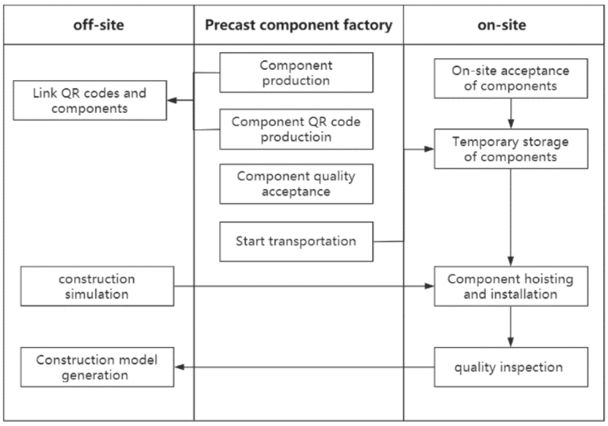



Figure 2. Multi-party collaborative processes for the track of PCs

## 3.1 Component identify

Current research extensively uses barcode, Quick Response Code (QR code) or Radio Frequency Identification (RFID) technology to give every component identities. Compared with RFID, barcode and QR code are widely used in many industries all over the world because of their low cost and perfect standard system. Since the QR code still could be identified after partial damage, it has a certain bearing capacity for the harsh environment; while, when scanning the code, mobile devices can not only read-only information, but also write information to other layers through the Internet. It can also quickly locate BIM components, query component attributes and related information, which can be updated on PC, and mobile devices can scan QR code to obtain the latest information.

Since this study focuses on the management of PCs after they are manufactured in the factory and transported to the construction site, the simulation method is used to obtain the QR code. Suppose that the manufacturer has already pasted the identification label for each prefabricated component, and has input the basic information, such as name, size, number, location, quality inspection and so on, as available for viewing at any time. The process of QR code application and corresponding responsible parties are shown in Figure 3.

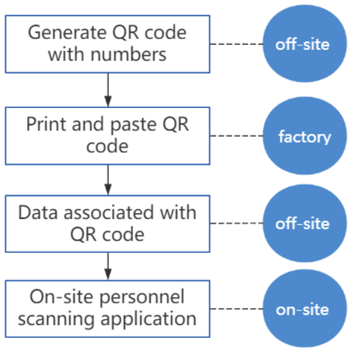



Figure 3. QR code application process and the corresponding responsible party in th whole process

## 3.2 Tracking management of production and delivery process

Efficient production and transportation scheduling are the key factors to ensure PC to be delivered on time. In practice, however, production and transportation planning are mainly based on experience. In addition, production plants are often reluctant to pursue timely delivery at the expense of costs[11]. Therefore, the implementation of information tracking for PCs to master the progress of engineering materials, in order to adjust the gap between the actual progress and the plan is very important and practical, so it is worth paying attention.

The phased tracking management of PCs during production and delivery is shown in the table 3.

Table 3. The work items of PC tracking management in different stages during production and delivery

| process | Work items |
|---|---|
| Production and quality control | • Print the QR code and paste<br>• Scan the QR code and input the information of each prefabricated component<br>• Quality check and input quality inspection information to upload platform |
| Leave the production plant | • Scan the QR code and input the relevant information of the transport vehicle, as well as the type and quantity of the components loaded<br>• When the vehicle leaves the factory, the vehicle number is scanned and submitted<br>• Scan again and confirm the component information and total number to complete the |

| | |
|---|---|
| | registration |
| Location tracking | • The location information of the vehicle with components being transported can be obtained through the driver's mobile phone positioning |
| Enter on-site management | • Scan the vehicle's QR code and enter the site to register<br>• Scan the QR code of components to confirm the quality file and quantity<br>• Check the quality of components again, and input the results according to the extent of damage on the QR code pasted by each component<br>• Stack PCs reasonably in order of installation |

### 3.3 Information management during the installation stage of PCs

Jeong[12] had constructed an automated concrete crack detection system implementing object detection method using deep learning. Quality of each PC component is being checked and analyzed after reaching the construction site. Rather than filling up the quality inspection checklists annually, an auto-checking and reporting system was proposed to reduce the manpower and time taken for quality inspection works of PC components at construction site. In their study, the main criteria for inspection and analysis is the present of crack on PC component, then each component is divided into three risk levels according to width and length of crack detected on the PC component. Based on the study, level 1 refers to PC component that need to be returned to the manufacture for dismantle or repairment purpose; level 2 refers to PC component that can be repaired on-site or returned to the manufacture for further repairment purpose; level 3 indicates the PC component that is safe to be used regardless of the existence of crack on the PC component.

In this study, a further procedure was proposed to help on-site workers to trace the PC components and manage the relevant information via a smart mobile device after each component is being inspected. All PC components are attached by different QR code respectively. All information can be read or updated by just scanning the QR code with minimum manual input. The installation schedule management in the construction stage of prefabricated buildings mainly relates the BIM model to the schedule plan, compares and analyzes the deviation between the two in real time, and then uses the BIM model to intuitively reflect the construction schedule. The changes in the state of the PCs on site are closely related to the progress of the project and also related to the information traceability during inspection.

The components on-site process and corresponding state changes of key nodes displayed on the system are shown in Figure 4.

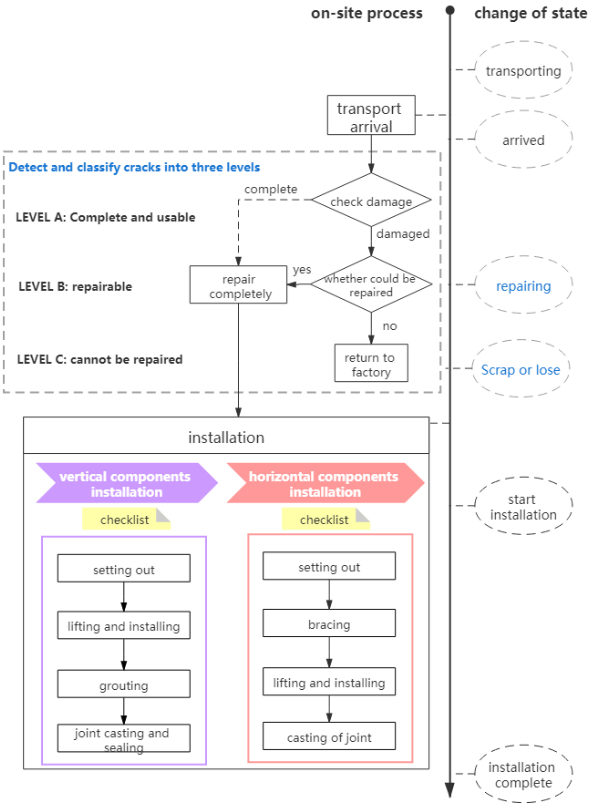



Figure 4. PCs on-site installation process and system display status changes of key nodes

As shown in the figure above, when PC enter a stage, their state changes accordingly. It is worth mentioning that according to the degree of damage, the components are divided into “complete and usable” “repairable” and “cannot be repaired”. PCs that need to be repaired would be in the state of "Scrap or Lose"; PCs that are not repairable or lost will be in the state of "Scrap or Lose", and no further state changes.

## 4 Combination of image recognition and PC information check

### 4.1 Experimental hardware and software

In recent years, there has been a lot of software about making the management system. Unity was chosen as the development tool in this study, not only because of the need for visualization on the construction site and subsequent research, but also because its powerful user interface (UI) design can meet almost all the needs. What's more, Unity is a universal, real-time 3D platform for creating visual products and building interactive and virtual experiences, real-time rendering with VR, AR and MR devices[13].

Meanwhile, Vuforia SDK for Unity is also used in this research as a Unity's package. Vuforia's AR Camera can well recognize any static image by extracting image features. Because at present, compared with image recognition, it is still difficult to automatically recognize PC objects[14], so the image with more feature points is selected to represent each PC. Two-dimensional image - QR code is well adopted in this paper.

Unity supports a variety of non-desktop and Web platforms, such as universal windows platform, tvOS, PS4, iOS, Android, WebGL, etc. Since the construction site needs a relatively convenient way to communicate and convey information, the hardware device selected in this research is the mobile device of iOS system.

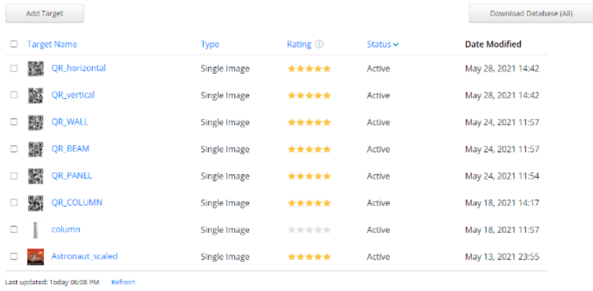
## 4.2 Build database for image target

Image target, in this article, refers to the images captured with a mobile device to generate the corresponding checklist that contains PC status and surrounding environment for pre-installation checking. Because PC physical features are difficult to extract, and the difference is not obvious enough. Therefore, the QR image with obvious features is selected as the representative of each component. The comparison of feature point extraction is shown as follow.


Figure 5. Comparison of QR code and PC image effects (yellow points mean feature points extracted by Vuforia)

As shown above, it turns out that the feature points of QR code image could be extracted easily; as for the PC image, due to the lack of distinct feature, only two feature points were extracted. Therefore, if the PC image is directly used, the camera will not recognize accurately, and QR image is a better substitute.

Besides, Vuforia engine developer portal is utilized to build a database for QR code images as shown in Figure 6. In the target manager, target name, type, status and date modified, etc. were shown for further checking.



| Target Name | Type | Rating | Status | Date Modified |
|---|---|---|---|---|
| QR_horizontal | Single Image | ★★★★★ | Active | May 28, 2021 14:42 |
| QR_vertical | Single Image | ★★★★★ | Active | May 28, 2021 14:42 |
| QR_WALL | Single Image | ★★★★★ | Active | May 24, 2021 11:57 |
| QR_BEAM | Single Image | ★★★★★ | Active | May 24, 2021 11:57 |
| QR_PANEL | Single Image | ★★★★★ | Active | May 24, 2021 11:54 |
| QR_COLUMN | Single Image | ★★★★★ | Active | May 18, 2021 14:17 |
| column | Single Image | ☆☆☆☆☆ | Active | May 18, 2021 11:57 |
| Astronaut_scaled | Single Image | ★★★★★ | Active | May 13, 2021 23:55 |

Figure 6. Screenshot of the image database

## 4.3 Build information management platform during the installation phase

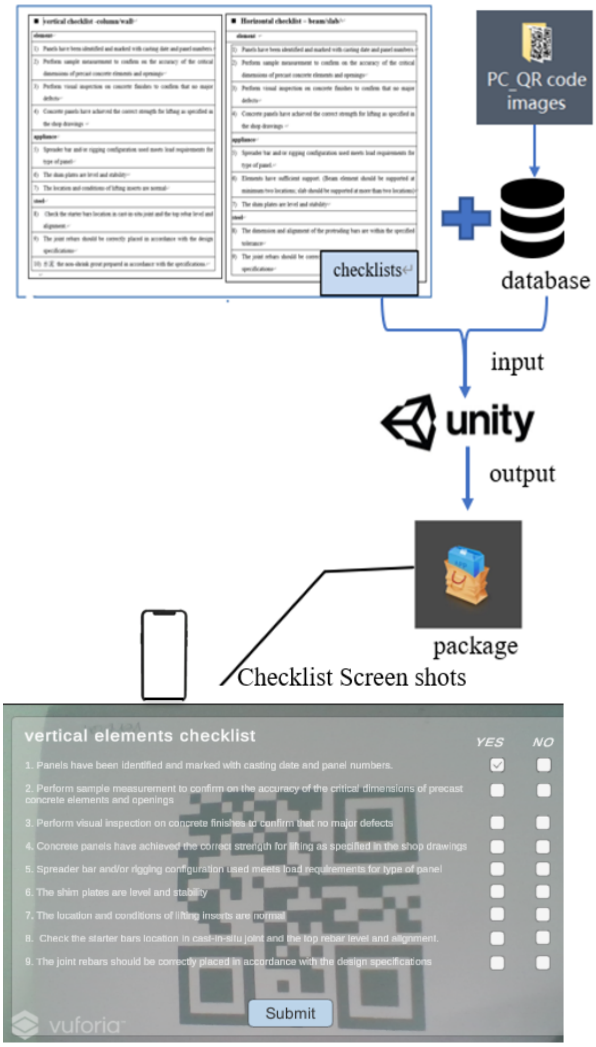



Figure 7. The flow of PC's checklists shown in mobile devices

In accordance with the general order of assembly, there are two pre-installation checklists about PCs, respectively vertical PC checklist and horizontal PC checklist. There are three aspects: component, appliance and steel, to confirm whether the component can start to be installed. Then import them into the corresponding QR code image in Unity as shown in Figure 7. The finished system is then generated as an installation package and sent to the mobile device.

As shown in the above interface, if all the items are checked "YES", then the checklist of the component can be submitted and the status of the component changes from "Start Installation" to "Installation completed". If any item is selected as "NO", then the "Submit" button will not run and the state of the component will remain "arrived".

## 5 Conclusion

In this paper, an algorithm was proposed in order to trace and manage the information of PC components which are being transported to construction site. Procedure to handle the PC components of different risk levels was summarized and checklist of information required for PC installation is constructed as well.

In addition, this study only preliminarily establishes the UI of PC information management in the installation stage of the construction site. The summary of the information after the installation of each PC and reflected in the BIM model for visualization is the direction of future research. There are two forms that can be adopted to achieve the purpose of visualization of installation progress: one is through statistical graphics that can reflect the progress, and the other is to establish a connection between each PC and BIM model.

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