ABSTRACT: Great amount of information is generated during the construction stage of an engineering project, and ineffectiveness in collecting the construction information will bring adverse effects on the achievement of project objectives. This paper firstly puts forward an original conception of ‘meticulous collection methods of construction information’, based on the evidence-based science theory. Then this paper conducts a three-class meticulous classification of the regular construction information. In combination with advanced information collection techniques and the characteristics of the construction information, the meticulous collection system of construction information is designed. The proposed system is proved to be instrumental by a case project and the proposed meticulous collection techniques of steel members implemented in the case project has been proved to be effective and convenient. This research offers a new perspective for construction information collection and provides useful inputs for project managers to improve the management efficiency of construction information. The system established in this paper will accelerate the development and combination of information collection techniques and project construction, and therefore boost the informatization process of engineering projects.

Keywords: engineering projects; information technology; three-class meticulous classification; meticulous collection system; evidence-based science theory

1 INTRODUCTION

The construction industry plays a fundamental role in China’s economic and social development. In 2014, China has witnessed an 8.9% increase in the total value of the construction industry, up to 4472.5 billion Yuan, which accounts for 7% of gross domestic product (GDP) of China[1]. However, various management issues, such as low efficiency in usage of raw materials and limited degree of informatization in the construction industry remain unsolved, which result in cost overruns, schedule delays and quality deficiencies of some construction projects[2]. According to statistics, the most amounts (about 50%) of information created during the total lifetime of a construction project come from the construction stage and the main causes to the above chaos come from the lack of in-time tracking of construction information[3].

The currently widely used information collection methods rely on classical manual process, making the efficiency and accuracy of information collection questionable[4]. Therefore, performing meticulous classification on construction information and applying to advanced information collection techniques are of great significance to the efficiency and accuracy of construction information collection and is necessary to obtain in-time information from the construction stage.

2 METICULOUS CLASSIFICATION OF CONSTRUCTION INFORMATION

2.1 Concept of meticulous classification of construction information

Due to the diversity of construction content, complexity of the construction process and the interdisciplinarity between different areas, as well as inner-outer environment coupling, an evident nonlinearity can be found in the construction process of engineering projects. Information in the form of speaking language and empirical communication seems to be straightforward, yet making it challenging to identify prob-
lems and make any inference during the construction process. Accordingly, meticulous classification of information is the basis for obtaining accurate construction information.

From the evidence-based science theory, information is a reflection in the change of dynamic states, characterizing interconnection and interaction between different subjects. Similarly, every characteristic corresponds to specific parameters, forming a dynamic combination. Following this procedure, information can be conducted to a three-class meticulous classification, including information property, characteristics of properties and characteristics parameters.

2.2 Establishing the meticulous classification system of construction information

Large amounts of information will be generated during the construction process, of which the complexity undergoes continuous change in the system comprised of people, equipment, materials, laws and the environment. In combination with characteristics of engineering projects and information properties, information during construction process was initially classified into eight categories, including risks, quality, process, cost, safety, environmental protection, resource supply and others[5]. Based on statistics from a large number of engineering projects, the distribution of information of the eight categories during the construction process was initially classified into eight categories, including risks, quality, process, cost, safety, environmental protection, resource supply and others[5]. Based on statistics from a large number of engineering projects, the distribution of information of the eight categories during the construction process was summarized in Table 1. From Table 1, we can see that quality, process, safety and resource supply amount for the most of the construction information and play a critical role in the achievement of construction objectives.

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Total times</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Engineering Risks</td>
<td>278</td>
<td>8.7</td>
</tr>
<tr>
<td>2</td>
<td>Engineering Quality</td>
<td>510</td>
<td>15.9</td>
</tr>
<tr>
<td>3</td>
<td>Engineering progress</td>
<td>590</td>
<td>18.4</td>
</tr>
<tr>
<td>4</td>
<td>Project cost</td>
<td>346</td>
<td>10.8</td>
</tr>
<tr>
<td>5</td>
<td>Engineering Safety</td>
<td>490</td>
<td>15.3</td>
</tr>
<tr>
<td>6</td>
<td>Environmental protection</td>
<td>210</td>
<td>6.6</td>
</tr>
<tr>
<td>7</td>
<td>Resource supply</td>
<td>480</td>
<td>14.9</td>
</tr>
<tr>
<td>8</td>
<td>Others</td>
<td>300</td>
<td>9.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3204</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1. The total times and frequency of information in the construction stage.

Classical information collection techniques can not satisfy the demand of engineering project management, making it an optimized alternative to perform a three-class meticulous classification on construction information. In combination with characteristics of engineering projects, a two-class classification was performed on the above four main characteristics of information, namely the quality, process, safety and resource supply. The first class was obtained based on the information properties. The second one was classified from different characteristics of information properties. With the third one being the characteristics of information parameters, a three-class meticulous information classification was achieved.

The three-class construction information can be organized into two categories: the virtual and actual ones. As illustrated in Table 2, A12v, B11v, B12v, C11v, D11v and D12v are virtual information, while the rest were actual information. Virtual information differs from actual information in that the virtual information can be obtained from manual statistics and calculation, while actual information is only available from related techniques during the construction process.

3 METICULOUS COLLECTION OF CONSTRUCTION INFORMATION

3.1 Characteristics of information collection techniques

The rapid development of information technology and widely applied computer system in the construction industry makes information identification automatic and intelligent, and thus have improved the efficiency of information collection. Currently, there are two main information collection systems applied in the construction industry, namely the non-spatial information collection and spatial information collection.

Non-spatial information collection includes: global positioning system (GPS), code scanning technology, radio frequency identification (RFID) and micro-electromechanical systems (MEMS). GPS is a positioning technology based on satellite, requiring direct connection between receiver and satellite, making this technology only available for outdoor application. Recently, the addition of laser and other technology units has made the GPS technology applicable for indoor usage, and mostly for tracking of labors and materials[6]. Code scanning is a reliable and low cost information collection technology. However, some concomitant shortcomings do exist concerning this technology, including limited scanning distance, low durability and strict environmental requirement. This technique is mainly used for tracking of the materials, construction schedule and control of labors[6]. RFID is suited to various construction applications and generates cost savings via increased speed and accuracy of data entry[7]. RFID shares many similarities with traditional code scanning techniques.

However, it has overcome the challenges of low durability and heavy reliance on environment. This technique is believed to be a new generation of the code scanning technique and it is mainly used in the monitoring of labors, tracking of materials and the control of construction schedule[6]. Built on the basis of cheap sensors, MEMS is a low cost system used mainly for system control, tracking modulus of fragment surface. Thereafter, MEMS has been dominantly
Spatial information collection includes: visual measurement and laser detection and ranging (LADAR) techniques. Vision measurement technique includes photograph measure technique, video measurement technique and 3D distance measurement camera. Photograph measurement technique is based on 3D reconstruction from 2D picture photographed by camera. Video measurement is similar to photograph measurement, except that frame is used for 3D reconstruction instead of 2D picture. 3D distance measurement camera has the advantage to analyze, track and model a moving object. Significant data about construction schedule and location of key materials will be obtained after manual analysis or process of advanced pattern recognition algorithm. LADAR is a laser scanning system which instantly build CAD 3D model by getting coordinate of various spatial points. Decrease in the cost of LADAR device and its increased reliability make LADAR an attractive tool in construction monitoring and control. Currently, LADAR has been widely used in materials tracking, mechanical monitoring, schedule tracking, quality control and construction safety monitoring. Comparisons of spatial information collection techniques are shown in Table 3.

### 3.2 Establishing the meticulous collection system of construction information

According to previous studies, current information collection system is focused on the first class of construction information and was rarely utilized for meticulous classification. This paper attempts to fill the gap of knowledge by focusing on the analysis and discussion on the applicability of the three-class meticulous classification of construction information.
Inspired by academic literatures, the three-class meticulous classification of construction information has been constructed in combination with the reality of engineering projects and characteristics of information collection techniques. The comparison between single information collection technology and combined information collection technology is shown in Table 4. Single information collection technique was obtained from applicability of the three-class meticulous classification of construction information, while combined information collection technique was made from the comparison and analysis of the differences between two or three different kinds of information collection techniques.

From Table 4, each kind of information corresponds with several different information collection techniques. For instance, A13, which corresponds to quality control, can be obtained from LADAR, LADAR-vision measurement and GPS-LADAR techniques. If the measurement is based on the LADAR measurement, more characteristics of target, like color, can be obtained by LADAR-vision combined technique, making 3D modeling more accurate. Conclusively, the exact technique decision for the collection of the three-class meticulous information is made on the basis of the project budgets and the information collection system established in this paper.

4 CASE STUDY

Nowadays, engineering projects tend to be more complex and large-scale, while construction management is still limited to the form based on manual process, necessarily assisted by software and equipment. This inconsistency cannot satisfy the demand of engineer-
ing projects management. The most challenging problem in the management of complicated engineering projects is the resources supply management. Resources supply, especially key materials, is needed during the entire construction process. The failure in tracking key materials will cause cost overruns, schedule delays and quality deficiencies of the engineering projects. Our research team has been invited, as the third party, to research on how to improve the tracking of resource supply of an engineering project.

The three-class meticulous classification was performed on the virtual construction information of the project, and the incompleteness corresponding to each class was utilized as the criteria to group statistic subjects. A five-class classification, 5, 4, 3, 2, 1 was attributed to the degree of incompleteness. Totally, 132 samples were obtained from the statistics. Therefore, for each criterion, 132 results for parameters, corresponding to degree of incompleteness, have been attributed. The parameters form these data, corresponding to each criterion, have been normalized between 0 and 1 to get specific parameters (shown in Table 5) for each criterion. On the basis of this normalization, the severity for each specific parameter was obtained. The results have been accepted by experts of the project. More importantly, meticulous classification of construction information has been used to solve the essential problems in tracking the resource supply of the project. After a quantitative in-depth analysis of available data, it has been found that the main factors cause the incompleteness of the project lie in the failure in in-time status tracking of construction materials. Based on the analysis of in-time meeting digest, process reports and working diaries, it has been further

<table>
<thead>
<tr>
<th>Code</th>
<th>Diagnostic index</th>
<th>Degree of incompleteness βij</th>
<th>Normalization xij</th>
<th>Severity Σβij xij</th>
</tr>
</thead>
<tbody>
<tr>
<td>D11</td>
<td>Make resource supply plan</td>
<td>11</td>
<td>9</td>
<td>55</td>
</tr>
<tr>
<td>D12</td>
<td>Implementation situation of resource security system</td>
<td>5</td>
<td>21</td>
<td>55</td>
</tr>
<tr>
<td>D21</td>
<td>The number of labor allocation</td>
<td>0</td>
<td>12</td>
<td>57</td>
</tr>
<tr>
<td>D22</td>
<td>The number of labor utilization</td>
<td>7</td>
<td>5</td>
<td>69</td>
</tr>
<tr>
<td>D31</td>
<td>Real time state of material supply</td>
<td>87</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>D32</td>
<td>Utilization situation of received materials</td>
<td>5</td>
<td>21</td>
<td>73</td>
</tr>
<tr>
<td>D41</td>
<td>Equipment working status</td>
<td>17</td>
<td>68</td>
<td>29</td>
</tr>
<tr>
<td>D42</td>
<td>Equipment utilization</td>
<td>21</td>
<td>63</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 2. Analysis of the severity of the diagnostic indices.**

**Figure 1. The procedure of in-time tracking of steel members.**
concluded that in-time status tracking of steel members is the origin of problems.

The supply information of materials for construction is one of the D31 information, which can be obtained by LADAR, RFID, code scanning, GPS, vision measurement, RFID-MEMS and GPS-RFID techniques. After analysis and comparison of information collection techniques and references from Table 3, RFID technique has been chosen by our research group to improve the tracking of resource supply of the project. Detailed engineering process will be discussed in the following parts, and the procedure of in-time tracking of steel members is illustrated in Figure 1.

In order to get accurate information about the in-time status of steel members used during the construction process, information collection device of PDA (a kind of information collection device of RFID) is equipped at four node positions, namely the material entrance, the material acceptance, the beginning and the finishing stage of construction. The use of RFID technology together with PDA mobile devices offers considerable advantages such as the reading/writing of RFID tags, irrespective of time and place; maximum security and user-friendliness[14].

During the process of material entrance to construction site, fixed PDA at the entry was used for the scanning and collecting information of electric sticker on the steel members, then updating the data in the database. The supervisors of the project are also informed with the information via emails. In-time information collection of data in this process provides precise and efficient transportation information for supervisors of the project, making it feasible to perform necessary adjustment.

During the process of material acceptance, portable PDA was used to check the functionality of steel members. Two resulting status will be reported: 0 and 1. 1 means the malfunction of steel members and will be sent back to the manufacturers, while 0 corresponds to the eligibility of steel members. Similarly, the status of corresponding materials will be updated in the database. For the beginning and finishing stage of construction, specialists were assigned to scanning and collecting information of electric sticker, then updating the data in the database. The supervisors of the project are also informed on the steel members, making it feasible to perform necessary adjustment.

The application of the three-class meticulous classification and related meticulous collection techniques of construction information has resolved the in-time tracking of resource supply of the project effectively. The proposed information collection technique of RFID and corresponding information collection process (Figure 1) has been implemented in the project. In combination with advanced information collection techniques, the reliability and feasibility of our meticulous collection system of construction information has been testified and approved.

5 CONCLUSION

Construction monitoring technology concerning construction progress, project quality and project cost has always been highly valued by researchers. A construction process should follow the requirement for construction quality, schedule, costs, materials, people, equipment, safety, information and environment. Therefore, huge amount of information will be generated during the construction process. In-time information collection is prerequisite for the realization of project targets. Based on the characteristics of engineering projects and up-to-date information collection techniques, meticulous collection system of construction information has been established in this paper. The reliability and feasibility of the meticulous collection system of construction information has been testified and approved by a project case. This research offers a new perspective for construction information collection and provides useful inputs for project managers to improve the management efficiency of construction information. Research on this meticulous information collecting system will promote the development and combination of information collection technology and project construction, and therefore boost the informatization process of construction management.

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REFERENCES


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