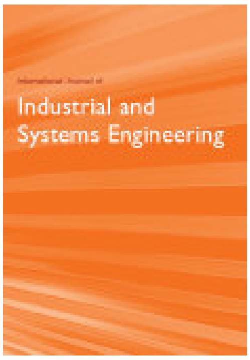

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Production and construction quality management system of prefabricated buildings based on BIM technology

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Abstract: In order to improve the efficiency of quality management of prefabricated building production and construction, a quality management model and system design method of prefabricated building production and construction based on building information modelling (BIM) technology are proposed. The BIM big data of prefabricated building production and construction quality management is collected by using internet of things technology to build BIM information database. The method of fuzzy parameter fusion and performance tracking recognition is used to realise BIM data scheduling and feature distributed fusion. Through rough set feature matching and autocorrelation feature fusion, the model information is optimised and analysed by big data, and the optimal control and convergence judgment of prefabricated component production and construction quality management are realised. The simulation results show that this method has high degree of information fusion and strong resource scheduling ability in the production and construction quality management of prefabricated components.

Keywords: BIM technology; prefabricated building; production and construction; quality management; big data; resource scheduling.

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1 Introduction

In the current use of prefabricated building components, because the related technologies are still in the development stage, there are still some problems in the related construction quality in the production process, and the construction quality and living safety of prefabricated buildings are the common concerns of the society. Therefore, it is necessary to construct an optimised production and construction quality management model of prefabricated buildings, and the related research on such models has attracted great attention (Yin et al., 2016).

Through optimising the monitoring design for parameters about production and construction quality characteristics of prefabricated buildings, state monitoring and optimal control to the production and construction quality of prefabricated buildings can be realised. Based on the analysis results of parameters about production and construction quality characteristics of prefabricated buildings, the production and construction quality of prefabricated buildings can be optimally monitored, which improves the monitoring and real-time state analysis ability to the quality (Huang and Xu, 2020). Conventional methods for production and construction quality management of prefabricated buildings include the statistical analysis method, online evaluation method, fusion control method, and fuzzy information processing method (Li et al., 2017). In Liu et al. (2017), a method for production and construction quality management of prefabricated buildings based on matching autocorrelation feature analysis is proposed to implement production and construction quality management of prefabricated buildings. This method performs not well in intelligent and fusion in production and construction quality management of prefabricated buildings. In Tim et al. (2015), a production and construction quality management model for prefabricated buildings based on fuzzy detection and statistical analysis is proposed to implement the dynamic interaction and optimal management of BIM information about production and construction quality of prefabricated buildings and improve information fusion. However, the statistical analysis and autocorrelation feature matching abilities of this method are poor in processing BIM information about production and construction quality of prefabricated buildings. In Chen et al. (2017), a method for production and construction quality management of prefabricated buildings based on adaptive association rule analysis is proposed for production and construction quality management of prefabricated buildings. This method causes high fuzzy in production and construction quality management of prefabricated buildings.

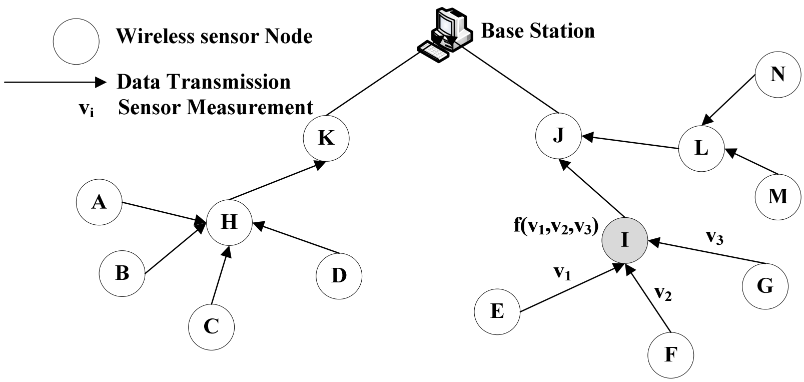
In order to solve the above problems, a method for production and construction quality management model and system design of prefabricated buildings based on building information modelling (BIM) technology is proposed. Big data of BIM are analysed, and the methods of fuzzy parameter fusion and performance tracking and recognition are used for scheduling of BIM data about production and construction quality management of prefabricated buildings and distributed fusion of features. A game model for scheduling of BIM information resources of production and construction quality management of prefabricated buildings is constructed, on which a real-time data cluster analysis model for production and construction quality management of prefabricated buildings is established. Through rough set feature matching and autocorrelation feature fusion, optimal control and convergence judgment are carried out to production and construction quality management of prefabricated buildings. Finally, a simulation test is carried out, which shows that this method has superior performance in improving the production and construction quality management of prefabricated buildings.

2 Analysis of the management of BIM information about production and construction quality of prefabricated buildings

2.1 Construction of dynamic information control model

In order to realise the production and construction quality management of prefabricated buildings based on BIM technology, wireless sensor network and the internet of things networking technology are adopted to collect big data of BIM information about production and construction quality management of prefabricated buildings (Sun et al., 2015). The big data acquisition model of BIM information for prefabricated building production and construction quality is shown in Figure 1.

Figure 1 Collection of big data of BIM information about production and construction quality of prefabricated buildings



In the data collection model shown in Figure 1, multi-dimensional fusion is carried out to BIM information about production and construction quality of prefabricated buildings. The related peak of BIM fusion of production and construction quality of prefabricated buildings is as follows:

$$T(n) = \sum_i R(n, i) + T(n+1) \tag{1}$$

where $T(n + 1)$ represents the load characteristic quantity for dynamic interaction of BIM information about production and construction quality of the $(n + 1)^{th}$ floor of a prefabricated building; $R(n, i)$ represents the balanced scheduling parameter set of the production and construction quality control information interaction node i of the prefabricated building (Zheng, 2016). In the analysis of energy cost of BIM information about production and construction quality of the prefabricated building, when $n = 0$, the equilibrium configuration parameter of BIM information about the quality is obtained, and it satisfies $T(0) = T(1)$. When $n = N$, the distribution characteristic quantity of adaptive finite element mesh of production and construction of the prefabricated building is obtained, and it satisfies $T(n)=\sum_{i} R(n,i)$. With the neighbourhood balanced scheduling method, the characteristic distribution sequence of structure elastic-plastic interaction in the production and construction of the prefabricated building is obtained as follows:

$$I(i)=\sum_{j\in Inf(i),\, j\neq i} T(j) \tag{2}$$

where $Intf(i)=B-\frac{L\mu(i)}{128{,}512}$. B is the stiffness information of BIM group set of production and construction quality of the prefabricated building, and $\mu(i)$ is the plastic parameter of discrete element.

In the ideal elastic-plastic model, the cluster analysis model for transmission of BIM information about production and construction quality of prefabricated buildings is constructed. With the fuzzy C cluster analysis method, the fusion cluster parameter of dynamic information sample of production and construction of prefabricated buildings is obtained and expressed as follows:

$$\alpha(i,j)=\begin{cases} 0, & i=0 \text{ or } j=0 \\ 1, & n-j<i, i\geq j \\ 1, & n-i<j, j\geq i \\ 1-{}_{n-j}C_i \big/ {}_nC_i, & n-j\geq i, i\geq j \\ 1-{}_{n-i}C_j \big/ {}_nC_j, & n-i\geq j, j\geq i \end{cases} \tag{3}$$

Under the constraint of elastic critical load, the error of production and construction quality management of prefabricated buildings is calculated, and the dynamic interactive transfer function is obtained $P_C=\sum_{i=0}^{n}\sum_{j=0}^{n}\alpha(i,j)P(i,j)$. Under the yield stress of prefabricated building materials, the impact characteristic quantity before the structure reaches the elastic critical load is obtained as follows:

$$h(t)=\sum_{i=1}^{P} a_i p\left(t-\tau_i\right) \tag{4}$$

where a_i and τ_i are the structural elastic-plastic buckling parameters of production and construction quality of the prefabricated building. Under the constraint of yield stress and elastic modulus of materials (Das et al., 2017; Wang et al., 2020), the stress time distribution sequence of local coordinate system is obtained by different stress-strain relation distribution fusion methods, and it is $a(t)$. The normal contact force is R_a and path loss is T_a, $T_a = 1/R_a$, so $a(t)$ is:

$$a(t)=\sum_{n=0}^{\infty} a_n R_a\left(t-nT_a\right) \tag{5}$$

With the small-area stress-driven control method, the dynamic control model of BIM information about production and construction quality of the prefabricated buildings is constructed to improve the online control ability to the production and construction quality of the prefabricated building.

2.2 Building BIM information fusion and association feature analysis mode

A BIM information database for production and construction quality of prefabricated buildings is constructed in distributed wireless sensor distribution nodes. With the methods of fuzzy parameter fusion and performance tracking and recognition (Gomes et al., 2018), the matching set of dynamic fusion parameters of BIM information about production and construction quality of prefabricated buildings is obtained as follows:

$$U_{v_i} = \beta_{v_i} \times \ln\left(1 + \partial_{v_i} \times \sum_{j=1}^{K} S_{v_i} e_j^T \frac{R_{C_j}}{n_{C_j}}\right), \qquad v_i \in v, C_j \in C \tag{6}$$

where $n_{C_j} = \sum_{j=1}^{K} S_{v_i} e_j^T$. $e_j^T = (0, \ldots, 1, \ldots, 0)$ represents the relevant characteristic quantity of ideal elastic-plastic model. Under the constraint β_{v_i} of elastic law, $\sum_{j=1}^{K} S_{v_i} e_j^T \frac{R_{C_j}}{n_{C_j}}$ is used to indicate the sampling interval of dynamic BIM information of production and construction quality of the prefabricated building. Therefore, the equation $U = \sum_{v_i \in V} U_{v_i} = \sum_{v_i \in V} \beta_{v_i} \times \log\left(1 + \partial_{v_i} \times \sum_{j=1}^{K} S_{v_i} e_j^T \frac{R_{C_j}}{n_{C_j}}\right)$ indicates the yield stress of the prefabricated building when a small area on the cross section is in the elastic stage, and the stress evaluation result of the construction quality of the building structure is obtained and output as follows:

$$CCP(i) = \frac{NCN(i)}{\sum_{j=1}^{CN} NCN(i)} \tag{7}$$

where *NCN*(*i*) represents the interference characteristic quantity of dynamic distribution of BIM information about production and construction quality of the prefabricated building. Higher *CCP*(*i*) level indicates higher monitoring and management reliability to production and construction quality of the prefabricated building (Jiang et al., 2018; Ahmadi et al., 2016; Vu et al., 2012). The efficiency factor of yield surface is obtained as follows:

$$\{b_1', b_2', \ldots, b_v'\} = \underset{\{b_1, b_2, \ldots, b_v\}}{\arg\min}\left(\max_{\sum_{v=1}^{V} b_v \bullet x_v < 0, 1 \le n \le N} \left|\sum_{v=1}^{V} b_v \bullet x_v\right|^2\right) \tag{8}$$

According to the above analysis, the fusion and correlation feature analysis model of BIM information about production and construction quality of the prefabricated buildings is constructed, and expressed by $x(t)$. The fading variance of dynamic interaction of BIM information about production and construction quality of the prefabricated building is defined as:

$$\sigma_x^2 = E\left[x^2(t)\right] \tag{9}$$

The complex envelope E of material loading surface and initial yield surface is calculated. Through prior fusion scheduling of production and construction quality, construction quality management is optimised.

3 Optimisation of production and construction quality management of prefabricated buildings

3.1 Building BIM information resource scheduling game model

The methods of fuzzy parameter fusion and performance tracking and recognition are used for scheduling of BIM data about production and construction quality management of prefabricated buildings and feature distributed fusion. A game model for scheduling of BIM information resources of production and construction quality management of prefabricated buildings is constructed, and described as follows:

$$\begin{cases} \max U = u_1 + u_2 + \ldots + u_n \\ u_i = p_i \\ \sum_i^n p_i = 1,\ 0 < p_i < 1 \\ \dfrac{p_1/(1-p_1)}{w_1} = \dfrac{p_i/(1-p_i)}{w_i} = \ldots = \dfrac{p_n/(1-p_n)}{w_n} = \dfrac{1}{K} \end{cases} \tag{10}$$

In the random distribution model of nodes, the coverage area A of BIM information about production and construction quality of the prefabricated building is divided into $W \times L \frac{\sqrt{2}}{2} R_c \times \frac{\sqrt{2}}{2} R_c$ matching regions. According to the distribution characteristics of directional yield surface, the distribution matrix of trial stress values of dynamic interaction of BIM information about production and construction quality of the prefabricated building is obtained:

$$Z^N = g \cdot X^N + W^N \tag{11}$$

where $Z^N = (z_1, z_2, \ldots, z_N)^H$, $X^N = (x_1, x_2, \ldots, x_N)^H$, $W^N = (w_1, w_2, \ldots, w_N)^H$ and $N = 1, 2, \ldots$ are fuzzy vector parameter sets for BIM information scheduling of production and construction quality of the prefabricated building.

$\boldsymbol{A} \in C^{n\times n}$ ($n \times n$ dimensional complex number space) is set as the covariance matrix for interactive management of production and construction quality of the prefabricated building, $\boldsymbol{v} \in C^n$. The high-order statistical distribution sequence associated with production and construction quality of the prefabricated building is obtained, $r(n) = r(n\Delta t)$, $n = 1, 2, \ldots, N - 1$, and

$$f_s(n) = f_s(n\Delta t) = \sqrt{s} f(sn\Delta t), \quad n = 0, 1, 2, \ldots, M - 1 \tag{12}$$

According to the plane section assumption, with the discrete element analysis method, the output expression of production and construction quality monitoring of the prefabricated building is obtained as follows:

$$P_{ij}(k) = \frac{\left(l_j(k) - l_i(k)\right)\eta_{ij}(k)}{\sum_{j \in N_i(k)} \left(l_j(k) - l_i(k)\right)\eta_{ij}(k)} \tag{13}$$

where

$$j \in N_i(k), N_i(k) = \left\{\left\|x_j(k) - x_i(k)\right\| < r_d(k)\right\} \tag{14}$$

In this way, the characteristic parameters of production and construction quality of the prefabricated building are fused and correlated. Based on the BIM information scheduling results, the management and optimisation control of production and construction quality of the prefabricated building are carried out.

3.2 *Optimisation of production and construction quality management of prefabricated buildings*

A real-time data cluster analysis model for production and construction quality management of prefabricated buildings is established, and with the methods of rough set feature matching and autocorrelation feature fusion (Kim and Kim, 2018), the method can obtain the correlation between the two input features and calculate the two transformations. The transformed features have higher correlation than the input two feature sets, so as to optimise the above model. The window function $h(t)$ for production and construction quality management of prefabricated buildings is obtained. With $x = \sqrt{x_1^2 + x_2^2}$, the channel allocation model for production and construction quality management and resource scheduling of prefabricated buildings is obtained:

$$p(x) = \begin{cases} \frac{x}{\sigma^2} \exp\left(-\frac{1}{2\sigma^2} x^2\right), & x > 0 \\ 0, & x < 0 \end{cases} \tag{15}$$

When $\sigma^2 = 1$, the axial strain increment caused by axial force in the production and construction of the prefabricated building is:

$$E(x) = \sqrt{\frac{\pi\sigma^2}{2}} \tag{16}$$

$$\text{var}(x) = \left(2 - \frac{\pi}{2}\right)\sigma^2 \tag{17}$$

With the stress allocation model of the discrete element plastic zone, the characteristic parameters of production and construction quality of the prefabricated building are fused by segments, and the autocorrelation statistical analysis and parameter matching characteristic quantity of production and construction quality of the prefabricated building is obtained, and it is $\{X_v, v = 1, 2, \ldots, V\}$. When $\tilde{x} = \sum_{v=1}^{V} b_v x_v$ is the minimum, the information fusion component of production and construction quality management of the prefabricated building is obtained as follows:

$$\begin{cases} H_0 : x'(t) = w(t) \\ H_1 : \sqrt{E}s'(t) + w(t) \end{cases} \quad 0 \le t \le T \tag{18}$$

where $x'(t)$ and $s'(t)$ are respectively

$$x'(t) = x(t) * h_w(t) \tag{19}$$

$$s'(t) = s(t) * h_w(t) \tag{20}$$

A real-time data cluster analysis model for production and construction quality management of the prefabricated building is established, and with the methods of rough set feature matching and autocorrelation feature fusion, the optimal control and big data analysis of production and construction quality management of the prefabricated building are realised (Wang and Zhou, 2018), and the expression for production and construction quality management of the prefabricated building and fuzzy function is obtained as follows:

$$-\beta \frac{\partial k(W^T z)}{\partial W} = sign\left(k(W^T z)\right) * \left[E\left\{z(W^T z)^3\right\} - 3W\|W\|^2\right] \tag{21}$$

$$k(x) = E\left(x^4\right) - 3E\left(x^2\right) \tag{22}$$

Based on the above analysis, optimal control and convergence judgment of production and construction quality management of the prefabricated building can be realised, and the production and construction quality management ability to buildings can be improved.

4 Simulation test and analysis

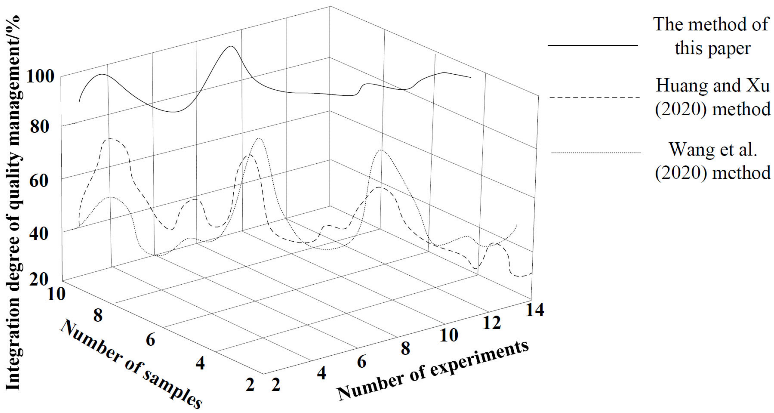
4.1 Experimental design

In order to verify the effectiveness of the system designed in this paper in realising real-time monitoring and management performance of production and construction quality of buildings, a simulation experiment was carried out. Test samples were selected, and the construction quality of sampled data was tested in MATLAB simulation environment. In addition, SPSS 14.0 statistical analysis software was adopted for information processing and data analysis of production and construction quality management. The sampling size of BIM information about production and construction quality of buildings was set to be 1,500, the size of test sample to be 120, the number of statistical characteristic distribution digits to be 12, and the sampling frequency of BIM information about production and construction quality to be 25 kHz. Based on these settings, the quality integration and convergence of the method proposed in this paper and conventional methods were tested, and statistical analysis was carried out to the description of construction quality management.

4.2 Experimental results of fusion degree

The fusion degree of production and construction quality management of prefabricated buildings is an index to test the optimal control of construction quality and the real-time matching of information. Firstly, the fusion degree of quality management of collected samples was tested in MATLAB simulation environment, and the fusion degree was obtained. In SPSS 14.0, three variables were defined: the times of experiment, the number of samples, and the fusion degree. The experiment was carried out 14 times, with 10 samples. The data were input, and analysed using the chi-square test. After test, the chi-square test results were output. According to the results of descriptive statistical analysis, the big data fusion results of the method proposed in this paper and the methods proposed in Huang and Xu (2020) and Wang et al. (2020) were obtained as shown in Figure 2.

Figure 2 Big data fusion results of production and construction quality management of prefabricated buildings

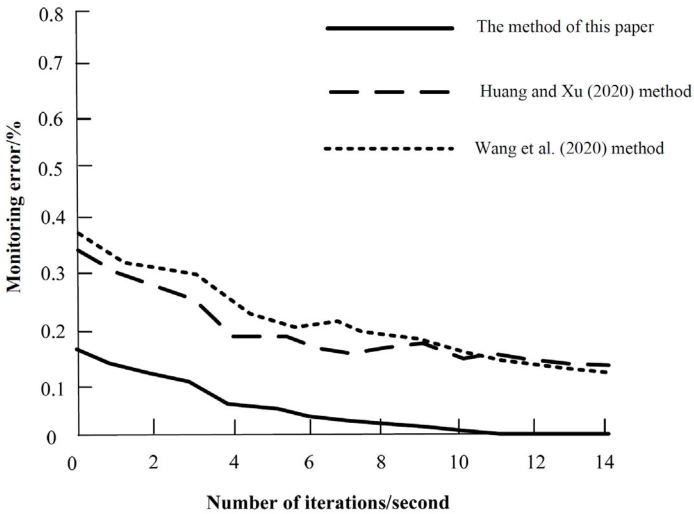


Analysis of Figure 2 shows that the average fusion degree of the method proposed in this paper in quality management is above 80% and that of the methods proposed in Huang and Xu (2020) and Wang et al. (2020) is below 80%. The results verify that the method proposed in this paper can effectively realise the production and construction quality management of prefabricated buildings, and has a high level of information fusion. This is due to the method in this paper in order to achieve the use of wireless sensor network and Internet of things networking technology, collect BIM information big data of prefabricated building production and construction quality management and build a model, in order to optimise the prefabricated building production and construction quality management, improve the ability of information fusion and feature analysis of prefabricated building production and construction quality and real-time monitoring performance.

4.3 Experimental results of convergence

The monitoring error of production and construction quality of prefabricated buildings is judged according to convergence. The minimum iteration parameter was set to be c_{2ini} = 0.67, the iteration step size of genetic evolution to be c_{2fin} = 5.4, the maximum detection threshold to be $\mu_{\max}$ = 0.67, and the minimum detection threshold to be $\mu_{\min}$ = 0.23. According to the above parameter settings, the convergence of different methods in production and construction quality management control of prefabricated buildings was tested in the simulation environment, and the results were obtained as shown in Figure 3.

Figure 3 Convergence test



According to the simulation results shown in Figure 3, the monitoring error of the methods proposed in Huang and Xu (2020) and Wang et al. (2020) is higher than that of the method proposed in this paper, and the monitoring error of the method proposed in this paper is lower than 0.2% and gradually tends to 0%, which indicates that the method proposed in this paper can provide high information fusion and has strong resource scheduling ability in production and construction quality management of prefabricated buildings. This is because this method constructs the channel allocation model of quality management and resource scheduling of prefabricated building production, improves the real-time monitoring and management ability of prefabricated building production and construction quality, and reduces the monitoring error to a certain extent.

5 Conclusions

In this paper, a BIM-based quality management mode and system for the production and construction of prefabricated components are proposed. By establishing the dynamic information control model of prefabricated components, fuzzy parameter fusion and performance tracking identification methods are adopted to improve the efficiency of the production and construction quality management of prefabricated components.

1 The research shows that the average fusion degree of the proposed method in quality management is more than 80%, which effectively realises the production and construction quality management of prefabricated buildings, and has a high level of information fusion.

2 The research shows that the monitoring error of the proposed method is less than 0.2%, and gradually tends to 0%, which indicates that the proposed method can provide high information fusion in prefabricated building production and construction quality management, and has strong resource scheduling ability.

3 However, this study only tested the fusion degree of production and construction quality management information and monitoring error, but did not test a wider range of prefabricated building information, which will be supplemented in the next study to improve the practicability of this method.

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