Architectural Design Model based on BIM Management System Model and Data Mining

Tiandong Shao\textsuperscript{a,}\textsuperscript{*} and Chunming Zhang\textsuperscript{b}

\textsuperscript{a}Kunming University of Science and Technology Design and Research Institute, Kunming, 650051, China
\textsuperscript{b}Yunnan Arts University, Kunming, 650051, China

Abstract

An empirical study of the architectural design model based on the BIM management system model and data mining is carried out. Combined with the current code for the design of building structures, a two-level hybrid optimization algorithm is proposed. The optimal design of the structure is divided into two levels: unit optimization and overall stiffness optimization. First, the result of the overall stiffness optimization is taken as the lower limit. The genetic algorithm is used to complete the structural strength optimization design, and then the result of the unit optimization is used as the lower limit. The above optimization algorithm is implemented on large finite meta-software and special software for building structure design. The tall building structure of the two-story is optimized, and the result shows that the proposed method is effective and operational.

Keywords: BIM management system; data mining; architectural design model

(Submitted on August 14, 2018; Revised on September 12, 2018; Accepted on October 16, 2018)

© 2018 Totem Publisher, Inc. All rights reserved.

1. Introduction

With the continuous improvement of information technology and computing power, the architecture industry has begun to learn from other manufacturing industries and introduce advanced technology to improve safety management [1–2]. In recent years, BIM technology has been gradually emerging in the field of architecture engineering, which has attracted the attention of academia and government departments. As an integrated project database, it has the characteristics of integration, coordination, simulation, and visualization and can store, share, and call data information. It has proven to be the core technology to upgrade the technology and management of construction industry in the future [3]. BIM technology is used in the process of station construction safety management and can integrate and deal with safety management information, enhance communication efficiency, and improve management process, thereby enhancing management level of construction safety [4]. In addition, the progress of the three-dimensional laser scanning technology, sensors, radio frequency identification, and other data acquisition technology can not only reduce data collection cost and improve data acquisition capability, but can maintain continuous monitoring during the construction process, combine the advanced data acquisition technology with BIM technology, meet the requirements of BIM for data analysis and processing, realize the integration of information collection and processing of safety management, expand the management time and space range, and improve the technology and means of safety management [5]. Aiming at a series of key problems of the optimization design of high-rise buildings, including the optimization problem of multi-objective beam selecting rebar, optimization of component section size, topology optimization of multi-objective structure scheme, and earthquake resistant design of multiple targets, the genetic algorithm and criterion method are used as tools. Research on an optimal hybrid algorithm is developed [6]. The second development is carried out based on the existing analysis and design software.

2. State of the Art

At present, the application of structural optimization is far behind theoretical research. The optimization design of civil buildings in high-rise buildings is seldom applied [7]. The main reasons are as follows: the optimal design of building...
structures is a complex discrete-variable optimization problem with multiple operating conditions, multiple variables, multiple constraints, and multiple objectives, and it has a great deal of uncertainty. Moreover, the system of building structures is complex, and there are many requirements for a standard structure. It is very difficult to establish a comprehensive and practical algorithm [8]. The problem of engineering design is very complicated, structural optimization design requires in-depth sensitivity analysis, and the speed and accuracy of the software are strictly required for it. In the optimization design, the structural finite element model evolves frequently, and the front and rear models are complex in the calculation analysis. The optimization algorithm provided by general large-scale software cannot meet the design requirements of building structure, whether computing efficiency or optimization results [9-10]. At present, the optimization research of building structure only focuses on the optimization of structural dimensions, while the optimization of structural integrity is ignored. The cost of the project is taken as the goal singly [11]. Therefore, it cannot be completely convincing. Some research results show that multi-objective topology optimization is more meaningful than single objective size optimization. The structure optimization algorithm needs to be further improved; the multi-objective optimization problem dealt with by the intelligent expert system is affected by the accumulation of expert knowledge. The internal force of innovation is insufficient and cannot adapt to the diversity and complexity of the current architectural structure [12-13].

3. Methodology

3.1. Model Algorithm of BIM Management System based on Architectural Design and Construction Safety

Construction safety management is a dynamic management process, and decision making should be based on the actual situation of the site, which requires timely information in the construction process to construct a dynamic model [14]. At present, there are three ways to construct the dynamic model of building main structure: one is pure manual construction, that is, to update the relevant parts of the BIM plan model by observing, photographing, or photographing the finished work, the defect of which is that it cannot set up an accurate and realistic dynamic model and is time-consuming, energy consuming, and prone to errors. Another way is the method created by automation, and there are more studies on it in foreign countries; for example, after many years of research, the framework that is automatically created by the BIM model was proposed by the Brilakis team. Through the six steps of visual and spatial data acquisition, spatial correlation, object feature extraction, object classification and matching, manual operation, parameterization, and application of system constraint parameters, the BIM model can be generated from data acquisition of field structures. However, this involves computer graphics, pattern recognition, and many other fields, and its application is not mature. The last way is real-time updating based on RFID’s BIM model, where the RFID label is posted after the construction of the field component and the ID is used to create the relationship between tags and BIM models to achieve updating of the real-time progress model. This method is often used in steel structure engineering, but it will not be applied when a design changes or construction deviations occur [15]. The above methods have their own shortcomings, and based on the existing planning model, the model is reversely constructed by using 3D laser scanning technology. The key technological processes are shown in Figure 1.

Scan: the bull’s-eye and the site are set at the construction site to ensure that each site can scan three or more bull’s-eyes. After setting up, coarse scanning, fine scanning, and fine scanning of the bull’s-eye, image acquisition is carried out for the spot, and hidden engineering or areas need to be scanned separately to get the initial three-dimensional digital model [16]. Data handling: the scanned data is imported into the Autodesk Recap360, and the registration, stitching, denoising, and optimization of point clouds are carried out to generate a triangular Irregular Network. AutodeskRecap360 can support data formats generated by most 3D laser scanners such as Las, Ptg, Pts, and Fls. For individual unsupported formats, it is able to convert the scan results into Txt text, and then they are imported into AutodeskRecap360 [17]. To generate the 4DBIM model: through the above steps, a real scene model at a certain time can be established in Revit. It will be imported into Navisworks, linking with the process plan generated by Project to build a 4DBIM dynamic model. Then, it works as safety analysis, and engineering quantity and material statistics can be carried out [18].

![Figure 1. The process of dynamic model](image-url)
3.2. Multi-Objective Genetic Algorithm based on Fuzzy Comprehensive Evaluation Technology

It can be seen from the above analysis that the process of beam selecting rebar is a complex multi-objective optimization problem [19]. Therefore, a multi-objective genetic algorithm based on fuzzy comprehensive evaluation is put forward, which not only has the same characteristics as the above genetic algorithm, but also has the following characteristics. The genetic algorithm is used for multi-objective optimization design, and an important question is how to determine the fitness value of individuals based on the multi-objective function value. Fitness assignment scheme and selection in the multi-objective genetic algorithm must consider several objects, and there are three kinds in general: method based on goal aggregation, method based on target (standard), and method based on Pareto superior relation. The fitness assignment method based on aggregation is generally used in the traditional multi-objective genetic algorithm. It is essentially a single objective optimization algorithm, because through the weights to aggregate each target into a goal function, a set of eclectic non-inferiority sets will be generated by the change of the system of the weight parameter commonly. Fuzzy comprehensive evaluation is based on the principle of fuzzy transformation, considering the various factors related to the evaluation object to make a comprehensive evaluation of it [20]. It can better solve the quantitative problem of qualitative indicators, and its characteristic is that the evaluation result is not absolute affirmation or negation but is expressed by a fuzzy set, that is, a relative membership degree set \( u = (u_1, u_2, \ldots, u_k) \). Finally, according to the principle of maximum membership, the optimal scheme is determined. Therefore, the relative membership degree \( u_i \) is put forward here as the quantitative description of the optimality of the individual Pareto, and the fitness value of individuals in the genetic algorithm is determined according to the relative membership degree. At present, the research of genetic algorithm is mainly focused on unconstrained multi-objective optimization problems, while there are few studies on constrained multi-objective optimization problems. Because the above group sorting method is only based on the relative membership degree of each chromosome to sort the individuals, it is simple and effective to solve the unconstrained multi-objective optimization problem. However, for constrained multi-objective optimization problems with constraints, it seems powerless. At present, various penalty functions are used to deal with constraint conditions (including single objective and multi-objective optimization problems). As for the point \( P = (x_{i1}, x_{i2}, \ldots, x_{in}) \) on the decision space, the following penalty function form can be adopted:

\[
f_{i0} = f_{i0} + \lambda R_{i0} \quad R_{i0} = \sum_{j=1}^{n} \{\max(0, g_{ij})\}^2
\]

Because of the finiteness of the group size, genetic manipulation cannot guarantee that the offspring will always inherit the best features of the parent, so some of the best individuals that have ever appeared may disappear in the filial generation. It is similar to the elitism preserving strategy in single objective optimization genetic algorithm, and in order to avoid the loss of the optimal solution in the multi-objective optimization problem, a solution set filter is introduced to record the current optimal solution. At the end of the genetic algorithm, a fuzzy comprehensive evaluation is carried out on the individuals in the solution filter set to find the optimal solution of the optimization problem. In order to get better survival opportunities for individuals with better fitness, individuals with poor fitness are eliminated, and group regrouping can be adopted. Group reorganizing method 1901 integrates two successive generations (parent and offspring) into a large group and then ranks according to the fitness values of all individuals. The better individuals with the same size as the original groups are chosen to form a new generation to prepare for the next reproduction.

3.3. Optimization Design Algorithm for Building Frame Structure

The overall (lateral sway) stiffness of the structure is only related to the section size of the component, which has no relation to the reinforcement of the component. Therefore, under the constraint condition of lateral displacement, the optimization problem of the overall stiffness can be expressed as follows. Design variable: to find out the sectional dimension of the beam-column. Objective function:

\[
\min w = \sum_{i=1}^{n} (w_i b_i l_i)
\]

Constraint condition:

\[
\delta(k) < u(k), \ k = 1, 2, 3, \ldots, t
\]

\[
b_i^{\text{min}} \leq b_i \leq b_i^{\text{max}}, \ i = 1, 2, 3, \ldots, n
\]


\[ h_i^{\min} \leq h_i \leq h_i^{\max}, \quad i = 1, 2, 3, \ldots, n \]  

(5)

Equation (2) represents the total weight or total cost of the structure. \( w_i \) represents the composite index of weight or cost of lever \( i \). \( \delta(k) \) represents the displacement of the \( K \) floor under the load, and \( \nu(k) \) represents the allowable displacement of the \( K \) floor under the load. Equations (4) and (5) define the upper and lower line of the section dimension of the lever. In order to solve the above optimization problems, Equation (3) must be expressed as an explicit form of the design variable. The floor displacement of the virtual work principle can be expressed explicitly as:

\[
\delta(k) = \sum_{i=1}^{n} \int \left( \frac{F_x f_y}{EA} + \frac{F_y f_x}{GA} + \frac{M_y m_x}{EI_y} + \frac{M_x m_y}{EI_x} \right) dx
\]

(6)

Among them, \( F_x, F_y, M_x, M_y \), and \( m_y \), express internal forces and moments of structures under \( J \) loads; \( f_y, f_x, f_y, f_x, m_y, m_y \), and \( m_y \), express the internal forces and moments of the unit caused when the structure is concerned with the action of a unit virtual load at the floor displacement; \( L_i \) is the length of unit \( I \); \( E \) and \( G \) are respectively the elastic moduli and shear moduli; \( A_x, A_y, A_z \) are respectively the axial area and shear area of the cross section; and \( I_x, I_y, \) and \( I_z \) are respectively the moment of inertia and rotary inertia of the section. According to the characteristics of the architectural structure, the optimal design of the RC structure is divided into two stages: the unit strength and stiffness constraints. The overall stiffness optimization under the constraint conditions of the structure side shift is as follows. From the above analysis, it can be seen that the genetic algorithm does not require complex sensitivity analysis, which is suitable for dealing with complex discrete variable optimization problems with multiple variables and constraints. Then, the overall stiffness optimization results are based to model and analyze whether the cell optimization constraints are satisfied. If it is satisfied, the optimal design is finished; otherwise, the overall stiffness optimization design result is taken as the lower limit of unit optimization design, and the unit optimization design is carried out again. The above process is repeated until the optimal result of all constraints in unit optimization and overall stiffness optimization design is achieved. The criterion method is applicable to the optimal design of continuous variables; therefore, the pseudo discrete technique proposed is used to transform the design results into discrete variables.

4. Result Analysis and Discussion

With the above algorithm, an optimal design is carried on the structure of a 30-layer residential building, with the 1st-30th floors of the structure being residential. The height between floors is 3m, the floor dead load and live load are 4.0kN/m² and 2.0kN/m² respectively, and the dead load and live load of roof are 6.5kN/m² and 0.5kN/m² respectively. One site, the seismic grouping is the first group, the fortification intensity is 7 degrees, the acceleration peak is 0.10g, and 15 modes of vibration are considered. The basic wind pressure is 0.7kN/m², and the ground roughness is class C. The initial cross section of the column is 1-4 layer 1000mm × 100mm, the 5-10 layer is 800mm × 800mm, and more than 10 is 500mm × 500mm. The initial cross section of the beam is 250mm × 600mm. The strength of concrete in the standard layer M is C45, C40, C35, and C30 respectively, and the strength of the rebar is \( f_y = 300kN/m² \). The allowable reinforcement ratio is \( \rho_{\text{max}} = 0.8 \), and \( \rho_{\text{min}} = 1.8 \), the allowable axial compression ratio of the column is \( U_{\text{max}} = 0.5 \) and \( U_{\text{max}} = 0.7 \), and the maximum interlayer displacement angle is 1/800. The combined unit price of concrete, rebar, and formwork are respectively: \( C_C = 450 \) yuan/m³, \( C_r = 6000 \) yuan/t, and \( C_f = 36 \) yuan/m². There are four standard layers in the optimization process, and there are 27 kinds of beams and 11 columns in each standard layer. The location and section of the wall are fixed, and the width of the beam is unchanged \( b=250 \). Only square columns are considered, so there are 108 beam design variables (depth of beam) and 44 column design variables (column width). According to the design experience, the cross-section heights of beams are taken as \( h_{\text{min}} = 300mm, h_{\text{max}} = 650mm, \) and \( \Delta h = 50mm \). The cross-section heights of columns are taken as \( h_{\text{min}} = 300mm, h_{\text{max}} = 650mm, \) and \( \Delta h = 50mm \). The initial design domain of the cross section of the beam and column is shown in Table 1.

| Serial number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|----------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Degree of beam cross section (mm) | 300 | 350 | 400 | 450 | ... | 1000 | 1050 | 1100 | ... | 1750 | 1800 | 1850 | 1900 | 1950 | 2000 | 2050 | 2100 | 2150 | 2200 | 2250 | 2300 | 2350 | 2400 | 2450 | 2500 | 2550 | 2600 | 2650 | 2700 | 2750 | 2800 |
| Column cross section height (mm) | 300 | 325 | 350 | 375 | ... | 650 | 675 | 700 | ... | 1025 | 1050 | 1075 | 1090 | 1115 | 1140 | 1165 | 1190 | 1215 | 1240 | 1265 | 1290 | 1315 | 1340 | 1365 | 1390 | 1415 | 1440 | 1465 | 1490 | 1515 | 1540 | 1565 | 1590 | 1615 |
In this case, the beam has at most 16 sections height to choose from, so the length of chromosome coding is 4. The column has at most 32 section heights to choose from, so the length of the chromosome coding is 5. The number of individuals within the population is 3, and the cross probability and mutation probability are pm=0.8 and pc=0.1, respectively. The optimal design on 152 design variables for all columns and beams in the standard layer is carried out, and Figure 2 and Figure 3 respectively show the optimization process of the structural cost and the lateral displacement angle. In the process of strength optimization, after six iterations, the total cost of the structure has been stabilized and the total cost is 1518000 yuan. The lateral displacement angle of the structure floor exceeds the allowable value, and then going into the stiffness optimization stage, after four iterations, it converges to 1761000 yuan. Structural stiffness changes due to local section adjustment. Because local section adjustment causes structural stiffness change, local components do not meet the requirements of strength, returning to the strength optimization design. Finally, after two intensity optimization designs and two stiffness optimization designs, the optimal structural design scheme satisfying all constraints is obtained.

![Figure 2. Optimal history](image)

![Figure 3. The y-direction interlayer displacement angle under earthquake](image)

It can be found by contrasting Figure 4 and Figure 5 that with the increase in floors, the section size of the column and the reinforcement area of the section constantly decrease. On the top floor, the section of the column has been reduced to the minimum limit of the cross section. The axial compression ratio is close to 0.5 in the three standard layers at the bottom and the distribution is uniform, and this is beneficial to the earthquake resistance of the structure. The reason is that the vertical force decreases with the increase in floors. In the past optimization design of building structures, the cost of components is often calculated by the rebar area in the calculation results, without considering the concrete reinforcement form and the requirement of construction. The difference between its objective function and the actual project is rather large. The credibility of the optimization result is reduced. Through the analysis and comparison of the literature, combined with the characteristics of the building structure, it is pointed out that there are both optimization problems of element (strength and stiffness) and optimization of overall stiffness in the optimization design of building structures.
The criterion method is used. Combining with the existing structural design specifications and the characteristics of the building structure in China, for the optimal design problems of discrete variables of reinforced concrete frame structures subjected to multiple loads, a two-level hybrid algorithm for the optimization design of reinforced concrete structures based on genetic algorithm and criterion method is proposed. The concrete flow chart of the solution is given. Optimal design is carried out on the two 30-layer building structures, and the example analysis shows that the proposed method can produce a reasonable, reliable, economical, and operational structural design.

For the proposed hybrid algorithm, the structure is optimized from two levels of structural unit and overall stiffness. In the design and algorithm realization of the optimization model, the actual models, calculation methods, and software in the engineering will be used as far as possible, so as to facilitate the application and popularization of the optimization results; the useful discussion has been made in this respect. The above optimization algorithm is implemented on the special software of building structure design SATWE and the large-scale finite element software ANSYS.

5. Conclusion

Through in-depth understanding of the relevant provisions of the design specification, the feasibility and convenience of design and construction is taken into full account. The past design experience and standard atlas are combined to put
forward the rebar selection formwork of beam section. On this basis, the sectional reinforcement selection database is established for common reinforcement types and section sizes. It is pointed out that the evaluation of the results of the reinforcement should not be taken only by the advantages and disadvantages of some parameters in the process of reinforcement. The method of fuzzy comprehensive evaluation should be adopted. The requirements of various indexes should be taken into account simultaneously. Target evaluation system of beam selecting rebar is established, and the detailed process of calculating the weight of influence factors by using the ordinal two element comparison method is given. The objective function is the minimum square sum of the square of the scheme weighted distance from the optimal and the weighted distance from the inferior, and the calculating formula for the optimal relative membership degree of the scheme is obtained. The characteristics of the continuous problem of optimizing selection of rebar of the beam, based on the genetic algorithm, and the multi-objective reinforcement selection of frame beams are discussed. A genetic algorithm based on fuzzy comprehensive evaluation is presented for solving constrained multi-objective optimization problems (FMOGA). Two objective functions are constructed respectively based on the minimum total cost of the frame beam, the standard adaptability of the reinforcement selection results, and the maximum construction feasibility. Based on the relevant design specifications, a reasonable formulation for multi-objective optimization of beam selecting rebar is presented, with a concrete flow chart solved by FMOGA.

References