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Research and Application of Intelligent Algorithm for Architectural Design Based on Big Data and CAD Technology

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Abstract. Computer-aided design (CAD) technology has become a pivotal tool in contemporary architectural design, finding widespread application across various design domains. The advent of big data has enriched the data resources available for architectural design and enhanced data analysis capabilities. This article delves into the study and application of intelligent algorithms for architectural design, with a specific focus on the utilization of the multi-objective genetic algorithm (MOGA) in optimizing building structures. Methodologically, we employed MOGA and conducted controlled experiments in conjunction with CAD systems. In comparing the step response curves of the traditional genetic algorithm (GA) and MOGA, we analyzed key performance metrics such as response speed, overshoot, and fluctuation amplitude. Additionally, we investigated the influence of population size on algorithm performance. Detailed analysis of convergence characteristics and solving efficiency was carried out through convergence curves. Our findings reveal that MOGA exhibits superior performance in terms of faster response speed, reduced overshoot, and minimized fluctuation amplitude when integrated with CAD systems. This alignment with the real-time and stability requirements of the controlled system underscores the potential of MOGA in architectural design optimization. In addition, a larger population size helps to improve the search and global optimization capabilities of the algorithm, resulting in more constrained building solutions.

Keywords: Architectural Design; Structural Optimization; Big Data; CAD; Multi-Objective Genetic Algorithm
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1 INTRODUCTION

With the swift advancement of information technology, big data and CAD technology have demonstrated immense potential and expansive application opportunities across numerous domains. Notably, in the realm of architectural design, where design requirements are increasingly intricate and varied, conventional design methodologies have proven to be insufficient. Traditional architectural design methods can no longer meet the diverse needs of modern society. The rise of interactive architectural design and the widespread application of CAD (computer-aided design) technology have brought unprecedented changes to the construction industry. Berseth et al. [1] explored the core concepts of interactive architectural design, the exploration of diverse solutions, and the application and impact of CAD visualization in it. Interactive architectural design emphasizes the interaction between designers, users, and the environment. It not only focuses on the structure and function of buildings but also emphasizes user experience and feedback. Through this design method, buildings can better adapt to different usage scenarios and user needs, improving their sustainability and flexibility. CAD visualization plays a crucial role in interactive architectural design. It can not only help designers better present design proposals but also improve communication efficiency and shorten project cycles. Consequently, the fusion of big data analysis with CAD technology to forge new design paradigms and strategies has emerged as a prevalent research focus. CAD digital tools provide students with more efficient and accurate design tools, enabling them to better understand and express design concepts. By using CAD digital tools, students can more intuitively see the three-dimensional effects of the design and better grasp spatial relationships and a sense of scale. In addition, CAD digital tools also provide a rich selection of materials, textures, and colours, allowing students to simulate the appearance and interior design of buildings more realistically. These factors all contribute to improving students' design perception ability. In order to gain a deeper understanding of the impact of CAD digital tools on architectural design perception, Ceylan et al. [2] conducted a case study. Two groups of students were selected, one using CAD digital tools for design and the other using traditional hand drawing methods. During the design process, we observed and recorded the design ideas, expressions, and results of two groups of students. The results show that students who use CAD digital tools pay more attention to details and accuracy in the design process, can grasp design points faster, and express design intentions more accurately. Meanwhile, these students place greater emphasis on communication and collaboration with team members during the design process in order to improve the consistency and completeness of the design.

With the rapid development of technology, big data, CAD technology, blockchain, and BIM (Building Information Modeling) are playing an increasingly important role in the construction industry. Douglas et al. [3] explored how to combine these technologies and constructed a decentralized architecture design BIM and blockchain integration framework based on big data and CAD technology. In the traditional architectural design process, the transmission and processing of information are often centralized, leading to information opacity, proneness to error, and low efficiency. The emergence of BIM technology has made the processing of building information more efficient and accurate. At the same time, the rise of blockchain technology provides new solutions to address issues of information opacity and trust. Applying blockchain technology to the architectural design process to achieve immutability and transparency of information. Through blockchain, all information and data during the design process can be recorded and verified. Build a decentralized design platform so that all participants can engage in collaborative design and information sharing on the platform. Through a decentralized design platform, information exchange and collaboration can be better achieved. The application of big data and computer-aided design (CAD) technology in the field of architectural design is becoming increasingly widespread. In order to better meet people's design needs for personalization, efficiency, and sustainability, the architectural design industry is seeking innovative methods and technologies. Among them, architectural design games based on big data and CAD technology have attracted widespread attention as an emerging design tool. Goli et al. [4] explored the principles, advantages, and future development trends of this gamified design approach. An architectural design game based on big data and CAD technology is an innovative method that utilizes a gamified design interface to simulate the entire process of architectural design, allowing users to experience and participate in architectural design in interactive games. By displaying the design scheme through 3D graphics, users can intuitively understand the design effect and existing problems. At the same time, users can adjust and optimize the design scheme through interactive operations. Provide relevant textual information to help users better understand design proposals and technical details. The text interface can also provide design specifications and standards to ensure the compliance and feasibility of the design. Architectural design is a profoundly interdisciplinary field, encompassing the convergence of multiple disciplines. While traditional design approaches primarily hinge on the designer's personal experience, intuition, and creativity, they often encounter limitations, such as inadvertent oversights and suboptimal outcomes, when tackling complex challenges. The infusion of big data, however, offers a plethora of data resources and robust analytical capabilities, empowering designers to scrutinize and refine design propositions from a more holistic and objective lens.

In contemporary architectural design, big data and computer-aided design (CAD) technology have become indispensable tools. These technologies not only change the way design is done but also offer new insights into the essence of design. Especially the relationship between numbers and physical materiality, as well as the role of materials in it, has become a topic worth exploring. Grigoriadis et al. [5] delved into the digital and physical materiality in contemporary architectural design based on big data and CAD technology, as well as how materials are involved. In traditional architectural design, physical materiality is the core of design, while numbers are more often seen as a tool. However, with the development of CAD technology, the relationship between numbers and physical properties has become increasingly close. Numbers are not only a manifestation of design but also the essence of design. Digital information can be directly transformed into physical structures, which can also be simulated and optimized through digital technology. Materials are an indispensable element in architectural design. Traditional material selection relies on the experience and intuition of designers, but now, through the combination of CAD technology and big data, material selection can be based on more accurate and comprehensive information. With the development of technology, augmented reality (AR) and virtual reality (VR) technologies have been widely applied in many industries. In the field of ship and offshore structural construction, these technologies provide designers and engineers with new tools to design and evaluate more intuitively and efficiently. Among them, the extraction and conversion of 3D CAD data is a key step in achieving this goal. In the construction of ships and offshore structures, designers usually use CAD software for modelling. In order to use these models in AR/VR environments, it is first necessary to extract 3D data from CAD software. If the CAD model contains material and texture information, corresponding conversions are required to ensure correct display in the AR/VR environment. If an animation display is required in an AR/VR environment, an architecture needs to be created based on the CAD model. This process may require a series of binding and weight allocation operations on the model [6]. Furthermore, CAD technology, as a pivotal instrument in contemporary architectural design, has found widespread application throughout the design process, significantly enhancing design efficiency and mitigating costs. Moreover, through accurate mathematical models and powerful calculation ability, CAD technology can quickly and accurately analyze and assess the design scheme.

By utilizing big data technology, various data during the operation of buildings can be quickly and accurately collected, such as energy consumption, environmental quality, equipment status, etc. By processing this data, we can better understand the performance of buildings and provide a basis for optimizing management. CAD technology can be used to create 3D models of buildings, providing managers with more intuitive and vivid visual effects. Through 3D models, spatial planning, layout optimization, and visual simulation can be better carried out. A building automation management system based on big data and CAD technology can achieve intelligent management. Real-time monitoring, prediction, and adjustment can effectively improve building operational efficiency, reduce energy consumption, and improve management quality. In practical applications, various devices and systems may come from different suppliers, and achieving technology integration and interoperability is an important challenge. With the deepening of the concept of sustainable development, future management systems will pay more attention to the design and management of green buildings. To achieve sustainable development goals through optimizing energy utilization, reducing environmental loads, and other means [7]. In urban and architectural design, performance simulation has become a key tool for evaluating the feasibility of design schemes and optimizing performance. Computational Fluid Dynamics (CFD), as a powerful simulation technique, can provide detailed information on fluid flow, heat transfer, pollutant diffusion, and other aspects, providing designers with in-depth insights. Hu et al. [8] explored the application of CFD plugins in the performance simulation of urban and architectural design platforms. In urban and architectural design, CFD simulation can solve many key problems. In addition, CFD can also be used to evaluate building energy efficiency and environmental impact, providing support for green buildings and sustainable development. Taking the design of a high-rise office building as an example, the designer used CFD plugins for performance simulation. During the design phase, the designer used CFD plugins to simulate the airflow inside the building. Through simulation results, the designer found that the natural ventilation inside the building was insufficient, resulting in excessively high indoor temperatures. Based on this result, the designer adjusted the design plan, increased the number of ventilation openings and windows, and optimized the airflow organization. Finally, through CFD simulation verification, the optimized design significantly improved the natural ventilation efficiency and comfort of the building. CAD visualization technology enables designers to present design proposals more intuitively and improve communication efficiency. However, spatial constraints are an issue that cannot be ignored in the process of architectural design. Livshits et al. [9] explored how to solve spatial constraint problems in CAD visualization. Spatial constraints refer to the limitations imposed on the spatial layout, structural form, and material selection of buildings in architectural design due to physical conditions, technical requirements, and functional requirements. Space constraints directly affect the feasibility and rationality of architectural design and are a problem that designers must face and solve. It uses CAD software for simulation analysis, and designers can simulate the spatial layout, structural form, etc., of buildings, predict possible spatial constraints, and optimize and adjust in advance. Through the parametric design function of CAD software, designers can flexibly adjust various parameters in the design scheme, such as size, angle, etc., in order to achieve optimal design results while meeting spatial constraints. Taking a commercial complex as an example, the building faces complex spatial constraints during the design process. Through CAD visualization technology, designers simulate and analyze the spatial layout and structural form of buildings and discover some potential spatial constraint issues. In response to these issues, the designer carried out parameterized design and adjustment, ultimately achieving the optimal design solution that meets various spatial constraints.

Despite its prevalence, traditional CAD technology still faces constraints when addressing intricate structural optimization challenges. To address these limitations, this article introduces an intelligent design algorithm tailored for architecture, leveraging the synergies of big data and CAD technology. This algorithm harnesses the data mining and analytical prowess of big data alongside the precise modelling and computational capabilities of CAD, paving the way for more intelligent, automated, and optimized architectural designs. By integrating optimization techniques like MOGA (Multi-Objective Genetic Algorithm), our aim is to elevate both the design quality and optimization efficiency in the field of architectural design. The Integration of big data and CAD technology into architectural design represents a paradigm shift, not just an incremental improvement to existing design practices. It signifies an ambitious exploration into the future of architectural design, one that holds profound implications for enhancing design quality, meeting complex design demands, and driving innovative growth within the industry. This study offers several novel contributions:

1. It seamlessly blends big data analytics with CAD technology, applying this fusion to real-world architectural design scenarios. Through big data analysis, a wealth of design case studies can be scrutinized, revealing critical design parameters and optimization insights. CAD technology, in turn, provides a powerful medium for visualizing, modelling, and refining these insights into tangible designs.

2. It introduces MOGA as a groundbreaking approach to handle multiple, often competing, optimization objectives simultaneously. These objectives range from structural integrity and material costs to aesthetic considerations, enabling designers to navigate the complexities of the design space and unearth optimal solutions.

In the ensuing chapters, this article delves into the current applications of big data and CAD technology in architectural design. It then shifts focus to elucidate the underpinnings, methodologies, and implementation workflows of the intelligent design algorithm. Through rigorous empirical analysis, the algorithm's effectiveness and value in real-world design projects are underscored.

Concluding with a summary and outlook, this article aims to contribute meaningfully to the evolving landscape of architectural design, shedding light on future research avenues and potential challenges along the way.

2 RELATED WORK

The application of big data and computer-aided design (CAD) technology in the field of architectural design is becoming increasingly widespread. In order to improve design efficiency, optimize design schemes, and meet increasingly complex design requirements, an automatic design network architectural design system based on big data and CAD technology has emerged. Ma et al. [10] discussed the basic principles, advantages, and application prospects of the system. The automatic design network architectural design system based on big data and CAD technology comprehensively utilizes computer science, artificial intelligence, big data analysis, and CAD technology to achieve an automated and intelligent architectural design process. The system first obtains massive architectural design data and cases through big data analysis, then uses artificial intelligence technology for learning and simulation, and finally uses CAD technology for automated scheme design and optimization. The automatic design network architectural design system based on big data and CAD technology has broad application prospects. It can be applied to the design of various building projects such as residential commercial buildings, public facilities, etc. Meanwhile, with the development of technologies such as 5G and the Internet of Things, this system is expected to combine with these technologies to achieve more efficient and intelligent design and management. In addition, with the deepening of the concept of sustainable development, the system also helps to promote the development of green and low-carbon buildings. CAD virtual visual simulation software provides designers with a brand-new platform, enabling them to present design solutions more intuitively and realistically. María and Gonnet [11] discussed how to establish a multipurpose routing process for architectural design in CAD virtual visual simulation software. In architectural design, the multipurpose routing process refers to creating flexible movement paths for building elements (such as walls, doors and windows, furniture, etc.) based on different design requirements and goals. This routing process not only helps improve design efficiency and flexibility but also helps designers better understand the relationships between building elements and optimize design solutions. Through 3D modelling, designers can present design proposals more intuitively, enabling clients and team members to better understand the design intent. The software supports real-time rendering, and designers can check the rendering effect at any time during the design process, promptly identify problems and make adjustments. Use the animation simulation function of CAD software to apply the movement path to architectural elements. Observe the performance of elements during movement to ensure the rationality and smoothness of the path. Based on the simulation results, adjust and optimize the design scheme. This may include modifying the path, adjusting the position and size of building elements, etc. Through continuous iteration and optimization, a satisfactory design solution is ultimately obtained.

Riaz et al. [12] explore how to combine these technologies to achieve more efficient and accurate 3D urban building modelling, as well as how to use these technologies to build warning systems and provide strong support for urban construction and management. Digital twin technology is an integrated framework based on physical models and sensor-updated data, which can simulate, monitor, and predict the operational status of actual systems in real-time. In the field of urban architecture, digital twin technology can be used to create 3D urban building models, which can accurately reflect the structure, materials, equipment, and other information of urban buildings. Through CAD technology, we can quickly create and modify 3D models of urban buildings. By combining big data technology, we can obtain and integrate a large amount of data from various sources, including meteorological data, traffic data, building energy consumption data, etc., making the model more realistic and comprehensive. Digital twin technology can achieve real-time updates and dynamic monitoring of models, providing strong support for urban planning and management work. Tai et al. [13] explored how to use these technologies to digitally archive the spatial experience of ancient architecture in cultural heritage sites. Ancient architecture is an important component of cultural heritage sites. It not only provides visitors with architectural culture but also creates a unique atmosphere and spatial experience for cultural heritage sites. However, with time, many traditional architectural methods and techniques have gradually disappeared. Therefore, digital archiving and protection of ancient architecture is particularly important. Take an ancient palace as an example and digitally archive its lighting. Firstly, use big data technology to collect lighting data for the palace, including the type, distribution, and intensity of lighting fixtures. Secondly, CAD technology will digitize the lighting facilities of the palace and establish a 3D model. Finally, the collected data will be integrated with the modelled model to form a complete digital archive.

With the rapid development of technology, digital technology has penetrated various fields, including architectural design and architectural history. Architectural space is not only a material existence but also a carrier of culture and history. How to preserve this intangible cultural heritage tangibly has become a hot topic in current research. Tai and Sung [14] explore computer-aided digital archiving technology and its applications for architectural spatial perception experience. Over time, many historical buildings face the risk of ageing, damage, and even disappearance. Although traditional paper-based and photographic archiving methods can record the appearance of buildings, it is difficult to comprehensively record information such as the spatial layout, decorative details, and historical changes inside the building. Digital archiving technology can fully record every detail of architectural space in a three-dimensional form, leaving valuable information for future generations. The application prospects of digital archiving technology are broad, which can not only help us better protect and inherit historical buildings but also be applied in modern architectural design, urban planning and other fields. Through digital archiving technology, we can gain a deeper understanding of past architectural culture and design concepts, providing inspiration for modern architectural design. Symmetry analysis is an effective point cloud processing method that can identify and extract symmetry features from point cloud data. Symmetry analysis can quickly identify key symmetry axes, planes, and angles of building structures. This intelligent colour point cloud technology not only improves the processing speed of point cloud data but also provides more accurate symmetry information, providing strong support for subsequent CAD drawing registration. Digital twin technology has brought revolutionary changes to the construction industry, allowing building information to be managed and applied digitally. Among them, CAD drawings, as an important carrier of architectural information, provide a foundation for the implementation of digital twins. However, the high production cost of traditional digital twin-building CAD drawings limits their application in small and medium-sized projects. Therefore, how to achieve low-cost digital twin-building CAD drawing production is an urgent problem to be solved [15].

With the rapid development of digital media technology, its application fields are becoming increasingly widespread. In architectural design, digital media technology provides designers with new creative tools and ways of expression. Especially in coastal areas, due to the unique geographical environment, cultural background, and natural conditions, the application of digital media technology in architectural exterior design is particularly important. Yu and Liu [16] discussed how to use digital media technology for the three-dimensional design of building appearances in coastal areas. Due to their unique geographical environment, cultural background, and natural landscape, coastal areas have put forward higher requirements for architectural appearance design. The application of digital media technology provides designers with more possibilities, making the exterior design of buildings more diverse, diverse, and innovative. Digital media technology has shifted the design approach from traditional manual drawing to digital design, greatly improving the efficiency and accuracy of design. Designers can use 3D software for modelling, rendering, and animation production to present design proposals more intuitively. With the rapid development of informatization and digitization, big data and CAD technology have brought unprecedented opportunities for architectural design. As an advanced tool, Building Information Modeling (BIM) technology can integrate information throughout the entire lifecycle of buildings, providing strong support for energy-efficient design. Zhao et al. [17] explored the application of BIM technology based on big data and CAD technology in computer-aided building energy-saving design. Big data technology can process massive amounts of data, mine valuable information, and provide data support for building energy-saving designs. CAD technology can efficiently create, modify, and optimize design schemes, improving design efficiency. In the energy-saving design of buildings, the combination of big data and CAD technology can provide designers with more comprehensive information, better understand building performance, and thus develop more optimized design solutions. BIM technology can integrate information from the entire lifecycle of buildings, providing a comprehensive perspective for the energy-efficient design of buildings. Through BIM technology, designers can simulate and analyze building performance in virtual environments, thereby predicting the performance of buildings in real environments. This helps designers identify potential energy consumption issues during the design phase and take effective energy-saving measures.

3 INTELLIGENT ALGORITHMS OF ARCHITECTURAL DESIGN BASED ON BIG DATA AND CAD TECHNOLOGY

3.1 Introduction of Algorithm Principle

As technology continues to advance, the architectural design industry is increasingly integrating big data and CAD technology, leading to notable industry transformations. The objective of this article is to offer a comprehensive examination of how these technologies are utilized in architectural design and how they are revolutionizing conventional design methodologies and mindsets.

Big data has played a key role in architectural design, which is embodied in:

⊖ Case study and data deep mining: Designers can now gather and analyze a large number of architectural design cases to obtain a more comprehensive perspective of design style, structural selection, and material selection. This not only enriches the design ideas but also enables designers to grasp the market trends and design trends more accurately.

⊜ Performance simulation and fine adjustment: Big data makes the simulation of building performance, such as structural stability, energy efficiency, ventilation effect, and lighting quality, more accurate. Designers can predict the actual performance of the building at the early stage of design and then make timely optimizations.

⊛ User behaviour insight: In addition, big data can also reveal the behaviour patterns of building users, including space utilization rate and people flow distribution, so as to provide designers with a deeper understanding of user needs and help create a more practical building space.

Although big data has brought great potential to architectural design, its implementation is accompanied by challenges, such as efficient data collection and processing and strategies for extracting valuable information from massive data.

CAD technology has become the cornerstone of architectural design, and its core applications include:

⊖ Integration of 2D drawing and 3D modeling: CAD software realized efficient 2D drawing and 3D modeling, which significantly improved the design efficiency. It enables designers to present design ideas more intuitively and strengthens the communication effect with customers and construction teams.

⊜ Comprehensive design analysis and optimization: CAD software equipped with various analysis tools can comprehensively analyze the structural integrity, material selection, and energy consumption of buildings and help optimize design decisions.

⊛ Collaborative work and information management: With the rise of BIM technology, CAD software has been expanded to a platform supporting multi-disciplinary collaborative design and information management, which promotes team cooperation and coordination of complex design tasks.

However, the application of CAD technology also faces some challenges, including a high learning curve, dual requirements for computer skills and professional knowledge, and performance limitations that may be encountered when dealing with complex designs and large-scale data. In the process of architectural design, it is often necessary to consider multiple design objectives at the same time, such as cost, structural stability, aesthetics, energy consumption, and so on. There are often conflicts between these goals, and it is necessary to find a balance point. The intelligent algorithm of architectural design based on big data and CAD technology, by introducing MOGA, can efficiently search the design space and find the optimization scheme that meets multiple design goals. MOGA is an optimization algorithm that simulates the biological evolution process. Through operations such as selection, crossover, and mutation, individuals in the population are iteratively optimized, and finally, the Pareto optimal solution set satisfying multiple objectives is found. In architectural design, each design scheme can be coded as an individual, and the fitness of each individual on multiple objectives can be calculated by an assessment function. Then, iterative optimization can be carried out according to GA's principle. See Figure 1 for the optimization principle of building structure based on MOGA.

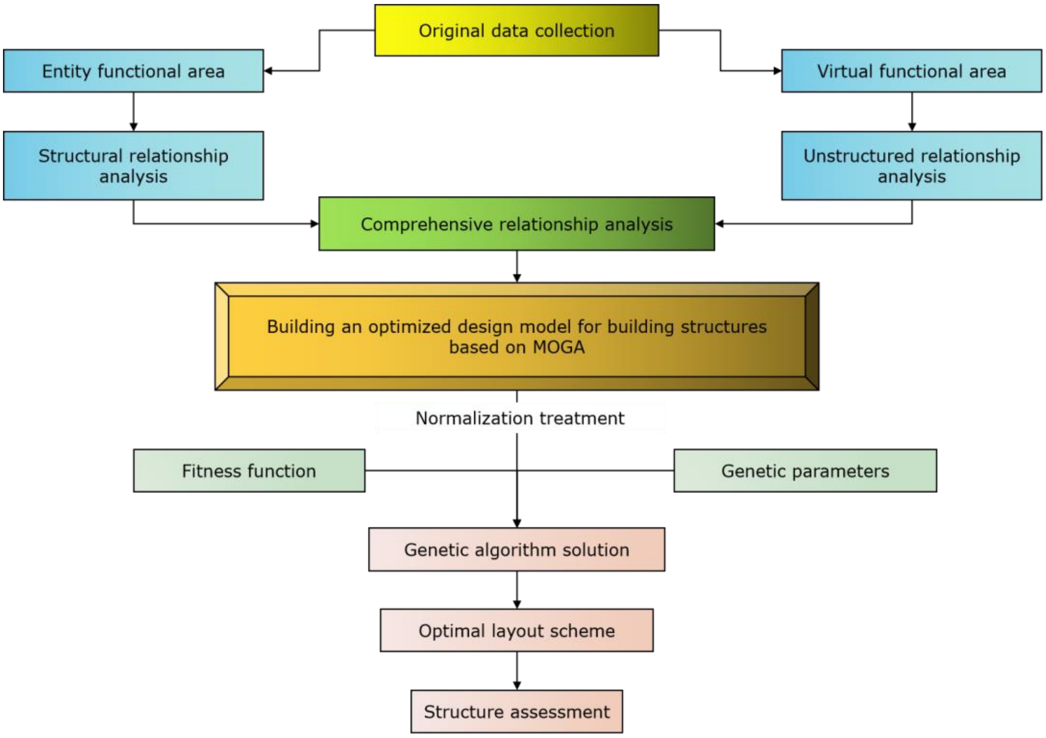

Figure 1: Optimization principle of building structure.

Structural optimization design is a systematic method that aims to make the design scheme meet all the given constraints and achieve the optimal objective function value by adjusting the design parameters. In the field of architectural design, structural optimization design is of great significance for improving the performance of building structures, reducing costs, and realizing sustainable development. In structural optimization design, the Establishment of the mathematical model is a crucial link. This model needs to accurately reflect the optimization problems in actual construction projects, including key elements such as design variables, objective functions, and constraints. Design variables refer to those parameters that can be changed in the process of optimization, such as the size, shape, and material of components. The objective function is the goal pursued by optimization, which is usually related to cost, performance, and other indicators. Constraints reflect the constraints that must be met in the design process, such as structural strength, stability, code requirements, and so on. Figure 2 is the running interface of the architectural design CAD system.

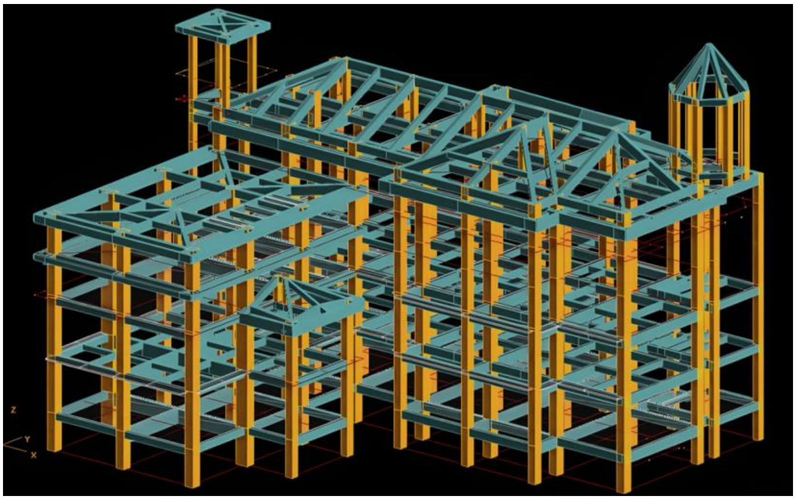

Figure 2: Operation interface of architectural design CAD system.

As a powerful optimization tool, MOGA plays an important role in the optimization design of building structures. Traditional structural optimization methods can only deal with single objectives or simple constraints, while MOGA can deal with multiple objectives and complex constraints at the same time. It searches for the optimal solution in the solution space by simulating the mechanism of heredity, variation, and selection in the process of biological evolution. The optimization model mainly includes design variables, objective function constraints, etc. The mathematical model is:

$$\begin{cases} X = \ x_1, x_2 \ ^T \\ \min f \ x \\ s.t.\ g_j \ X \ \le 0 \ \ j = 1,2,\ldots,m \\ x_1 \ge a_1, x_2 \ge a_2 \end{cases} \tag{1}$$

Taking the truss structure as an example, the cross-section size of the optimized cross-section area is taken as the design variable, the objective function is the quality of the truss structure, and the stress constraint or constraint node member displacement constraint is adopted to minimize the overall weight. The mathematical model is expressed as:

$$\begin{cases} A = \ A_1, A_2, \ldots, A_n \ ^T \\ \min f \ A \ = \sum_{i=1}^{NV} \rho_i A_i l_i \\ s.t.\ \sigma_{ik} \le \bar{\sigma}_i \ \ i = 1,2,\ldots,p \\ \mu_{jlk} \le \bar{\mu}_{jl} \ \ i = 1,2,\ldots,m; l = 1,2,\ldots,ND; k = i = 1,2,\ldots,p \end{cases} \tag{2}$$

Where A_i is the cross-sectional area of the i branch; l_i is the length; ρ_i is density; NV is the number; σ_{ik} is the stress borne by the i pole under the k load; μ_{jlk} is the displacement of j in l direction under k load; $\bar{\sigma}_i$ is the stress value of i rod; $\bar{\mu}_{jl}$ is the displacement of j in l direction; p is the total quantity of load cases; m is the quantity of nodes in the truss structure; ND is the displacement direction.

In order to design a suitable fitness value, the following penalty function is used to deal with the constraints:

$$P(x)=\sum_{i=1}^{m}\alpha\max\left(0,g_i(x)\right)^{\beta} \tag{3}$$

Where $g_i(x)$ is the constraint condition, a and β are penalty parameters, where a is the accuracy of satisfying the control constraints, and β usually takes 2. The additional penalty objective function of the optimization problem equation (3) is:

$$\varphi(x,\alpha,\beta)=f(x)+\sum_{i=1}^{m}\alpha\max\left(0,g_i(x)\right)^{\beta} \tag{4}$$

3.2 Methodology

When applying MOGA to optimize architectural design, we must pay attention to several core issues. The first is coding strategy, that is, transforming the design idea into the individual in the algorithm. This can be achieved by binary or real coding, and the key is to choose the appropriate coding method according to the characteristics of design parameters. Secondly, the assessment mechanism, that is, to determine a function to quantify the performance of each design scheme in multiple objectives. This function needs to fully reflect all aspects of the design performance while ensuring the efficiency of calculation. Furthermore, the design of genetic operation. This includes how to screen outstanding individuals in the population, how to create new designs through crossover operation, and how to introduce more diversity through mutation. Each operation needs careful design to ensure the effectiveness and innovation of the algorithm. Finally, the treatment of constraints. Architectural design is often subject to various restrictions, such as structural stability and budget. In the algorithm, these constraints should be handled by appropriate methods, such as using penalty function or constraint dominance technology, to ensure that the generated design scheme is innovative and feasible.

When we deeply study the application of MOGA in building structure optimization, we realize that the traditional fixed crossover probability may not meet the needs of different optimization stages, which sometimes leads to premature convergence or local optimization of the algorithm. In order to overcome this limitation, this article proposes a new adaptive crossover probability strategy. This strategy can dynamically adjust the crossover probability according to the evolutionary state of the population and the characteristics of the problem so as to improve the search efficiency and global optimization ability of the algorithm. Specifically, we construct an adaptive crossover probability model by introducing relevant evolutionary indicators and problem characteristic parameters. The model can provide appropriate crossover probability in different stages of the algorithm, thus balancing the exploration and development ability of the algorithm. The crossover probability introduced in this article is adaptive in nature:

$$p_c^q=\begin{cases} p_{c,\max}\times e^{-q/Q} & p_{c,\max}\times e^{-q/Q}<p_{c,\min} \\ p_{c,\min} & \text{other} \end{cases} \tag{5}$$

q represents the q iteration process, whereas Q it denotes the total quantity of iterations undertaken. Additionally, $p_{c,\max},p_{c,\min}$ represent the predetermined upper and lower limits for crossover probability, respectively.

The crossover process in GA involves the swapping of genetic material between two paired chromosomes, generating two distinct new individuals. This serves as the primary mechanism for introducing novel genetic variations. In this study, we employ the arithmetic crossover technique, whereby the creation of two new individuals is achieved through a linear blend of genetic material from two parent individuals.

Given two parent individuals labelled as x_a^t,x_b^t the crossover operation yields two distinct offspring individuals.

$$\begin{aligned} x_a^{t+1} &= \alpha x_b^t + 1-\alpha\ x_b^t \\ x_b^{t+1} &= \alpha x_a^t + 1-\alpha\ x_b^t \end{aligned} \tag{6}$$

a represents a randomly generated number within the range of (0,1), conforming to a normal distribution. When dealing with integer variables, the crossover operation may result in a non-integer value. To address this, we employ a rounding technique to ensure the final outcome is an integer.

The linear function of architectural design penalty cost for multi-objective optimization shown in Figure 3 is a key visualization tool in the process of architectural structure optimization. This function image not only visually presents the cost changes of the design scheme under different optimization objectives but also reflects the penalty cost when the design scheme deviates from the optimal solution.

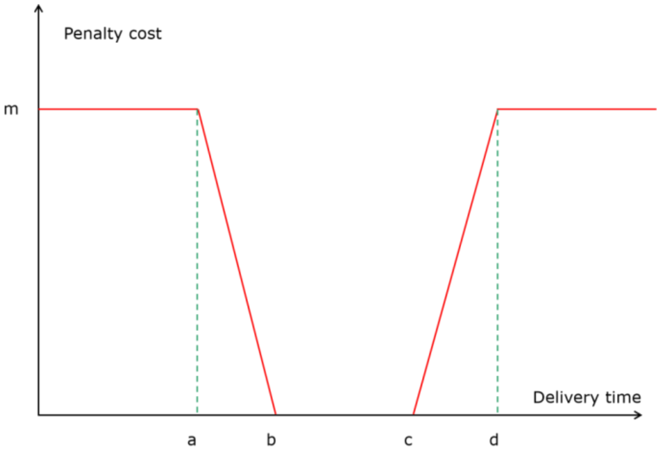

Figure 3: Linear function of penalty cost.

In the field of architectural design, multi-objective optimization problems often involve cost, performance, aesthetics, environment, and many other aspects. There are often conflicts between these goals; for example, reducing costs may sacrifice some performance or aesthetics. Therefore, designers need to weigh these goals and find a comprehensive and optimal design scheme. By simulating the mechanism of heredity, mutation, and selection in the process of biological evolution, MOGA can search for the optimal solution set that meets multiple objectives and complex constraints in the solution space. In the search process, the algorithm will assess and select the design scheme according to the linear function of penalty cost so as to gradually approach the comprehensive optimal design scheme.

The measure of a solution x_i's infeasibility is determined by calculating the cumulative squared value of all its conflicting constraints.

$$\delta\ x_i\ = \sum_{k=1}^{m} \min\left[0, g_k\ x_i\ \right] + \sum_{j=1}^{p} \left[h_j\ x_i\ \right]^2 \tag{7}$$

In the realm of optimization problems, $g_k\ x_i\ , h_j\ x_i$ it encompasses both inequality and equality constraints. Separately, m, p quantifies the collective quantity of these inequality and equality constraints.

In the context of single-point intersection, regardless of whether binary or real coding is employed, the average of the decoded offspring remains identical to that of the parent. When applying GA-based optimization to building structures, it is postulated that the length of the chromosome is denoted by l , and the intersection occurs at the k location.

If the parent:

$$\begin{cases} P_1 = A_1 t^k + B_1 \\ P_2 = A_2 t^k + B_2 \end{cases} \tag{8}$$

Descendants:

$$\begin{cases} C_1 = A_1 t^k + B_2 \\ C_2 = A_2 t^k + B_1 \end{cases} \tag{9}$$

When it comes to encoding, binary encoding utilizes $t = 2$ real encoding sets $t = 10$. As for the crossover probability p_c, it is defined adaptively:

$$p_c = 1 - 0.4 * \left(\frac{G_l}{G_{\max}} \right) \tag{10}$$

G_l is the current algebra and $G_{\max}$ is the largest genetic algebra.

3.3 Implementation Procedure

The implementation process of intelligent algorithms for architectural design integrating big data and CAD technology includes:

⊖ Data integration stage: extensively collect and systematically sort out rich cases and multidimensional data in the field of architectural design, such as innovative design schemes, key performance indicators, cost budget information, etc. These data will become an important cornerstone for the subsequent construction of assessment systems and training machine learning models.

⊜ Initial population generation: a series of initial design schemes are randomly generated as the starting point of the population. These schemes are widely distributed in the design space to ensure the initial diversity of the population.

⊛ Establishment of assessment system: Use big data and machine learning algorithms to build a comprehensive and accurate assessment function. Firstly, the key features are extracted from the case base, and a feature matrix is constructed. Then, the machine learning model is trained to predict the performance of the design scheme under multiple objectives. Finally, these performance indicators are organically combined to form a perfect assessment system.

④GA iterative evolution: Evaluate the fitness of the design scheme in the population according to the assessment system and follow the essence of GA to perform evolutionary operations such as selection, crossover, and mutation. In the iterative process, the Pareto optimal solution set is tracked and recorded continuously so as to ensure that the excellent scheme that meets multiple design objectives can be screened out at the end.

⑤ Presentation and visualization of results: Finally, the Pareto optimal solution set is presented, and the final scheme is selected according to the specific needs. Moreover, with the help of the visualization function of CAD technology, the optimized design scheme is presented intuitively, which is convenient for designers, users, and other participants to communicate and discuss in depth.

4 ALGORITHM TESTING AND ANALYSIS

The primary goal of the experiment is to evaluate the efficacy of MOGA, leveraging big data and CAD technology, in optimizing building structures. This evaluation encompasses testing various population sizes, contrasting with the conventional GA, and examining the CAD system integration.

The metrics for assessment comprise convergence rate, solution efficacy, and fitness value. Great care has been taken in constructing the experimental setup, execution, and result interpretation to guarantee the authenticity and dependability of the findings. These findings subsequently bolster the credibility of intelligent architectural design.

A crucial indicator for gauging the algorithm's performance is its convergence curve. This curve offers a direct visualization of the algorithm's convergence and problem-solving proficiency during the optimization phase. By referencing the convergence curve depicted in Figure 4, one can delve into the algorithm's convergence traits and its overall efficiency in finding solutions.

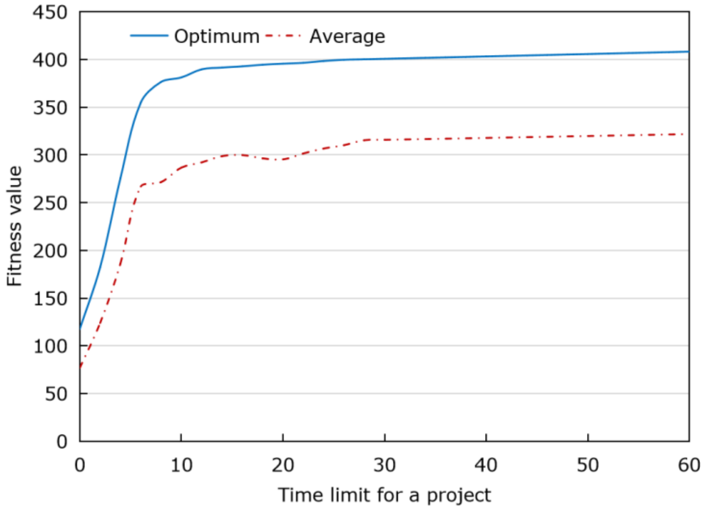

Figure 4: Fitness convergence curve.

From the point of view of convergence speed, the algorithm basically converges in about 25 generations, which indicates that the algorithm has a faster convergence speed. This means that in practical application, the algorithm can find the near-optimal solution in a short time, thus meeting the requirements of engineering practice for time efficiency. The algorithm shows high efficiency in the process of convergence. The algorithm can effectively explore and use the search space in the search process, avoid falling into the local optimal solution, and thus find the global or nearly global optimal solution.

In the experiment of building structure optimization, this article adopts MOGA and sets four populations with different sizes, namely 5, 50, 100, and 150, to explore the influence of population size on the performance of the algorithm. Each population has carried out many experiments, and the running results of four of them are randomly selected for analysis, as shown in Figures 5 and 6.

With the increase in population size, the running time of the algorithm shows an obvious growth trend. This is because the increase in population size means that the algorithm needs more calculations and operations in each generation, which leads to the extension of running time. Although the running time has become longer, the performance of the algorithm has not been obviously degraded or unstable, which shows that the algorithm still maintains good efficiency and stability when dealing with large-scale populations.

With the increase in population size, the fitness value of the final result also increases. This means that a larger population size is helpful for the algorithm to find a better solution in the search space, that is, a building scheme that is more in line with the constraints. This is because the larger population size provides more search points and information, which increases the searchability and global optimization ability of the algorithm.

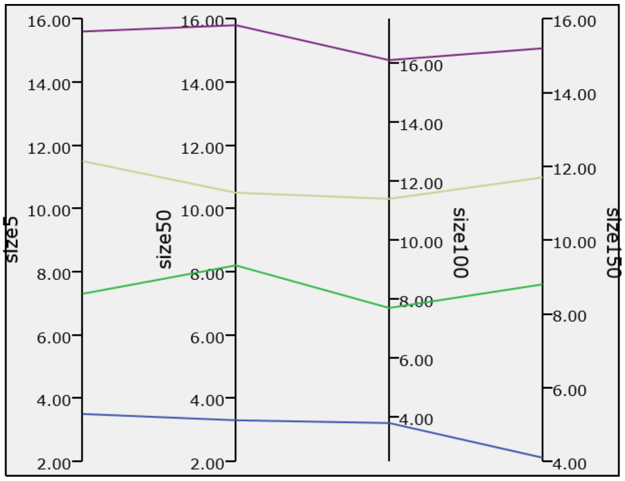

Figure 5: Influence of population size on result fitness value (6 building subjects).

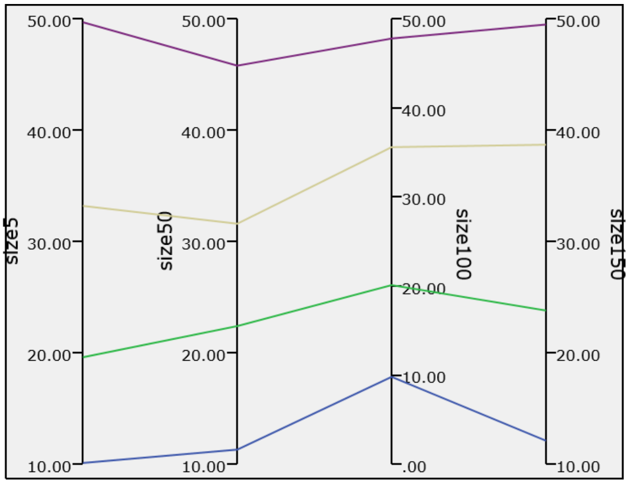

Figure 6: Influence of population size on result fitness value (12 building subjects).

When comparing the performance of traditional GAMOGA in controlling CAD systems, valuable insight is gained by observing the step response curve. Figure 7 and Figure 8 show the step response characteristics of these two algorithms when controlling a CAD system, respectively.

In the step response curve, the system controlled by MOGA can reach the steady state or close to the steady state more quickly, which shows that MOGA has higher efficiency in dealing with dynamic changes and control requirements. This is very important for CAD systems that need quick response, especially when real-time design optimization is carried out. From the point of view of overshoot and fluctuation amplitude, the overshoot of the MOGA control process is obviously smaller than that of the GA control process, and the fluctuation amplitude is also small. Overshoot refers to the maximum deviation exceeding the stable value in the system response process, and the fluctuation amplitude reflects the degree of oscillation before the system reaches the stable state. MOGA's superior performance in these aspects means that it can provide a more stable performance when controlling CAD systems, thus helping to reduce uncertainty and risk in the design process.

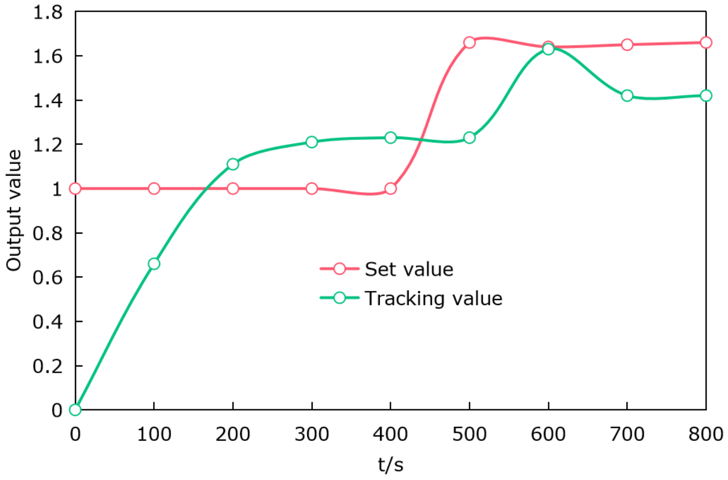

Figure 7: Step tracking based on GA control.

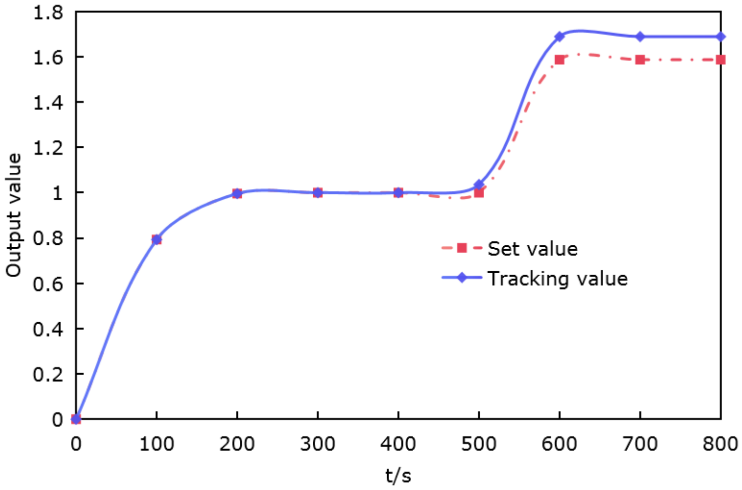

Figure 8: Step tracking based on MOGA control.

5 CONCLUSION

Architectural design is a highly comprehensive field involving the cross-integration of many disciplines. Traditional design methods often have limitations, such as thoughtlessness and insufficient optimization when dealing with complex problems. In the field of building structure optimization, MOGA has shown remarkable advantages and potential. By comparing the performance of traditional GA and MOGA in controlling CAD systems, it is found that MOGA has superior characteristics in response speed, overshoot, and fluctuation range. This fully proves the effectiveness and practicability of MOGA in dealing with complex optimization problems. MOGA basically converges in about 30 generations, showing fast convergence speed and high solution efficiency. This shows that the algorithm can find the near-optimal solution in a short time and meet the requirements of engineering practice for time efficiency.

Although the larger population size will increase the running time of the algorithm, it can also improve the searchability and global optimization ability of the algorithm so as to get a more constrained architectural scheme. Therefore, in practical application, the appropriate population size can be selected according to the complexity and time requirements of specific problems to balance the running time and solving quality of the algorithm.

The research content and results fully prove the superior performance and broad application prospect of MOGA in the field of building structure optimization. In the future, we can further study the parameter setting, optimization strategy, and the combined application with other intelligent optimization algorithms in order to achieve more breakthroughs and innovative results in the field of building structure optimization.

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