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Collaborative CAD Technology and Computational Geometry Algorithm in Digital Building Skin Design

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Abstract. This study explores the application and effect of CAD (computer-aided design) collaborative technology and computational geometry algorithms in digital building skin design. In order to achieve this goal, this paper selects a typical architectural skin design case and designs and implements a series of simulation experiments. The experiment constructs a collaborative design environment including multi-professional designers, simulates the collaborative work process in real projects, and records relevant data to evaluate the effect of collaborative technology. At the same time, the computational geometry algorithm is used to generate and optimize the architectural skin shape, and the running process and results of the algorithm are recorded in detail. Through the in-depth analysis of experimental data, this paper finds that CAD collaborative technology can significantly improve the design quality, reduce design conflicts, and provide strong support for digital building skin design. The application of the computational geometry algorithm shows its powerful ability in shape generation and optimization, which can quickly generate innovative and aesthetic skin shapes to meet different design requirements. These findings not only verify the effectiveness and feasibility of collaborative technology and algorithms but also bring new design ideas and methods to the architectural design industry.

Keywords: Digital Building Skin Design; Collaborative CAD Technology; Computational Geometry Algorithm; Genetic Algorithm
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1 INTRODUCTION

Parametric technology is driving the diversified development of building skins, and it can be said that parametric technology is the foundation for designing building skins. Chen et al. [1] mainly studied the narrow definition of building skin and building facade and summarized and classified building skin here. Secondly, based on the classification of building skins, typical cases of various types of building skins are selected for parameterized simulation modeling, attempting to explore the methods of parameterized generation of various types of building skins. For the parameterized simulation generation of different types of building skins, Georgiadou [2] uses the Grasshopper software platform to parameterize the simulation generation of corresponding cases. Firstly, for linear building skins, simulation is conducted on three different types of linear skin building cases. The design of building skin is a very important part of the entire architectural scheme design, and the overall effect of the scheme cannot be ignored in any case. With the application of parametric design in building skin design, the forms of building skin are becoming increasingly diverse and complex, making it difficult to design such effects using traditional design thinking. The design of building facades is often a direct reflection of the application of parametric technology in architectural design. With the advancement of parameterization technology and theory, more building skins that are more in line with function and form will be presented.

Parametric design is widely used in the field of architectural design, including the generation of building forms, spatial relationships, and building skins. The design of building facades is often a direct reflection of the application of parametric technology in architectural design. Parametric technology is driving the diversified development of building skins, and it can be said that parametric technology is the foundation for designing building skins. Therefore, Hafizi and Karimnezhad [3] studied the parameterization of building skins. And set the research scope as "Research on Building Skin Generation Based on Parameterization Technology". The main research content is to study and discuss different types of building skins, and to generate parameterized simulations of corresponding cases through the Rashopper software platform. Display the generation process of building skins with clear parameterized generation logic, and summarize the logical methods for parameterized generation of different types of building skins. Digital twin technology, as a bridge between the physical world and the digital world, has also shown enormous potential in the field of architecture. With the rapid development of digital technology, architects need to have more creative tools than ever before. These tools help architects free themselves from the complexity of work, giving them more time and free space to engage in creative work. But when faced with some novel architectural shapes and complex skins, if architects cannot deeply understand the generation logic and process behind these ever-changing skins, they often can only stop at simple appreciation and get lost in these ever-changing forms. The digital building facade, in terms of its form itself, is ever-changing and has countless types. However, the most widely used and versatile one is the non-linear gradient building facade. Hou et al. [4] conducted systematic research on this type of epidermis. Combining the investigation and research results of numerous famous digital architects both domestically and internationally in terms of experiments and theories. Classify a large number of nonlinear gradient-building skin forms. It aims to think about the underlying logic from the perspective of attractor interference. It explores the manifestation and underlying reasons for the formation of nonlinear gradient-building skins and the generation mechanism of complex skin forms. Algorithm is the essence of parameterizing building skins, and Khan et al. [5] attempted to study commonly used algorithms for generating building skins from an algorithmic perspective. By studying and discussing different types of building skins, and using the Grasshopper software platform to parameterize simulation generation of corresponding cases, it is proposed that the inherent logic of building skin generation is the role of algorithms. In general, when it comes to building skins and facades, they often refer to the same meaning. It attempts to make a narrow distinction between the definition of building skin and building facade.

Krner et al. [6] combined the thinking mode of nonlinear science with the research methods of building skins and respectively explored the principles and methods of mediocre attractors and strange attractors interfering with the gradient of building skins. It has sorted out the prototypes of various forms of colourful gradient skins and summarized them into six representative nonlinear gradient architectural skins, including stretching behaviour, sliding behaviour, rotation behaviour, folding behaviour, assignment behaviour, and deformation behaviour, as well as the combination and superposition of these six behaviours. We conducted in-depth research on its corresponding design ideas and ultimately proposed a systematic method for achieving nonlinear gradient parameterized design results of building skins through attractor interference. The unique perspective of constructing nonlinear gradient architectural skin design reveals the development trend of this emerging technology. Efforts should be made to study the architectural skin, which has both practical and theoretical significance, providing useful references and inspiration for the creation of new types of architecture. The exterior of a building is attached to the building space as an outer packaging that wraps around the perimeter of the building. It is the interface between the indoor and outdoor spatial environment of a building, as well as the surface layer of the building that people directly feel through touch and vision. In the era of classical architecture, the continuity of walls was the most important, playing a role in load-bearing and spatial enclosure and separation, while doors and windows played a role in communication between the building and the external space [7]. However, its load-bearing role in hybrid structures greatly limits the freedom of the components themselves. This means that the epidermis can only attach to the structural enclosure wall in an extremely heavy posture. Later, with the emergence of frame structures, the structural functions of the exterior walls were significantly weakened or even disappeared, often only used as infill walls. Just dividing or enclosing the space, the position of components such as doors and windows in the realization of architectural functions and the expression of architectural art is gradually increasing, and the coverage area is also constantly expanding. Especially after the appearance of curtain walls, the building skin has freed itself from its load-bearing properties and can be separated from other construction elements, giving the building greater creative freedom in expression. From this moment on, the surface of modern architecture has ushered in an opportunity for reform and evolution, actively participating in architectural design activities as an independent and innovative role.

CAD collaborative technology underpins these conceptualizations with robust technical backing. Fostered architectural-environmental harmony: Digital architectural skin design promotes a meticulous consideration of the architectural-environmental nexus, achieving a seamless amalgamation of architecture, nature, and humanity. This elevates architectural aesthetics and contributes to the sustainable progress of the construction industry.

The originality of this paper is primarily embodied in its exploration of:

(1) A digital building skin design method based on collaborative CAD technology is proposed. By integrating the strength of multi-professional designers, the real-time synchronization and sharing of design data are realized, and the design efficiency and quality are improved. This method has a wide application prospect in practical projects.

(2) In this paper, a computational geometry algorithm is introduced into architectural skin design, which provides a new solution for shape generation and optimization. Through the selection and optimization of the algorithm, innovative and aesthetic skin morphology can be quickly generated to meet different design requirements. This brings new design ideas and methods to the architectural design industry.

(3) The effectiveness and feasibility of the collaborative technology and algorithm are verified by simulation experiments. The experimental results provide strong data support for related research and also provide a reference for the application of practical projects.

Firstly, this paper systematically sorts out and deeply analyzes the relevant theories and establishes the theoretical framework of CAD collaborative technology and computational geometry algorithm in digital building skin design. Secondly, through the method of case study, the successful digital building skin design cases at home and abroad are analyzed, and their design concepts and technical characteristics are summarized and refined. Finally, the proposed technical method and theoretical framework are verified and optimized by simulation experiments.

2 RELATED WORK

Lin [8] discussed how to apply algorithmic frameworks to develop topology algorithms for digital architectural conceptual design, as well as the application prospects of topology vision in architectural design. Topological vision is a visual analysis method based on topology theory, which focuses on the changes and continuity of spatial morphology. In architectural design, topological vision can help designers better grasp spatial structure, morphological changes, and the relationship between spaces. The types of building skins are diverse and complex. The main research approach of Liu et al.

[9] is to generate a parameterized simulation of a typical type of building skin case, and then summarize the logic of its parameterized generation. In the study of the types of building skins, by summarizing relevant literature and case studies of building skins, analyzing their characteristics, and summarizing their patterns. Further, classify and categorize the building skins. Secondly, in the parameterized simulation generation of building skins, typical cases of different types of building skins are parameterized and modelled, revealing their generation process from scratch through detailed steps. Finally, by summarizing the generation process of typical cases of different types of building skins, the corresponding generation logic is summarized.

At present, the development of three-dimensional digital technology is extremely rapid. It has many advantages in managing infrastructure, environmental simulation, civil engineering industry, and urban construction, providing a three-dimensional display of spatial scenes and decision support. BIM and GIS, both of which are three-dimensional digital technologies, play indispensable roles in their respective industries, but there are also obvious drawbacks. Máder et al. [10] explored the importance of integrating BIM and GIS technologies. It integrates three-dimensional BIM model information into the GIS platform. On the one hand, GIS enriches the internal information of buildings from macro to micro, and on the other hand, BIM solves the problem of micro-to-macro information. Unlike linear systems, nonlinear systems can provide reasonable explanations for phenomena such as being far from equilibrium, self-organizing, irregular, and dynamic. Since its rise, it has rapidly spread globally, breaking free from the inertia of modern classical aesthetic rationality and providing people with a new methodology. Under the leadership of nonlinear science and the transformation of contemporary architectural aesthetics, corresponding forms and spatiotemporal imagery have emerged, promoting the emergence of nonlinear skin forms in architecture. The nonlinear skin dynamic system of architecture has many parameter inputs, and the interrelationships between parameters affect the entire system. When the correlation logic of these parameters is established, a mathematical model can be constructed to achieve the desired skin effect through operations. As a result, non-linear building skins using parametric design as a technical means emerged [11].

Due to the large amount of data in BIM models and the emphasis on spatial scene display in GIS platforms, the integration of BIM models with GIS platforms will inevitably lead to problems such as data redundancy, high operational load, and model mismatch with the surface. Nie et al. [12] imported the Revit model of a small villa into the SuperMap platform as an operational object and solved the technical difficulties of geographic data caching, terrain matching, and model optimization through the platform's functions. BIM+GIS technology data fusion has great potential advantages and broad application prospects. Ancient architecture is a precious historical and cultural heritage. In the current situation where natural disasters, human wars, and urbanization have caused extensive damage, a detailed BIM model of ancient architecture has been constructed using the modern information technology of BIM+GIS, and virtual roaming has been carried out through the 3D GIS platform. So as to break down the barriers of time and space, restore the true position of ancient buildings, and enable them to be represented. Pepe and Costantino [13] introduced the detailed theoretical content of the IFC standard for BIM and the CityGML standard for GIS. It analyzed the similarities and differences between the two types of standards for model expression and description. And explore the transformation approach of IFC data and CityGML data based on semantic constraints. The use of dynamic thinking to understand the form of architecture is the essence of parametric design, and every change in data and their logical relationships will affect the generated results. The integrated function concept allows for feedback and optimization in the design, using more efficient design techniques to complete a design. The intervention of parametric design and production technology has triggered another disruptive change in the architectural design industry.

The 3D modelling process of AutoCAD is based on 2D building drawings, generating 3D building entities through steps such as stretching, rotating, merging, and intersecting 2D elements. Its advantages are high efficiency, high dimensional accuracy, convenient model making, high compatibility, and the ability to export multiple formats that can be converted to each other. However, due to the simple and rough modelling process, the model expression is greatly limited, as only points, lines, and planes can be used for modelling. Unable to draw surfaces, it is only suitable for simple block models, and the level of 3D visualization is low, making it only suitable for simple displays. The model drawn by Rasmussen et al. [14] software has high precision, and each part of the building can be independently and flexibly edited. It has a real-time rendering function and a good rendering effect. It is possible to convert various formats of 3D models into 3D format for import. However, modelling programs are relatively complex, have a large amount of data, and are prone to generating redundant data. Large-scale modelling requires high software and hardware requirements for electronic computers. In fact, they share the same essence, all of which are composed of complex building skins and several simple structural forms stacked together. Sepagozar et al. [15] et al. need to solve the problem of how to create personalized building skins on the basis of repetitive combinations to showcase the facade of our building. The less repetition, the stronger the personality, and of course, the higher the cost. Variation is the key to architectural personality, while repetition is the key to economy and timeliness. Of course, "repetition" also brings us another rhythmic visual impact, which is a commonly used architectural expression technique. Therefore, architects strive to find a relative balance between repetition and variability, a design method with constructive logic. To achieve novelty, personalization, and diversity through a fast and efficient construction method with fewer types of modular components. Works with contemporary significance seek a balance between complexity and logic to meet the multiple requirements of rationalization in terms of function, structure, construction, etc. This makes logical and systematic architectural skin design a key focus of current architectural design research.

The emergence of parametric design ideas is the result of the combination of Foucault and Deleuze's philosophical ideas and complex systems science. It is precisely because of the fusion of these two ideas that there has been a qualitative change in architectural design concepts, which has promoted the development of the field of architecture. In the initial stage of applying parametric design to architectural design, Shim et al. [16] proposed the concept of parametric design, which takes various factors that affect the building scheme as parameter factors. By combining certain logical relationships through computers, the final building plan is generated. Interpret diagrams as functional relationships, and further point out that diagrams are abstract expressions of certain functions and definitions based on Foucault's proposed functional relationships. Philosophers' understanding of the concept of charts prompts architects to consider whether design can create clear logical representations and become a source of formal generation. Through the 3D digital twin model, we can monitor the deformation, cracks, vibration and other status information of bridges in real-time, and compare and analyze them with theoretical models. Computer-assisted methods, as an efficient and precise tool, provide a new way of recording and archiving the perception experience of architectural space. Tai et al. [17] explored the application and significance of computer-aided methods in the digital archiving of architectural spatial perception experiences. Through high-precision 3D scanning technology, computer-aided methods can obtain detailed data about building spaces, including dimensions, shapes, materials, etc., in order to construct accurate digital models. Digital archiving provides rich recording and expression methods for the perception experience of architectural space. The traditional perception and experience of architectural space often rely on personal memory and feelings, making it difficult to accurately and completely record and share. Digital archiving can transform perceptual experiences into visual digital information, allowing observers to intuitively understand the form, structure, and atmosphere of architectural spaces.

In the context of Industry 4.0, digital technology is changing the production and business models of the traditional construction industry, promoting its development towards intelligence, efficiency, and greenness. Wang et al. [18] explored the current status and future directions of systems using digital technology in off-site construction, in order to provide useful references for the digital transformation of the construction industry. Intelligent construction management: By introducing IoT technology and sensors, real-time monitoring and data collection of the construction process can be achieved. This helps management personnel to timely understand construction progress, quality, and safety issues, and improve construction efficiency. Utilize BIM (Building Information Modeling) technology to achieve three-dimensional digital modelling of building projects. This helps designers and construction personnel to communicate and collaborate better, reduce errors and rework, and improve project quality. Digital media technology provides strong technical support for the three-dimensional design of building appearances in coastal areas. By using 3D modelling software, designers can accurately construct a 3D model of a building and simulate realistic environmental effects through material mapping, light and shadow rendering, and other means. This not only helps designers better grasp the form and spatial relationships of buildings but also provides accurate references for subsequent construction and decoration. Yu and Liu [19] use digital media technology to combine traditional architectural elements with modern design concepts, creating a unique architectural appearance. At the same time, digital media technology can also achieve rapid switching and comparison of multiple design schemes, helping designers better grasp the design direction and optimize design schemes.

3 THEORETICAL BASIS AND LITERATURE REVIEW

3.1 Digital Building Skin Design Theory

Digital building skin design refers to the design process of conceiving, simulating, optimizing, and expressing building skin by using digital technology tools and methods. This process emphasizes digital generation, performance simulation, and shape innovation in skin design, aiming to create architectural skin with both aesthetic value and functional requirements. Digital building skin design not only pays attention to the visual effect of skin but also pays attention to its comprehensive performance with environment, structure, and energy. In the digital building skin design, the principles to be followed are shown in Table 1.

Serial number	*Principle name*	*Specify*
1	Principle of integrity	The skin design should be coordinated with the overall design of the building to form an organic whole.
2	Functional principle	The skin design should meet the basic functional requirements of the building, such as heat preservation, heat insulation, ventilation, and lighting.
3	Innovative principle	Encourage designers to use digital technology to carry out innovative design and break the shackles of traditional design.
4	Principle of sustainability	The concept of sustainable development such as environmental protection and energy saving should be considered in skin design to reduce the impact of architecture on the environment.

Table 1: Design principle of digital building skin.

Table 1 clearly lists four main principles that need to be followed in digital building skin design. These principles can be used as guidelines for designers in digital building skin design.

As digital technology progresses relentlessly and architectural design concepts undergo transformation, the evolving trend in digital architectural skin design is delineated in Table 2.

Development trends	*Specify*
Parametric design	Through parametric modelling and algorithm optimization, the automatic generation of skin morphology and performance optimization is realized.
Intelligent design	Using artificial intelligence and machine learning technology to improve the intelligent level of skin design.
Interactive design	Emphasize the interaction among designers, users and computers, and realize real-time feedback and adjustment of skin design.
Ecological	Pay attention to the integration of skin design and the natural environment, and

design	improve the ecological performance of buildings.

Table 2: Development trend of digital building skin design.

Table 2 outlines four emerging trends in digital building skin design, influenced by advancements in digital technology and evolving architectural design concepts. These trends offer insights into potential future directions and focal points for this field.

3.2 Fundamentals of Computational Geometry Algorithm

Nonlinear gradient mode is a common form of non-linear skin, which is the optimal expression for achieving a logical and systematic balance between repeatability and variability—for example, the location, size, and quantity of openings on the building surface. Gradual evolution occurs with the influence of a physical factor or other influencing factors. Its design concept is actually influenced by a variation factor called an attractor. The basic process of constructing design using parametric methods is to first go from design to control and then from control to design. This process has two characteristics. Compared with traditional design methods, parameterized design adds control through parameterized models, which are the core of the design process. All design behaviours are ultimately implemented by establishing and moderating parameter models. The development direction of design basically ranges from conceptual design to development plan design. In conceptual design, it is necessary to comprehensively analyze various influencing factors and create parameterized models by writing scripts on different parameterized software platforms. The development of scheme design is to deepen the design of the selected scheme, including structural design, structural design, and skin design, and optimize the form of the building based on the results of structural and environmental analysis.

Parameterized design not only changes the design process but also changes the design concept itself. The concept of architectural scheme design has become more diverse, with the main design inspiration coming from geometric shapes, natural phenomena, or mathematical models, as well as the functional requirements of design tasks and environmental factors of the site. Architects must integrate and select factors that they can grasp in order to find the right entry point. With the continuous development of computer technology, the ability to calculate and process information is becoming stronger, and many factors can be incorporated into parameter models to affect design results, which is more efficient than traditional design methods.

4 CAD COLLABORATIVE TECHNOLOGY OF DIGITAL BUILDING SKIN DESIGN

4.1 CAD Software Tool Selection

In digital building skin design, it is very important to choose appropriate CAD software as the research platform. At present, there are many CAD software in the market, such as AutoCAD, Revit, SketchUp, Rhino, etc. They have their own advantages and disadvantages and are suitable for different design scenarios and requirements. For this study, we need CAD software that can support complex building skin design and have good collaborative design functions. After comparative analysis, we chose Revit as the research platform. Revit is a software specially designed for building information models, which has a powerful parametric modeling function and rich building component library and can meet the needs of complex building skin design. At the same time, Revit also supports multi-person online collaboration and can realize real-time data synchronization and version control, which is very suitable for collaborative design.

4.2 Collaborative Design Strategy

With the widespread application of computer technology and digital technology, there have been qualitative changes and leapfrog developments in many aspects of architectural skin design, such as thinking patterns and design requirements. However, for the widely used nonlinear gradient skin, the selection of attractors and the parameter processing of interference sources are crucial. The principle analysis and implementation methods of gradient form still lack a systematic and highly operational design theory and a convenient and logical simplification scheme. Therefore, faced with complex surface concepts, many designers face many difficulties and even find it difficult to get started. This article attempts to introduce the basic theoretical knowledge related to the study of attractor gradient interference based on the introduction of relevant theoretical achievements such as digital science, attractor theory, gradient interference, and nonlinear science. By analyzing the diverse and complex cases of nonlinear gradient building skins in contemporary times, this paper analyzes the typical characteristics of skins from the perspective of attractor interference, thereby helping to clarify the logic behind the generation of such skins. Study the diversity of nonlinear gradient skins, explore the use of typical blocks as prototypes, and ultimately output rich and varied buildings through parameterized regulation. Conduct regular design reviews and collision detection. In the process of collaborative design, design review, and collision detection are carried out regularly to ensure design coordination among disciplines and to find and solve potential design conflicts and problems in time.

4.3 Case Study of Collaborative Design

In order to illustrate the application effect of collaborative design in architectural skin design, this section selects a specific case for analysis. This case is a skin design project of a large commercial complex, involving architecture, structure, electromechanical and other majors. In the project, the above-mentioned collaborative design strategies and methods are adopted. Through collaborative design, the project has achieved remarkable results (as shown in Table 3).

Evaluating indicator	*The situation before collaborative design*	*Improvement after collaborative design*	*Degree of improvement*
Design cycle	The original planned design cycle was 12 months.	Through collaborative design, the actual design cycle is shortened to 8 months.	Shortened by 33%
Design conflicts and problems	There are a large number of design conflicts among majors, and 5 conflicts are solved on average every month.	After collaborative design, the average monthly conflict resolution problem is reduced to one.	Reduced by 80%
Quality of design	Many incongruities and mistakes were found in the preliminary design review.	After collaborative design, the design review passed at one time, without major modification.	Improve markedly
Repeated labour and waste	The information among designers is not shared, which leads to a lot of repetitive work and waste of materials.	After collaborative design, information sharing and resource integration are realized, and repeated work and material waste are avoided.	The repetitive work is reduced by about 50%
Customer satisfaction	The customer put forward many amendments to the preliminary design scheme, and the satisfaction was low.	After collaborative design, customers are very satisfied with the final design scheme, without any modification requirements.	Satisfaction has greatly improved
Market response	Due to the long design cycle and quality problems, the project faces the risk of delay and	After collaborative design, the project was delivered on time, with high quality and good market response and	The project was successful and recognized by the market

	budget overrun.	reputation.

Table 3: The application effect of collaborative design in building skin design is shown in detail.

The data in the table quantifies the actual effect of collaborative design in building skin design projects. It can be found that: firstly, the design cycle is greatly shortened, and the design conflicts and problems among various majors are solved in time. Secondly, the design quality has been significantly improved, and the design among the specialties is coordinated, avoiding duplication of work and waste; Finally, customer satisfaction has been greatly improved, and the project has been successfully delivered and received a good market response. This case fully proves the importance and application value of collaborative design in architectural skin design.

5 DIGITAL BUILDING SKIN DESIGN BASED ON COMPUTATIONAL GEOMETRY ALGORITHM

5.1 Algorithm Optimization and Implementation Process

In digital building skin design, the choice of computational geometry algorithm is very important for design efficiency and innovation. Among many algorithms, the parametric algorithm and GA (Genetic algorithm), which are suitable for architectural skin design, are chosen in this paper. The parametric algorithm can quickly generate and change the shape of the building skin by adjusting parameters, which is very suitable for the design process that needs repeated modification and optimization. The morphological generation formula can be expressed as:

$$F\ x,y,\theta\ = A\cdot\sin\ B\cdot\ x^2+y^2\ \ \cdot\cos\ \theta \quad (1)$$

Among them, A stands for the size of epidermal elements, B controls the compactness of morphology and θ stands for wind direction or light angle. This formula can generate an architectural skin shape that changes with the changes in parameters.

In this paper, the parametric algorithm is optimized and improved to meet the actual needs of architectural design better. The optimization and improvement mainly focus on two aspects: First, this paper adjusts the parameterization algorithm to meet the actual needs of architectural design better. This includes fine adjustment of the parameters of the algorithm so that it can control the changes in skin morphology more accurately, and at the same time, it takes into account the key factors such as structural performance and material consumption of buildings. Secondly, we enhance the interactivity and operability of the algorithms so that designers can use these algorithms in CAD software more conveniently, thus improving design efficiency and quality.

In this paper, the cost optimization formula is combined with the material consumption and structural performance to optimize the cost. The cost optimization formula is as follows:

$$C = M\cdot C_m + S\cdot C_s \quad (2)$$

Where C is the total cost, M is the material cost, S is the structure cost and C_m and C_s are the coefficients of the material and structure costs, respectively. Dynamically adjust the material dosage according to the change in epidermis morphology. The formula for material dosage is as follows:

$$M = k\cdot A \quad (3)$$

Where M represents the material consumption, k is the material consumption coefficient per unit area, and A is the total area of building skin.

GA, an optimization algorithm, mimics the process of biological evolution and discovers the best solution through simulating natural selection and genetic mechanisms. In the design of building skin, GA can be used to optimize the skin shape to meet various performance requirements. In this paper, it is improved to improve its search efficiency and optimization accuracy. Firstly, this paper optimizes the algorithm's coding method so that it can more accurately represent the morphological characteristics of building skin. Secondly, we introduce more efficient genetic operators- crossover, mutation and selection- to improve the algorithm's search efficiency (as shown in Figure 1).

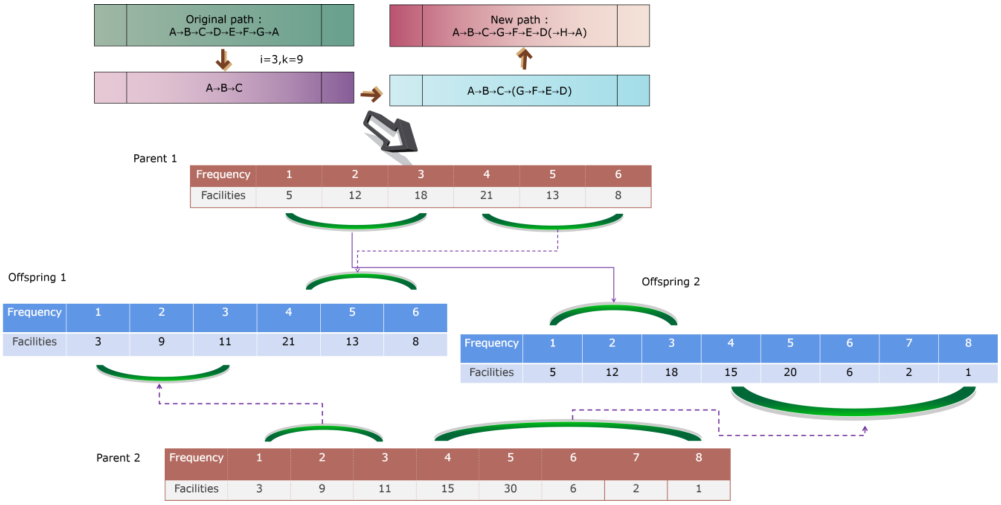

Figure 1: Schematic diagram of improved cross-process.

In this paper, a conditional mutation operator is used, and the adaptive mutation probability is as follows:

$$p_m = \begin{cases} p_{m1} - \dfrac{p_{m1} - p_{m2} \quad f_{\max} - f_m}{f_{\max} - f_{avg}} & f_m \geq f_{avg} \\ p_{m1} \quad f_m < f_{avg} \end{cases} \tag{4}$$

Among them:

$$f_{m1} = 0.1, f_{m2} = 0.001 \tag{5}$$

Where $f_{\max}, f_{avg}$ are the maximum fitness values and average fitness values in the parent and f_m is the fitness value of the individual to be mutated? Digital building skin design is a multi-objective optimization problem. In GA, the corresponding mathematical model can be described as follows:

$$f\ T,C,Q\ = Min\ T,C,-Q \tag{6}$$

$$MinC = \sum_{i=1}^{N} C_i^D + \sum_{i=1}^{N} C_i^j \tag{7}$$

$$Min\text{-}Q = -\sum_{i=1}^{N} q_i \omega_i \tag{8}$$

$$MinT = \sum_{i=1}^{J} t_i \tag{9}$$

Among them, T,C,Q are the total construction period, total cost and total quality of building skin design respectively; N stands for N processes, and C_i^D stands for direct cost; C_i^j stands for indirect cost; t_i is the duration of the active i on the critical path; ω_i is the score under a certain evaluation factor; q_i is the weight of operation i. At the same time, this paper adopts the elite retention strategy to ensure that the best individuals in each generation can be retained, thus accelerating the convergence speed of the algorithm.

In this paper, the steps to realize computational geometry algorithm in CAD software are as follows:

Firstly, according to the principle and characteristics of the selected algorithm, the corresponding program code is written. These program codes need to be able to deal with geometric data in architectural design, such as coordinates and attribute information of points, lines, surfaces and other elements.

Secondly, the program code is integrated into CAD software to realize the interactive operation with CAD software. This usually needs to be realized through an API interface or plug-in mechanism provided by CAD software. The integrated algorithm tool should be able to conveniently call the geometric data in CAD software and feedback on the calculation results to CAD software for visual display and editing.

Finally, the algorithm tool is tested and verified to ensure its correctness and reliability. These include testing with standard test data sets, comparing with other algorithm tools, and application testing in actual design projects.

5.2 Case Analysis of Algorithm Application

To demonstrate the effectiveness and novelty of the chosen computational geometry algorithm in enhancing building skin design, this section presents a practical case study. Specifically, we examine a cultural center's skin design project, where designers strive for both aesthetic and functional shapes. Figure 2 illustrates design examples utilizing the fractal algorithm-based method and the optimized approach proposed in this study. Based on the above items, the corresponding scoring situation is shown in Figure 3.

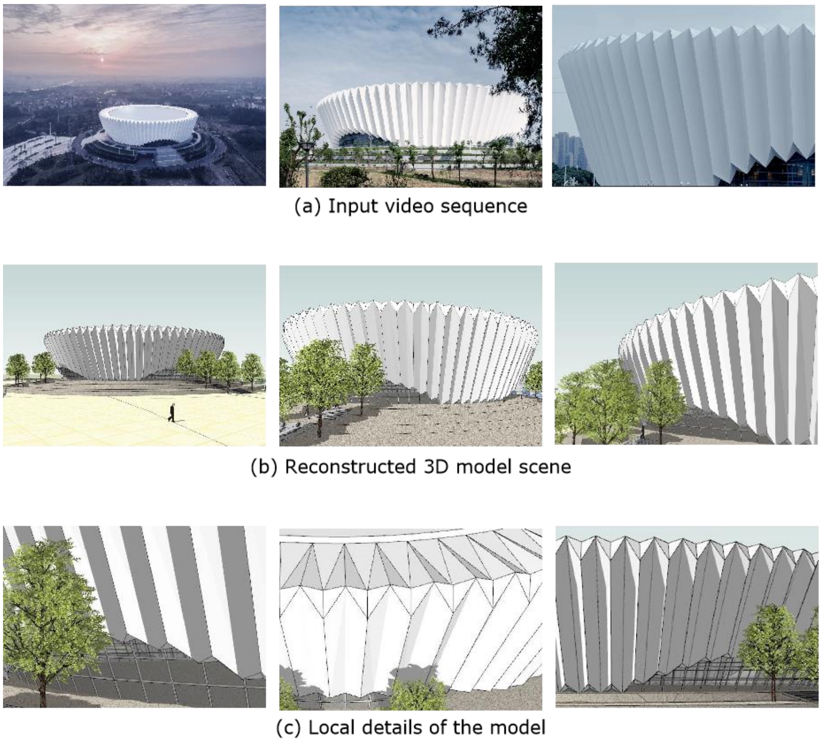

Figure 2: Example of skin design project of the cultural centre building.

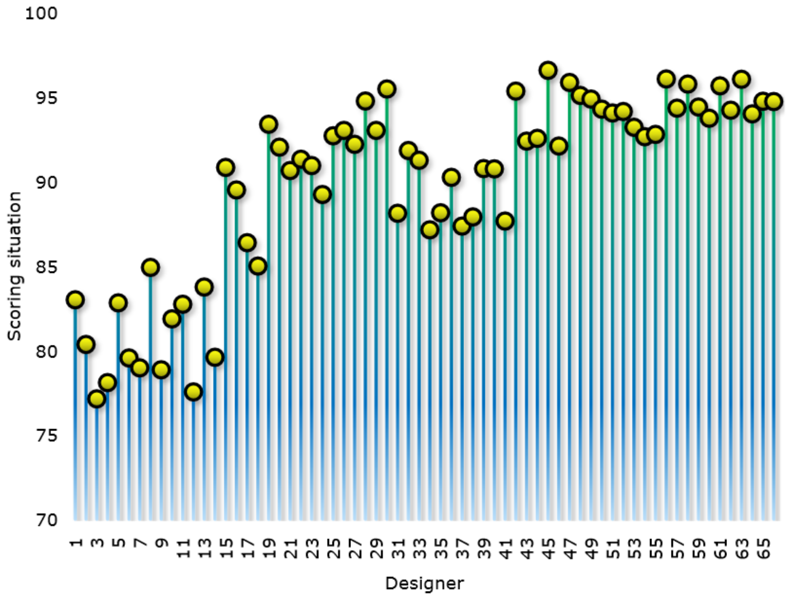

Figure 3: Project scoring situation.

The design method based on a fractal algorithm needs a lot of time and energy to model and adjust, and it is difficult to ensure the innovation and optimization of the form. However, by applying the optimized computational geometry algorithm in this paper, designers can quickly generate a variety of innovative skin morphology schemes and optimize them according to performance requirements. The final skin shape not only meets the requirements of artistic beauty but also has good structural performance and energy-saving effects. This fully proves that the selected computational geometry algorithm plays an important role in improving the efficiency and innovation of building skin design.

6 SIMULATION EXPERIMENT DESIGN AND RESULT ANALYSIS

6.1 Simulation Experiment Design

To validate the efficacy and practicality of CAD collaborative technology and computational geometry algorithms in digital building skin design, this study devised and executed simulation experiments. The aim was to mimic the collaborative workspace of an authentic design process and assess the algorithm's utility in generating and refining architectural skin shapes.

Initially, we established a collaborative design setting with multiple professional designers to emulate real-world project collaboration. Within this setting, designers employed CAD software for building skin design, leveraging collaborative technology for real-time data synchronization and sharing. We documented various metrics during the collaborative design phase, such as design duration, conflicts encountered, and revisions made, to assess the impact of the collaborative approach.

Subsequently, we chose representative architectural skin design scenarios and applied the computational geometry algorithm for shape generation and optimization. These scenarios encompassed diverse architectural styles and design specifications, ensuring the experiment's breadth and relevance. We recorded the algorithm's parameters and outcomes during execution, facilitating subsequent data analysis and insights.

6.2 Experimental Implementation and Result Discussion

After collecting enough experimental data, this section makes a detailed data analysis. For collaborative design experiments, we compare the design efficiency and quality with and without collaborative technology. The comparison of design efficiency between using collaborative technology and not using collaborative technology is shown in Figure 4. The comparison of design quality between using collaborative technology and not using collaborative technology is shown in Figure 5.

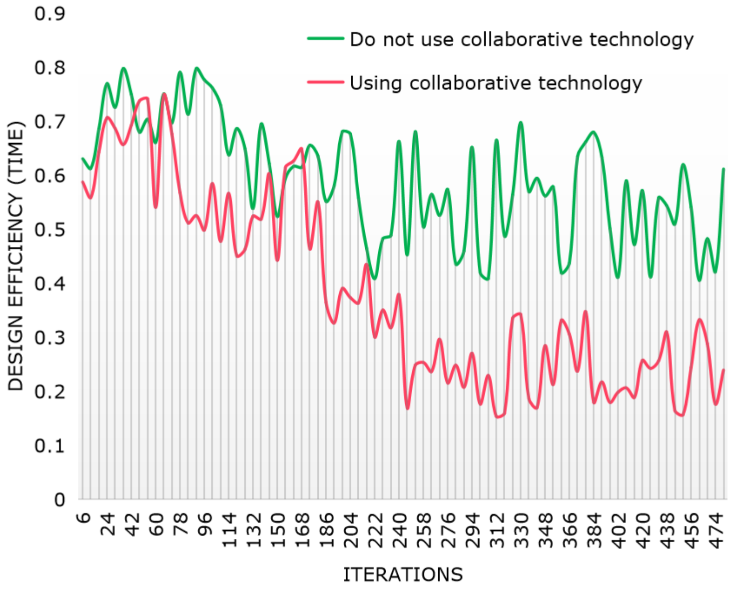

Figure 4: Design efficiency situation.

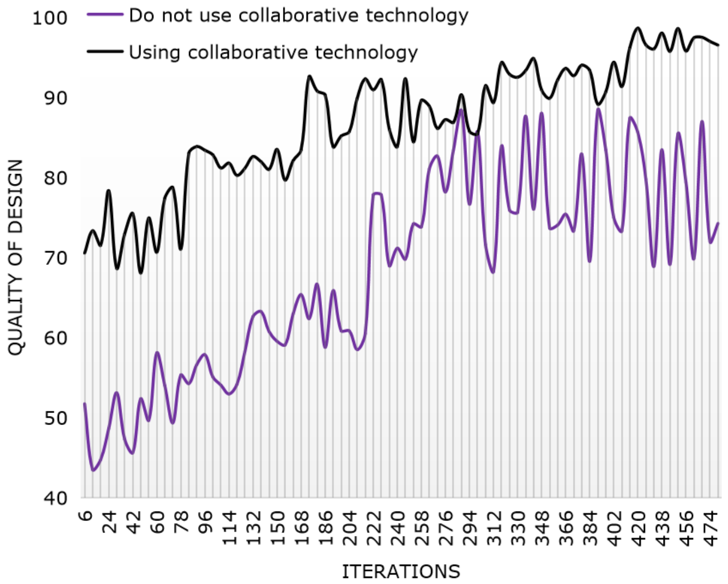

Figure 5: Design quality situation.

The findings reveal that incorporating collaborative technology notably decreases design time, minimizes design conflicts, and enhances the efficacy and quality of design modifications. This underscores the substantial worth of collaborative technology in digital building skin design. Regarding the computational geometry algorithm experiment, this section assesses the algorithm's performance in generating and optimizing architectural skin morphologies, as illustrated in Figures 6 and 7. The low curve display error observed in Figure 6 indicates the algorithm's high precision in skin generation.

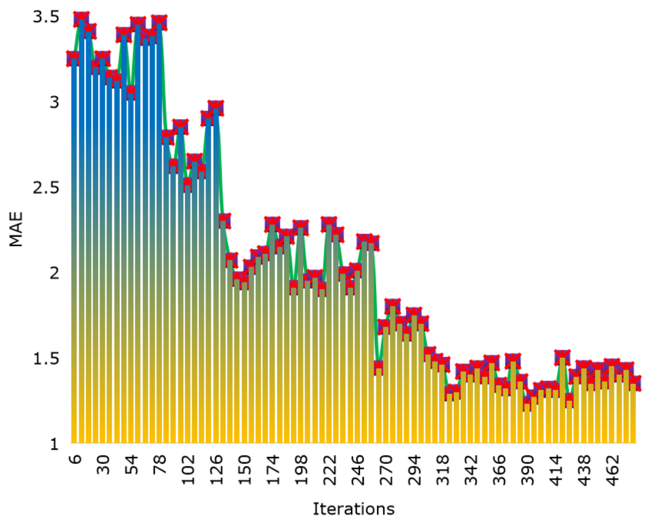

Figure 6: Algorithm generation error.

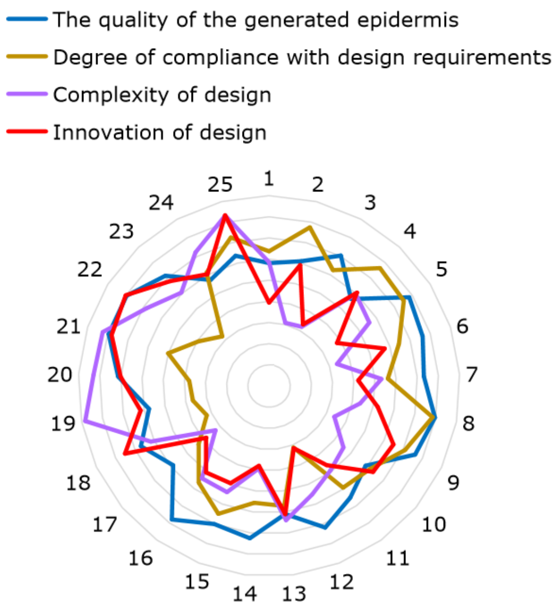

Figure 7: Algorithm optimization performance.

Figure 7 shows that the algorithm in this paper shows high quality, complexity, and innovation and meets the design requirements. This means that the algorithm can not only accurately generate the skin structure that meets the design intent, but also bring novelty and beauty to the shape.

Through the above experimental results, it is found that this algorithm can generate innovative and aesthetic epidermis quickly and accurately, and it also has good performance in optimizing performance. The computational geometry algorithm proposed in this paper has obvious application potential in the field of architectural skin design and can provide powerful and flexible tools for architects and designers to quickly generate and optimize innovative and aesthetic architectural skin forms.

7 CONCLUSION AND PROSPECT

7.1 Research Conclusion

This study comprehensively examines the utilization of CAD collaborative technology and computational geometry algorithms in digital building skin design, arriving at the following primary conclusions:

Firstly, CAD collaborative technology holds significant importance in building skin design. Through the establishment of standardized design practices, the utilization of a centralized file for collaborative efforts, and the implementation of worksite functions for task allocation and authority management, design efficiency can be notably enhanced, conflicts minimized, and overall design quality elevated.

7.2 Research Deficiency and Prospect

Computational geometry algorithms merit further investigation and refinement to enhance the precision and efficiency of epidermis morphology generation and optimization. Lastly, fostering collaboration and knowledge exchange with related disciplines holds the potential to jointly propel innovation and development within the architectural design industry. Concurrently, active participation in international exchange and cooperation initiatives could facilitate the assimilation of globally advanced design concepts and technological advancements.

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