THE LOTUS BIONIC PARAMETRIC DESIGN OF CONTEMPORARY CHINESE ARCHITECTURE

By
Mr. Zhizhi LIU

A Thesis Submitted in Partial Fulfillment of the Requirements
for Doctor of Philosophy DESIGN
Silpakorn University
Academic Year 2023

โดย
Mr.Zhizhi LIU

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปรัชญาดุษฎีบัณฑิต

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Title	The lotus bionic parametric design of contemporary Chinese architecture
By	Mr. Zhizhi LIU
Field of Study	DESIGN
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Bionic parametric architectural design is related to the design concept, cultural inheritance, technological innovation, and sustainable development direction of Chinese architecture. In recent years, construction engineering, as an essential pillar of the economy, has become a consensus in China's economic development. The 19th National Congress of the Communist Party of China proposed to promote the coordinated development of intelligent construction and new building industrialization as the driving force to accelerate the transformation and upgrading of the construction industry, achieve green and low-carbon development, and effectively improve the quality and efficiency of development. As an essential part of the construction project, Lotus bionic parametric architectural design has the characteristics of equal emphasis on theoretical knowledge and practical operation. Contemporary Chinese architectural design needs to think about green buildings and intelligent buildings. Therefore, the cultivation of architectural design trends becomes even more critical. To this end, researchers based on the characteristics of contemporary Chinese architectural development, taking the Lotus bionic parametric architectural design as an example, conduct detailed research and elaboration as a guide to the development trend of contemporary Chinese architectural design.

This research paper covers aspects such as lotus bionic design, parametric modeling technology, architectural design, and 3D printing concrete building production. Comprehensive application of research methods. Combining research tools and data analysis, completed the design experiment and design practice of Lotus bionic parametric architectural design, improve China's architectural design capabilities. Through this research content, we can understand the development trends and design research methods of Chinese architectural design, expand design thinking, and improve work efficiency when designing architectural plans. This paper combines knowledge and practicality, is easy to understand, and provides reference and help for the architectural design profession.

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Zhizhi LIU

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CHAPTER 1

INTRODUCTION

Contemporary Chinese bionic parametric architectural design combines bionics and advanced computer parameterization technology applied to the emerging field of architectural design. Biomimicry is a discipline that draws design inspiration from the characteristics of biological forms, structures, and functions in from nature. Parametric technology is a method that uses digital algorithms to optimize the design and performance of buildings and realize architectural design. In contemporary Chinese architectural design, the bionic parametric design method, buildings with bionic principles, and intuitive and natural forms, which some buildings apply parametric technology to make architectural design more scientific and accurate. It has become a highlight in contemporary Chinese architectural design to cope with complex architectural design issues and increasingly stringent environmental protection requirements.

The significance and value of bionic parametric architectural design in contemporary China, which is more than just applying advanced technical means. It also includes rethinking and exploring traditional Chinese cultural elements and environmental awareness. The focus is to integrate the concept of harmonious coexistence between nature and human beings in traditional Chinese cultural elements into architectural design. To achieve the goal of sustainable development of contemporary Chinese architecture. Find the intersection between disciplines, become an innovation point in research, connect various disciplines, and apply the research results of various natural disciplines to contemporary Chinese bionic parametric architectural design. Research and explore new design method models to cope with the different challenges brought about by the development of the times, inspire and guide contemporary Chinese architectural designers to solve complex architectural design problems, and combine visual communication design with various computer-aided designs, serving the contemporary Chinese construction industry, combining innovative thinking and logical algorithms, to improve the technology and aesthetics of Chinese architectural design. Inspire Chinese architectural designers to devote themselves to studying the local urban spiritual culture and natural environment characteristics and conditions, and according to the bionic parametric design method, design an architectural plan suitable for the local urban spiritual culture and environment. Therefore, contemporary Chinese bionic parametric architectural design is a design method full of vitality and creativity. It provides important help for the sustainable development of urban architecture in China; it is also an important research content of innovative visual communication design.

1.1 RESEARCH BACKGROUND

Background research on bionic parametric architectural design in contemporary China mainly includes three aspects: political background, economic background, and cultural background. Information age, human resources, and technological progress are the general trends. The construction industry needs to improve the professional capabilities of talented professionals and continuously upgrade technology. Improve the refined manufacturing and management of engineering projects, reduce human resource costs, improve integrated model capabilities, and improve the effectiveness and efficiency of construction projects.

1.1.1 POLITICAL BACKGROUND

According to the Recommendations of the Central Committee of the Communist Party of China on Formulating the Fourteenth Five-Year Plan for National Economic and Social Development and Long-term Goals for 2035, the ecological environment will fundamentally improve. Realizing the long-term goal of building a beautiful China, the major strategic decision and implementation of urban renewal action was put forward. The city's master plan covers the period from 2017 to 2035. This is a long-term plan of the Chinese government. It aims to guide the development of urbanization and emphasizes ecological priority, people first, and the principle of coordinated development. The construction of beautiful cities is an integral part of beautiful China. It is an essential carrier for building a beautiful China. The urban ecological civilization construction pilot work plan aims to strengthen the construction of urban environmental civilization, promote sustainable urban development, and improve the ecological environment quality of the city.

On October 7, 2022, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the Opinions on Strengthening the Construction of High-Skilled Talent Teams in the New Era. And give notice that all regions and departments across the country are required to implement it based on actual conditions conscientiously. Strengthening the team building of senior vocational skills talents, enhancing the country's core competitiveness and scientific and technological innovation capabilities, and Promoting high-quality development in China is of great significance.

1.1.2 ECONOMIC BACKGROUND

The report of the 19th National Congress of the communist party of China pointed out that socialism with Chinese characteristics has entered a new era. China's economy has shifted from a stage of rapid growth to a stage of high-quality development. We are in a critical period of transforming development methods, optimizing economic structure, and converting growth momentum. As a pillar industry of the national economy, building on the outstanding achievements made by the construction industry in the past, technological progress, One Belt and One Road, rural revitalization, new infrastructure construction, and other opportunities and challenges. The 14th Five-Year Plan and the outline of long-term goals for 2035 propose accelerating the construction of new infrastructure. It must center on strengthening digital transformation, intelligent upgrades, Integrated innovation support, layout and build information infrastructure, integrated infrastructure, and new infrastructure such as innovative infrastructure. In this economic context, the Chinese government adopts high-tech buildings, reflecting China's economic and technological levels. New infrastructure construction is infrastructure construction that focuses on science and technology. The vigorous development of new infrastructure will drive demand in the construction industry. The construction industry faces broad development opportunities for urban and rural revitalization.

1.1.3 CULTURAL BACKGROUND

China's traditional culture carries the Chinese people's historical memory and cultural identity. Chinese architecture has different characteristics in different eras. It is a cultural symbol and art form. Ancient Chinese architecture was influenced by philosophies such as Buddhism, Taoism, and Confucianism. At present, most of the ancient buildings left in China are Buddhist temples, pagodas, palace buildings, etc. These Buddhist buildings embody the beliefs and spirit of ancient Chinese people. Taoist thought pursues the laws of nature; the design and layout of the building must comply with the principle of harmony between man and nature, architecture, and the trinity of heaven, earth, and man. In ancient Chinese architecture, many building designs are inspired by elements such as landscapes, flowers and birds, clouds, and mist in nature, pursuing the integration and coordination of architecture and nature. Chinese traditional architectural layout, many ideas in orientation come from Confucianism, which aims to pursue the harmonious unity of architecture and the natural environment. Because Confucianism emphasizes the harmonious relationship between man and nature, man and society, it affects the design and manufacturing of ancient Chinese buildings. Found in traditional Chinese architecture, during the construction process of the building, the decorative components of the building contain profound cultural heritage and historical memory. In architectural decoration components, sculpture, painting, copper and ironware, porcelain, etc., the art form demonstrates the cultural connotation and artistic charm of traditional Chinese architecture. Chinese conventional architecture has historical and cultural value and provides a source of inspiration and essential design support for contemporary architectural design.

With the development of the times and the process of modern information, the cultural background of China's current architectural design is rich and colorful, constantly evolving and expanding. We must part ways with China's traditional cultural impression, based on Chinese traditional culture, continuously integrate new ideas and technologies, continuously innovate and develop, and Establish a new impression of

Chinese architectural culture. In contemporary China, the construction industry has progressed rapidly since the reform and opening up. Significant changes have also created enormous economic value. Researching and developing intelligent, green, energy-saving, and environmentally friendly buildings has become an important direction in current Chinese architectural design. China vigorously promotes green energy-saving and environmental protection measures, reducing energy consumption and environmental pollution; with a new construction industry towards new green buildings and energy-efficient buildings, the direction of development of smart buildings takes the right path toward energy conservation and sustainable development.

1.2 RESEARCH QUESTIONS

In recent years, China has been affected by the COVID-19 epidemic. Compared with the construction industry in developed countries, there is still a big gap between China's construction industry and those of developed countries. Special attention is paid to the architectural design industry in the exchange of world cultures, in the case of mutual economic circulation, how to improve the competitiveness of China's architectural design market, how to improve the design capabilities of Chinese architectural designers, issues such as how to integrate building construction organization need to be focused on research and analysis.

(1) Research integrating traditional Chinese cultural model plant elements in Chinese architectural decoration.

(2) Advanced parametric scientific and technological modeling and generation of Chinese traditional cultural elements and modern fashion.

(3) Analysis and verification of art design education by transforming parametric 2D traditional Chinese cultural elements into 3D modern bionic architectural geometric models.

(4) Contemporary Chinese bionic parametric architectural design, production, and evaluation based on 3D printing technology.

The study found that bionic parametric architectural design has been rarely studied in Chinese academic circles.

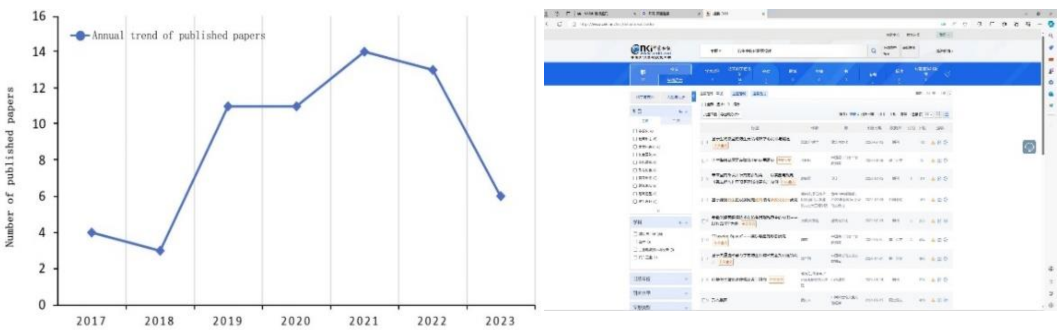


Figure 1 *CNKI retrieves the annual trend chart of published papers on bionic parametric architectural design*
Note. Researchers draw their own, 2023

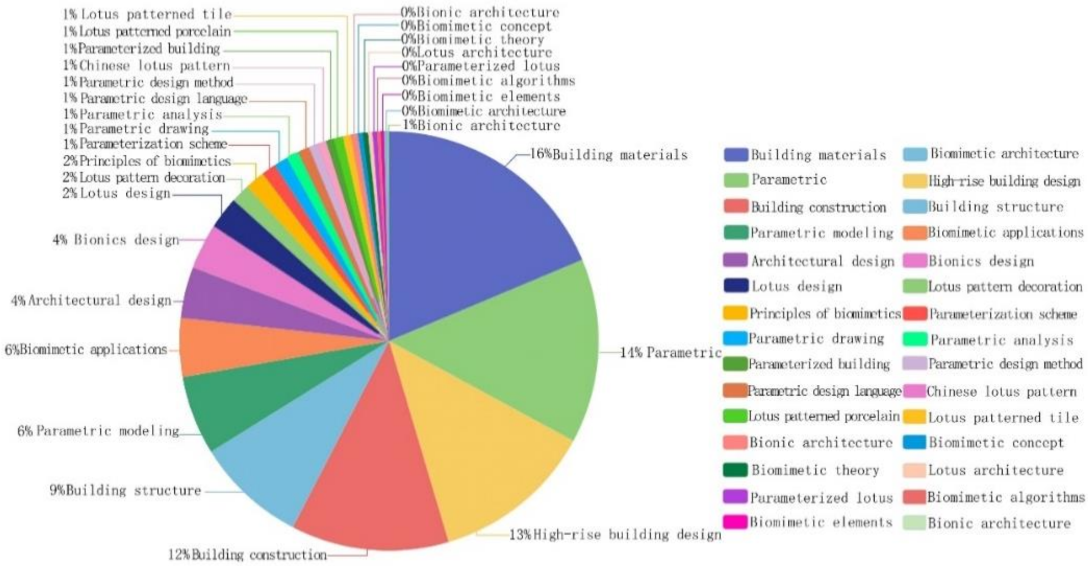


Figure 2 *CNKI retrieves bionic parametric architectural design theme distribution map*
Note. Researchers draw their own, 2023

1.3 RESEARCH OBJECTIVES

As global environmental problems intensify, studying the beauty of cities and, more importantly, creating them is the purpose of China's urban development. The research goals of contemporary Chinese bionic parametric architecture are to explore new architectural design concepts of green and sustainable development based on protecting and inheriting traditional cultural heritage and to use modern digital and intelligent technologies to improve architecture through simulation and optimization. Designers design efficiency and quality to promote the integrated development of architecture and cities and achieve the goal of sustainable energy development.

(1) Study the plant elements of traditional Chinese cultural patterns, take traditional Chinese Buddhist lotus patterns as an example, and study the cultural significance and folklore functions of lotus patterns in China. A research and analysis on the changes in the lotus pattern from different periods of Chinese history, other cultures, and contemporary Chinese traditional architectural decoration components. Design, and re-integrate the standard features of the lotus pattern, which are traditional Chinese cultural elements.

(2) Digital technology should be used in the information age, and the methods of combining parametric design methods with traditional Chinese cultural model plant elements and research ways and means to improve the efficiency of architectural designers.

(3) Combined with bionics, innovative green architectural forms are extracted from nature, and an art design education method is developed that transforms 2D Chinese traditional cultural model plant elements and 3D geometric models to realize

parametric 3D bionic architectural models and educate students majoring in architecture and Chinese architecture. Designers provide training to achieve the goal of benefiting the public.

(4) Combined with China Construction Engineering, 3D printing technology will promote construction industrialization and innovate to achieve integrated energy conservation and manufacturing generation methods.

There are three innovative points in this study.

First, the subject of this study is bionic, parametric, and architectural concepts. There are few proposals in related research fields, and there needs to be a complete theoretical research and design system to query.

Second, few previous studies in China integrate lotus pattern bionics, parametric digital design, and architecture into collaborative design and development. It provides valuable data reference for contemporary Chinese architectural designers and is well-founded. It can be followed.

Third, from the perspective of related disciplines, the plant lotus is a comprehensive cross-disciplinary study that tries to integrate it into the architectural discipline and integrate architecture into the natural environment.

1.4 RESEARCH HYPOTHESIS

Contemporary Chinese bionic parametric architectural design is a dynamic and innovative field. Integrating current modern architecture with traditional cultural elements, protecting and passing on traditional culture, making good use of renewable energy, sustainable development, allowing digital technology and intelligent technology to be applied to architectural design, improving design efficiency and quality, realizing the integrated development of architecture and city, these are essential assumptions in contemporary Chinese architectural design.

(1) Studying the significance and benefits of bionic parametric architectural design in contemporary China is a way to advocate that living bodies exist in nature most reasonably.

(2) Study the plant elements of the traditional Chinese lotus culture model. Because it has different historical and cultural values in various historical periods, it can provide a design basis and theoretical basis for contemporary architectural design.

(3) Researching the latest technology and parametric design to ensure that there are data reasons to follow to realize rational design. Use new technologies or theories to solve problems encountered in the development of human life.

(4) By studying contemporary Chinese bionic parametric architecture, we will provide valuable reference for contemporary Chinese architectural designers and allow more architecture students to gain access to design methods.

1.5 RESEARCH SCOPE

The research scope of contemporary Chinese bionic parametric architecture involves complex topics in multiple disciplines. It is necessary to comprehensively apply bionics, architecture, art, engineering, semiotics, ecology, parametric design technology, interaction research, nonlinear research, genetic algorithm, various subject knowledge such as the reconfiguration of materials and structures in the material organization, parameter, unit, both distributed grid systems and three-dimensional organisms can be used in the architectural field. Therefore, the scope of the research is complex; the range is extensive.

(1) The research focuses on the inheritance of plant elements in traditional Chinese cultural patterns, especially analyzing element extraction and deformation using the traditional Chinese Buddhist lotus pattern.

(2) Study the deformation of plant element units in traditional Chinese cultural models and how they are affected by association rules and the complexity of the unit itself. The original numbers of plant elements in traditional Chinese cultural patterns were initially derived from living organisms; the surface forms a complex distributed grid system, and these biological and natural shapes show the most efficient structures. Using parametric methods, combined with the effective structure of traditional Chinese cultural model plant elements, develop ways to improve architectural designers' work efficiency and design accuracy.

(3) Combining algorithms and geometric logic to define the organizational rules of primitives, generate bionic parametric energy-saving, intelligent, and environmentally friendly green building models.

(4) From the perspective of construction projects in the construction industry, in response to the current adjustments to the quality, technology, and cost of labor resources in China, using 3D printing technology, developing in the direction of green buildings, energy-saving buildings, and information-based buildings, integrated energy-saving construction and manufacturing model.

1.6 RESEARCH METHODS

The research method adopted a mixed research approach, including the literature survey method, comparative analysis method, combination of qualitative analysis method and quantitative analysis method, field investigation method, case study, design practice, expert consultation method, etc. A survey and research on contemporary Chinese architectural design evaluation were carried out through questionnaires and structured interviews. At the same time, I was studying and researching, setting the interview theme for China’s future architectural development trends, conducting in-depth interviews with experts, conducting a research method that combines quantitative and qualitative research methods, conducting on-site inspections of existing buildings in China and Thailand, and conducting theoretically constructive research. Finally, the existing literature was collected and analyzed through literature research. Documentary materials include text, numbers, symbols, pictures, and other information to explore and analyze Chinese architectural practices. Interdisciplinary and comparative studies are combined. Through an exploratory approach, research will be conducted according to the logical sequence of architectural design, and the research process of the lotus bionic parametric design of contemporary Chinese architecture will be gradually completed.

1.7 RESEARCH FRAMEWORK

The research framework starts from the basic structure of raising questions, analyzing problems, and solving problems to complete the research on contemporary Chinese architecture's lotus bionic parametric design. Taking the traditional lotus pattern among the plant elements of conventional Chinese cultural patterns as a case study, use parametric technology to conduct bionic parametric design research, analysis, and experiments on contemporary Chinese architecture.

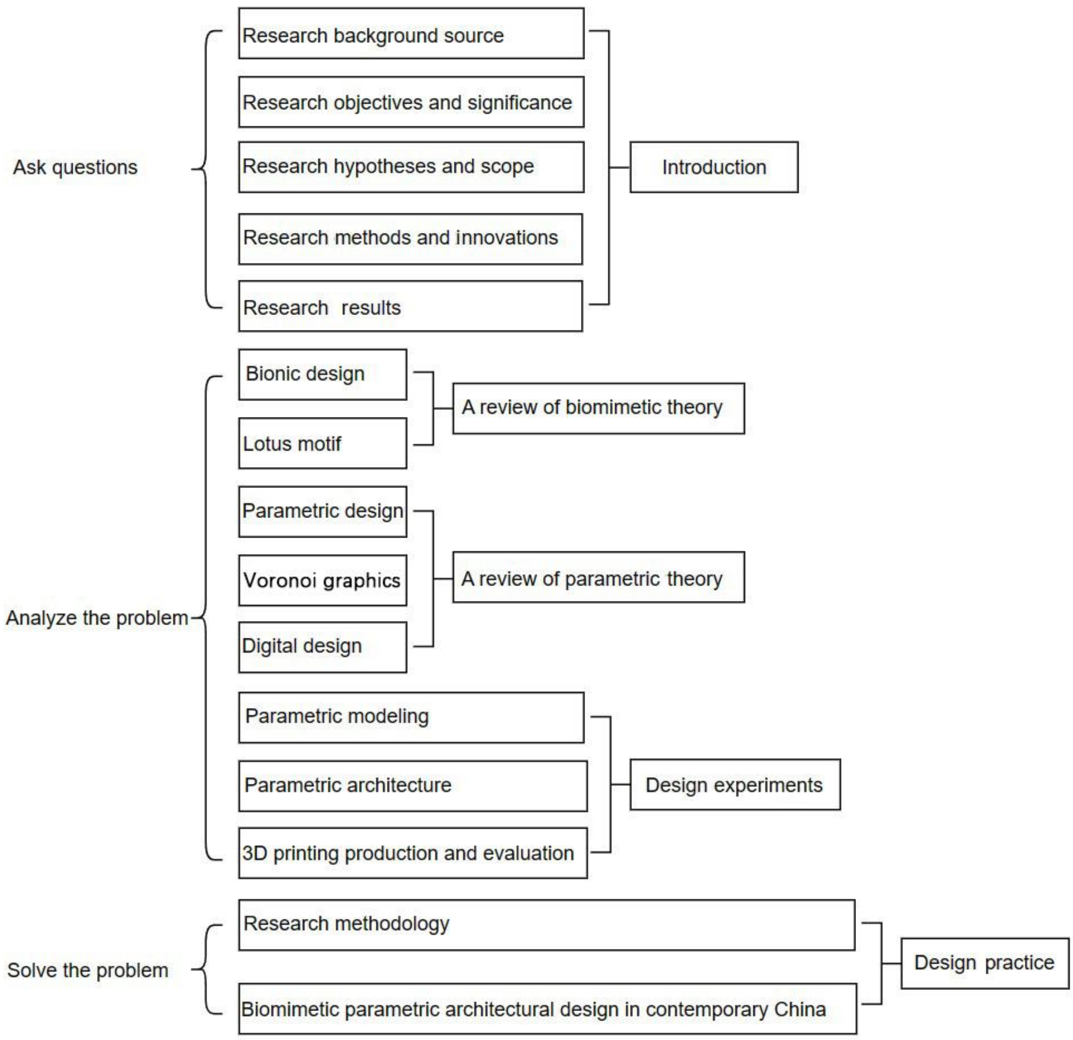


Figure 3 *Thesis research framework logic diagram*
Note. Researchers draw their own, 2023

1.8 RESEARCH RESULTS

This study provides framework steps for contemporary Chinese bionic parametric architectural design. This model research is no longer an independent discipline. Instead, it is a complex research of multiple disciplines. Research results also include geographical terrain modeling, shadow and sunlight analysis, visual field analysis, ventilation simulation, daylighting calculation, energy consumption simulation, and project optimization analysis to stimulate the interest of contemporary Chinese architectural designers and university students in future architectural design; it also provides professional reference value. It forms a complete set of scientific bionic parametric design samples for contemporary Chinese architecture.

1.9 DEFINITION PREDICATE

In the design of this study, the biomimetic parameterization of the lotus became a key element. Using advanced computing technology, researchers accurately analyze the morphological characteristics of lotus flowers and convert them into adjustable design parameters. This parametric approach gives the building the appearance of a lotus and achieves a high degree of flexibility and optimization in structure and function. The unique feature of architectural bionic parametric design is that it is an imitation of nature and an in-depth understanding and innovative application of natural laws.

(1) Lotus is one of the oldest dicotyledonous plants in the world. There are records of lotus cultivation as early as the Zhou Dynasty in China, and it is widely spread across the globe. The lotus pattern is an integral part of Chinese traditional culture. It has been commonly used in Buddhist art, literature, architecture, and other fields. The lotus pattern has become a clan totem. Due to different periods and cultures, it is an auspicious symbol expressing different beautiful meanings. The lotus pattern is one of the essential research patterns of contemporary Chinese traditional decorative patterns.

(2) Biomimetic design is also called design bionics; it is a discipline that integrates design and bionics. Bionic design is different from bionics application. It takes the shape, color, sound, function, structure, etc., of all things in nature as its research object. A design that selectively applies these characteristic principles in the design process, combined with the research results of bionics, provides new ideas, principles, methods, and approaches to design.

(3) Parametric design is a design method. In modern design, design solutions are generated through parameter combinations, parameters are used to define the design thinking process, and design prototypes are built. This kind of design is called parametric design. The characteristics and attributes of parametric design objects are described and controlled by introducing parameters. Establish a relationship between design variables and parameters by changing the value of the parameter; features and behavior of designs can be changed automatically. Parametric design exists in a system and the elements of each component change. The topological relationship causes the entire structure to change.

(4) Voronoi diagram, defined as a division of the space plane, is the primary data structure for spatial division. It has unique graphical relationships and mathematical properties that are closely combined. The Voronoi diagram is an important research content in computational geometry. The Voronoi diagram, as a natural subject form, has attracted the design community's attention. The graphical form design of the Voronoi diagram relies on algorithms and parametric design methods. The complex form of the Voronoi diagram has natural laws and artistic rhythm in natural subjects, often used in art and design. Many natural structures in nature are very close to the Voronoi diagram; the Voronoi diagram itself has specific aesthetic characteristics.

(5) As a new technology, 3D printing technology integrates digital software with processing equipment to achieve personalized customization and mass production of objects. 3D printing technology has mold-free molding features such as material saving and customization, which are gradually emerging in the construction industry, showing great potential in improving construction productivity and safety. The unique potential of 3D concrete printing is that it can create complex geometric structures and has economic and environmental benefits.

(6) Parametric architectural design is an architectural design method based on parametric design ideas. The shape of architectural elements, structure, material, and other properties are controlled and adjusted by adjusting a series of parameters. Designers use computer programming or professional design software; many design variations can be generated by defining parameters and corresponding rules.

Through lotus bionic parametric design, the building is no longer just a cold structure but a living installation art piece. The appearance of the building is like a blooming lotus. Unique curves and proportions let people feel the revival of natural beauty in modern architecture. This design concept respects and innovates traditional culture, and the building incorporates advanced elements of contemporary technology. At the same time, it also inherits the profound meaning of lotus in Chinese culture.

1.10 CONCLUSION

This research on lotus bionic parametric design of contemporary Chinese architecture is an innovation that combines traditional culture and modern technology. The bionic parametric art architectural design concept is a new design vitality. Researchers introduced the elegant form of conventional lotus flowers into the field of architecture. Create a unique look and structure. Because parametric design is experimental, characteristics of research and cross-fertilization, therefore, its value has been verified in research and practice. Lotus bionic parametric design focuses on appearance and has made breakthroughs in practicality and sustainability, achieving efficient use of resources through intelligent design parameters. This design concept respects traditional culture and actively explores new possibilities of modern architecture. It brings unique aesthetic experience and technological innovation to the field of architecture. Study contemporary Chinese architecture's bionic parametric design results and deepen parametric design, bionics, and artistic architecture to a smaller scale. Combining the three also studies the symbiosis between man and nature. It is the embodiment of the pioneering trend of contemporary Chinese architectural design. Provide professional help and professional reference value for contemporary Chinese architectural designers and college graduates.

CHAPTER 2

LITERATURE REVIEW

In recent years, nature, green, and environmental protection have become hot topics, reflected in people's clothes, food, living, and walking. Natural food has gained everyone's attention, and natural color dyes have also become popular in clothing; for furniture used in family life, we began to choose furniture made of solid wood, green energy-saving, and environmentally friendly buildings are used in urban construction. These phenomena reflect people's ideological desire to be close to nature and their desire to return to nature. At the same time, these social phenomena put forward requirements for design, integrating nature into design, satisfying people's psychological needs to be close to nature, and echoing the development trend of the times. The integration of ecology, technology, art, and architecture represents the future development direction of the new civilization of architectural design. Through interdisciplinary research on plant bionics, parametric three-dimensional space construction model analysis, and 3D printing technology, this paper constructs a new form and method of contemporary bionic parametric architectural design. On June 2, 2023, Xue Xi Qiang Guo reported that Chinese President Xi Jinping attended a symposium on cultural inheritance and development in Beijing and delivered an important speech. They emphasize that continuing to promote cultural prosperity from a new starting point, building a culturally powerful country, and building a modern civilization for the Chinese nation is our new cultural mission in the new era.

Figure 4 *Chinese President Xi Jinping attended the symposium on cultural inheritance and development 2023.6.2.*
Note. https://www.xuexi.cn/2023

2.1 BIONIC DESIGN AND RESEARCH

As an interdisciplinary subject, bionic design must be integrated with natural subjects. Many human daily necessities are derived from natural bionics, including animal and plant bionics. This paper uses existing systematic natural subject knowledge to serve the design, digest knowledge of plant natural subjects, translate it into botany for design, integrate the two fields of humanities and nature, propose the concept of plant modeling elements, and establish cases of plant modeling elements. It will provide architects with a convenient way to carry out bionic design; the knowledge of plant cases is presented to architects in detail and systematically, broadening designers' horizons and sources of inspiration.

2.1.1 CONCEPT OF BIONICS

Biomimicry is the study of biological principles and their application in engineering and technology; it is a science that imitates natural organisms and is also a borderline subject. In 1958, American Steele first proposed the concept of bionics. The core idea of bionics is to study the structure, form, function, energy conversion, information control, and other excellent characteristics of biological systems. They can be applied to technical systems to improve existing technical engineering equipment and create a comprehensive science of new technological processes, architectural configurations, automation devices, and other technical systems.

At present, the scope of research in bionics in China is vast. It is reflected in bionic architecture, bionic robots, bionic computing, materials, medicine, etc., the bionic architecture field mainly studies issues such as architectural form, building materials, building life cycle, and building ecological environment from the perspective of bionics, designing innovative architectural solutions suitable for people to live and work(Jan, Ulrich, & Thomas, 2019). Research on bionic robots is through the study of the physiology, morphology, movement, perception, control, and other functions of organisms, achieve innovative applications with more efficient, flexible, and precise operations, exploration, rescue, collection, medical care, nursing, military, education, entertainment, and other powerful functions. Bionic computing is mainly used in computer model design, simulating biological systems, carry out computer autonomous learning to form an intelligent computing system. Biomimetic materials are widely used in science, biomedicine, and other fields. The application in bionic medicine has made significant progress in medicine, medical treatment, and other aspects.

Biomimicry is a very promising and challenging subject, combining biology and engineering to create more efficient and intelligent technologies and materials for people(Junior & Guanabara, 2005).

2.1.2 BIONIC DESIGN CONCEPT

Biomimetic design is also called design bionics; it is a discipline that integrates design and bionics. Landhay proposed in the particular study of bionic design that bionic design differs from bionics applications. It takes the shape, color, sound, function, structure, etc., of all things in nature as its research object. This design selectively applies these characteristic principles in the design process and, at the same time, combined with the research results of bionics, provides new ideas, new principles, new methods, and new approaches to design. Therefore, bionic design is a continuation and development of bionics. The bionic design combines both art and science. Not only materially but simultaneously, we also pursue the diversified design integration and innovation of tradition and modernity, nature and human beings in spirit. To achieve a high degree of harmony between human beings and nature.

The bionic design has the characteristics of two disciplines: bionics and design. It is mainly manifested in the scientific nature, infinite reversibility, and cross-disciplinary comprehensiveness of art.

Table 1 *Bionic design features*

Features	Design Philosophy	Bionics
Scientific nature of art	A branch and supplement of modern design. Have common artistic characteristics. It is based on certain design principles and has a very rigorous scientific nature.	Based on certain bionics theories and research results.
Infinite reversibility	The research objects of design are infinite, and the prototype of bionic design is also infinite, studying nature.	Looking for design prototypes in nature, promote the research and development of bionic design.
Interdisciplinary comprehensive	Possess certain basic knowledge of mathematics, ergonomics, psychology, mechanics, aesthetics, ethics, and other related disciplines. Based on design, a new interdisciplinary discipline is produced at the intersection of several disciplines.	Have certain basic knowledge of biology, materials science, color science, and other related disciplines. Have a clear understanding of current research results in bionics.

Note. Researchers draw their own, 2023

2.1.3 CURRENT STATUS OF BIONIC DESIGN

From the perspective of the development status and research application fields of bionic design, it is mainly reflected in morphological and functional bionics. Currently, bionic design in China is in a stage of rapid development; in recent years, the research and application of bionic design have made significant progress and development. People continue to expand their life experiences and learn from natural creatures' wisdom and structural principles to solve human problems. Summarize and summarize biological forms. Human knowledge systems have gradually become more complex and systematized; people understand the natural world through basic knowledge of mathematics, ergonomics, psychology, mechanics, aesthetics, biology, materials science, color science, ethics, and other related disciplines. From ancient times to the present, people have continued imitating nature. Bionic design activities in contemporary China are ongoing, and many areas show tremendous potential. For example, in scientific research, Chinese scientific research institutions and universities have extensive activities in biomechanics, materials science, electronic engineering, etc., to study the functions and structures of living organisms and apply them to high-tech, new materials, etc. In construction engineering, explore and apply bionic design to improve the efficiency and sustainability of construction, transportation, aerospace, and other projects, promoting the development of related industries. In the field of innovation and industrial development, integrated into product development and service innovation, integrating into industry provides a new way of thinking to solve problems from multiple angles and aspects, promote innovation, transformation, and upgrading of China's economic and industrial sectors, promote industrial development and inject new impetus into innovation. At the same time, China's bionic design is also facing opportunities and challenges. Interdisciplinary collaboration and symbiosis are vital to advancing bionic design. Although some progress has been made, cooperation and exchanges in different subject areas still need strengthening. The talent shortage is also a vital issue; it is necessary to cultivate new types of compound talents and improve professional skills; bionic design talents with comprehensive knowledge and skills are needed. With the continuous progress and development of China's artificial intelligence, biotechnology, materials science, and construction engineering, in the future, more cutting-edge technologies will be combined with bionic design to promote breakthroughs in innovation and application.

2.1.4 EVOLUTION AND DEVELOPMENT TRENDS OF BIONIC DESIGN

With the continuous advancement of science and technology and people's in-depth study of the natural world, bionic design has gone through a long development process, showing its unique charm, and with the development of modern design, it is constantly innovated and enriched, from the initial reference to natural forms to today’s interdisciplinary collaboration and innovation. Remarkable progress has been made over the past few decades and has shown great potential. Due to the influence of social, cultural, economic, technological, aesthetic, and other factors, each stage of bionic design has its distinctive characteristics of the times.

Early bionic designs were influenced by ancient wisdom and traditional culture. The form, structure, and function of nature in ancient times and its application in various fields. Restricted and influenced by the materials, craftsmanship, and aesthetics of the times, more have aesthetic value, it can also improve energy efficiency, environmental adaptability, and human comfort, and it is rich in symbolic meaning. Early bionic design ideas laid an important foundation for subsequent scientific research and modern bionic design.

Progress in science and technology, and the development of human society, provide a more scientific basis for bionic design and expand multiple design areas. With the rise of interdisciplinary collaboration, research on bionic design is more diversified. System design, sustainable design, integrated design, postmodern design, and ecological design trends, affect the development direction of bionic design. Biomimetic design shifts from the functional expression of biological systems to the semantic expression. From objective and rational design to subjective and emotional design. The pursuit of material and technology to the satisfaction of emotion and spirit. From globalization to urban regional diversification and personalization has become a trend. Biomimetic design will become a key tool in achieving eco-friendly and sustainable development goals. The individual characteristics, unique beauty, and meaning of the design are expressed more through morphological language, as well as association, imagination, representation, and other methods.

2.1.5 MORPHOLOGICAL BIONIC DESIGN

The biomimetic morphological design uses living things as imitation objects. By refining and summarizing the characteristics of living organisms, methods such as imitation, deformation, and abstraction can be applied to design and design techniques to achieve styling purposes.

Morphological bionic design is based on natural organisms, including animals and plants, based on the recognition of the typical external forms of microorganisms, etc., seeking breakthroughs and innovations in the form of emphasizing the expression of the aesthetic characteristics of the external form of the organism and human aesthetic needs. Object functional bionic design mainly studies natural organisms' objective functional principles and characteristics. Get inspiration from it to promote the improvement of object functions or the development of new product functions. Object texture and color bionic design is based on the study of biological surface texture and color, gets a simulation and re-creation on the object, and enhances the functional significance and expressiveness of bionic design forms. Morphological and functional bionic design are currently essential areas of bionic design research and application. This paper's Lotus bionic parametric architectural design will mainly focus on morphological bionic design(Z. Wang, Long, Huang, & Hu, 2024).

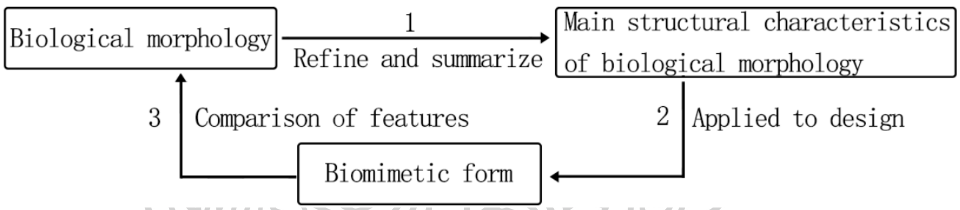


Figure 5 *Principle diagram of bionic morphology design process*
Note. Researchers draw their own, 2023

During this process, researchers extracted the main structural features of biological forms and simplified the extracted main structural features. Finally, this main structural feature is reproduced in front of people in bionic form under specific requirements.

From the perspective of object semantics, in most cases, bionic form design gives the object form a symbolic role and other visual aesthetics. In contrast, the biological form meets and fits the functional role of the bionic form. According to the object semantics theory, it usually has a dual meaning; its morphological language is used to express the object's physical properties. That is, denotative meaning; to project human emotions, describing the things of the soul is the connotation or meaning. Corresponding to this are the two roles played; one is the functional role, that is, its inherent role. The second is the symbolic role, which means a symbol to represent something invisible. It has a permanent connection to meaning. An object's symbolic role is formed by people's subjective emotions projected onto the object. It shows people's psychological, social, and cultural symbolic value in the context of use.

2.1.6 STRUCTURAL BIONIC DESIGN

Structural bionic design is based on understanding natural organisms' structural characteristics from the inside out. Design innovation combines different object concepts and design purposes, giving objects the meaning and aesthetic characteristics of natural life.

Structural bionics is based on the principles of engineering mechanics, studies the different structural levels of organisms microscopically, and takes a closer look at macroscopic shapes for inspiration; furthermore, for materials and structure, the system performs bionic simulation, a discipline that improves the efficiency of engineering structures. Structural bionics involves biology and engineering sciences such as materials science, structural design, control science, aerodynamics, and systems engineering, and it belongs to the field of interdisciplinary research.

Early structural bionics often started by simulating biological appearance, for example, designing a boat to imitate the shape of a fish and aircraft designs modeled after birds. Typical examples include imitating the structural characteristics of bees' hives, made of engineered honeycomb structural materials, lightweight, with Great strength and stiffness, features good thermal and sound insulation properties, it is now widely used in aircraft, on rockets, and buildings structures, functional simulation plays a positive role in promoting bionic design. Most of the early structural bionics in architecture imitated shapes. For example, the Sydney Opera House, with a thin shell structure built in 1973, is a typical application of structural bionics; Laboratory Building, Johnson Wax Company, Wisconsin, designed by Wright in 1944, USA imitates Arizona cactus hollow structure, the Baha'i Temple in New Delhi, India, built in 1986, is shaped like a giant lotus and more(Gruber & Imhof, 2007).

Structural bionics has been researched and developed for several decades; it has been widely used in many fields. Applications in the field of architecture include the Sears skyscraper in Chicago, USA, which imitates the bamboo structure; the segment type of bamboo includes bamboo nodes and internodes(X. Wang & Song, 2022). The internodes are hollow, light in weight, high in strength, and good instability. Kuwait Exhibition Hall at World Expo in Seville, Spain, its roof can be opened and closed freely, mimicking the free movement of animal joints. The Millennium Tower in Tokyo and the Swiss RE headquarters building designed by Foster simulate the skin fibers of sharks and the double helix structure of shrimp nests, enhancing the ability to resist external forces. Beidaihe Biluo Tower strives to express bionic architecture through a structural system, among them, the space spiral structure system is an expansion and innovative application of structural technology; the overall structure also adopts a green and environmentally friendly structure. Beehives and bird's nests inspire the Tianjin Natural History Museum and Beijing Bird's Nest Stadium designs. While achieving a beautiful overall design, they also realize the idea of using less material to obtain a larger space. In addition to aesthetics, the purpose of structural bionics is the corresponding structural functions, and green and environmental protection concepts have also been fully developed.

2.2 RESEARCH ON LOTUS PATTERN

2.2.1 WHY CHOOSE THE PLANT LOTUS PATTERN FOR RESEARCH?

In China, the lotus pattern was the beginning of primitive society. China's Shang and Zhou dynasties began to use patterns, and during the Southern and Northern dynasties, the style of the lotus pattern began to change and was used in architectural decoration; the lotus pattern flourished during the Tang Dynasty; it was widely popularized in society during the Ming and Qing Dynasties. The lotus pattern is an integral part of Chinese traditional culture and has been commonly used in Buddhist art, literature, architecture, and other fields. Due to different periods and cultures, contemporary Chinese traditional architectural decorative components have also undergone various changes. The lotus theme is a significant symbol in conventional Buddhist art; as an ornamental component, it is widely used in ancient Chinese architectural decoration and Buddhist decoration. The materialized image of Buddhist teachings in the current rapidly developing China of the new era is also significant and needs to be passed on and carried forward.

Similarly, through big data, artificial intelligence search engines ask three questions. First, what are the traditional Chinese plant patterns? The answers include plum blossoms, orchids, chrysanthemums, bamboo, peach blossoms, lotus flowers, pine trees, pomegranates, wisteria, and osmanthus. Second, what are the auspicious plant patterns in China? The answer is peach trees, plum blossoms, pomegranates, auspicious grass, bamboo, peonies, Lotus, and magnolia. Third, what kind of plant patterns are generally used in Chinese Buddhism? The answer is Lotus, Bodhi tree, Vajra flower, chrysanthemum, and Brahma flower. In the search for big data, the Lotus pattern consistently answers consistently answers that the Lotus's value as a traditional Chinese pattern can be researched.

In a study investigating traditional plant and flower patterns, it was shown that nearly 82% of the public are familiar with conventional plant and flower patterns, almost 12% of the public are very familiar with them, believe that the study of patterns should be meaningful in culture and art, it is of great value to apply traditional plant and flower patterns to modern design.

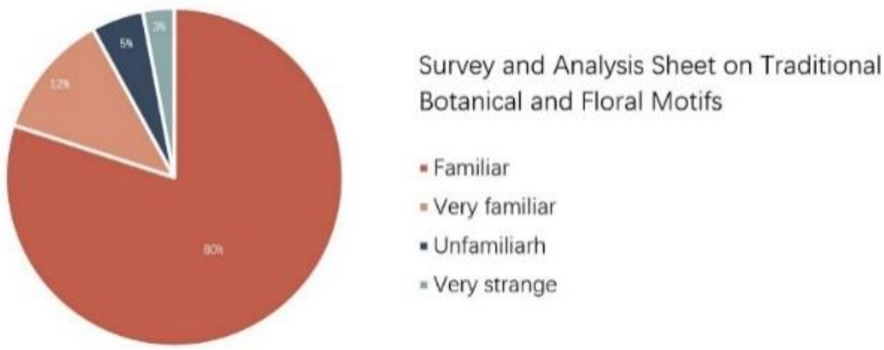


Figure 6 *Traditional plant and flower pattern survey data analysis table*
Note. Researchers draw their own, 2024

As shown in the results of a study investigating traditional Buddhist decorative patterns, about 60% of the respondents have some understanding of conventional Buddhist decorative pattern design, and 15% of people are very familiar with this design concept. They believe this design can better integrate with nature and improve the beauty and harmony of Buddhist decorative patterns. Another 20% of people expressed that they were not very concerned about Buddhist decorative patterns, looking forward to seeing more design cases of traditional Buddhist decorative patterns.

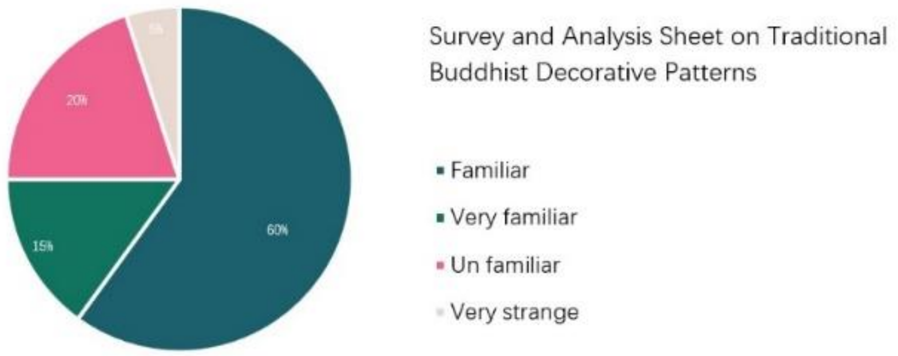


Figure 7 *Survey and analysis form of traditional Buddhist decorative patterns*
Note. Researchers draw their own, 2024

As shown in the research results of investigating traditional plant and flower auspicious patterns, 70% of the public is familiar with China's traditional plant and flower auspicious patterns, and 15% of the respondents think they are familiar with the application of conventional plant and flower auspicious patterns in various fields, the interviewees hope that through innovative redesign of traditional plant and flower auspicious patterns, enabling the conventional auspicious patterns of plants and flowers to be better inherited and developed in folk customs.

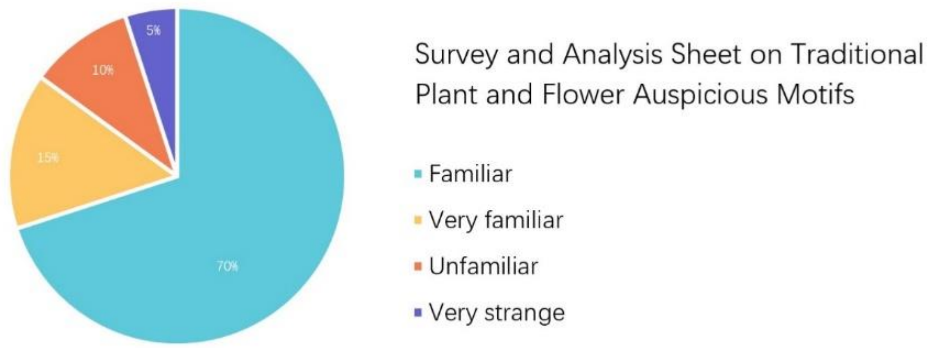


Figure 8 *Survey and Analysis Form on Traditional Plants and Flowers Auspicious Patterns*
Note. Researchers draw their own, 2024

The results of the investigation and comparison of traditional lotus patterns and other plant and flower patterns show that lotus patterns, green plants, flowers, and other bionic elements are trendy. More than 20% of the respondents believe that lotus pattern elements can help enhance the integration of architecture and nature, and more than 60% of the respondents think they are very familiar with lotus decorative patterns if they can be used in architectural decoration design, making people more willing to get close to and enjoy the architectural space. At the same time, the interviewees believed that the lotus pattern bionic architectural design should pay attention to environmental protection and sustainability.

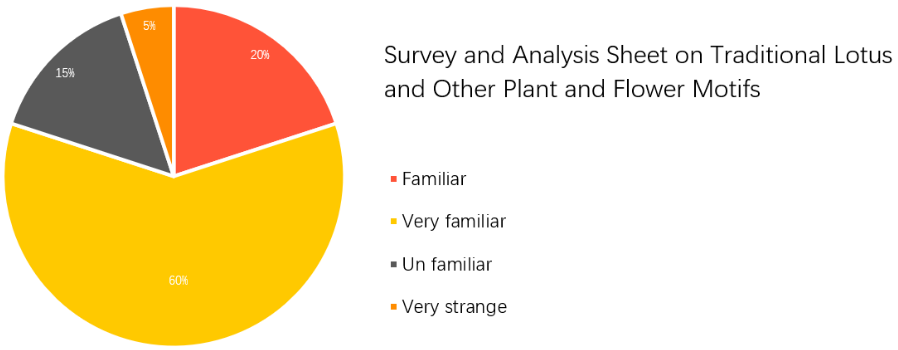


Figure 9 *Survey and analysis form on traditional lotus patterns and other plant and flower patterns*
Note. Researchers draw their own, 2024

2.2.1.1 THE PROPERTIES OF THE LOTUS PLANT

In the plant kingdom, lotus is one of the earliest plants among angiosperms; it is also one of the oldest dicotyledonous plants in the world. At the same time, it has some characteristics of monocotyledonous plants. Therefore, lotus is called a living fossil(Dong et al., 2005). There are many types of lotus flowers, and people divide them into two categories: ornamental and edible. China is rich in lotus variety resources; there are more than 200 traditional varieties, and new varieties are constantly emerging(Liu amei, 2022).

2.2.1.2 GEOGRAPHIC CHARACTERISTICS OF LOTUS

There are records of lotus cultivation in China as early as the Zhou Dynasty. Lotus flowers can be found in most areas across the country. It stretches from Hainan Island in the south to Heilongjiang in the north, Shanghai and Taiwan Province in the east, and Xinjiang in the west. Originating in tropical and temperate regions of Asia, A few species occur in temperate and boreal areas of South Africa, Europe, and Asia. The lotus is one of the ten most famous flowers in my country. It is also the national flower of India, Vietnam, Malawi, Japan, North Korea, India, the former Soviet Union, Siberia, and Europe.

2.2.1.3 THE SYMBOL OF THE LOTUS

The symbolic meaning of the lotus is expressed in four aspects: religious symbol, female symbol, folk symbol, and gentleman's sentiment symbol; these four symbolic meanings develop independently and intersect; they blend into each other.

In ancient society, the lotus pattern became a clan totem; it is an auspicious symbol that represents prosperity and has a beautiful meaning in people's pursuit of reproduction. In Chinese folk culture, the lotus symbolizes peace, harmony, unity, union, etc. The lotus symbolizes the cause of peace and the nobility of a harmonious world. Coming out of sludge but not stained, the lotus symbolizes nobility, incorruptibility, holiness, and wealth. Lotus is one of the ancient Chinese poets' singing and painting themes. Therefore, it promotes Chinese culture.

2.2.1.4 LOTUS FENG SHUI THEORY

Feng Shui is a traditional culture left over from the long history of the Chinese nation; in Feng Shui knowledge, architecture is also divided into five elements: wavy and curved buildings belonging to the water. Therefore, buildings mostly use curved surfaces; lotus is also the principle of mutual growth between water and wood in Feng Shui. According to Feng Shui, water is wealth; the vital breath of the lotus is just enough to bring about the wealth of abundant water. Lotus is a tenacious flower plant that benefits architectural Feng Shui. Moreover, the lotus has lush branches and leaves, making it a promising feng shui object.

2.2.1.5 LIAN'S TEACHINGS

After Buddhism spread to China from the East, the lotus was considered an auspicious flower by the Chinese; not only did they plant it widely, but people also ate lotus seeds, lotus pods, and lotus roots. Buddhism says flowers bloom, and you can see the Buddha's nature. Flowers blooming means that the practitioner has reached a certain level of wisdom. This sentence is a metaphor for the state of mind of a person with a lotus; Buddha's nature will appear. Lotus also represents a state of wisdom, which is called enlightenment. The character and characteristics embodied in the lotus flower are consistent with Buddhist teachings. Buddhism has always revered the lotus as a sacred and pure flower; Buddhism advocates that people learn from the innocent and tenacious spirit of the lotus flower; the Eight Treasures of Buddhism are auspicious and headed by the lotus flower. The lotus symbolizes practitioners of Buddhism and Taoism(Weibang, 2023).

Lotus Taoist teachings: Taoism is a native religion of China; China has loved lotus since ancient times; the lotus is a symbol of practitioners in Taoism, is a gentleman, the magic weapon of He Xiangu, the eight immortals in Taoism, the treasure in hand is the lotus, practitioners should cultivate themselves with virtue, virtue carries things.

2.2.2 LOTUS PLANTS AND CULTURAL FORMS

2.2.2.1 THE HISTORY OF THE LOTUS PATTERN IN CHINA

Chinese traditional decoration, the lotus pattern, is one of the earliest plant patterns that appeared in the history of decorative patterns in my country, and it has maintained a long period of continuity in the historical development of patterns. The lotus pattern has a long history in our country; it has gone through different dynasties such as the primitive period, Xia, Western Zhou, Spring and Autumn and Warring States, Qin, Han, Wei, Jin, Southern and Northern Dynasties, Sui, Tang, Song, Yuan, Ming, and Qing, its meaning and appearance correspond to different dynasties, continuously developing and evolving. Lotus flowers are used on buildings with decorative techniques such as engraving, wall-pasting, relief carving, painting, and printing; art forms such as paper-cutting, embroidery, and New Year pictures in traditional folk decorative arts also have varying degrees of expression.

2.2.2.2 THE EVOLUTION OF LOTUS PATTERNS IN DIFFERENT PERIODS OF CHINESE HISTORY

The development of the lotus pattern in China has four periods. They are the initial period, including Xia, Western Zhou, Spring and Autumn Warring States, and Qin. The period of Buddhist influence includes the Eastern Han Dynasty, Wei, Jin, and Southern and Northern Dynasties. The fusion period consists of the Sui and Tang Dynasties. The period of prosperity and popularity includes the Song, Yuan, Ming, and Qing dynasties(Xinyu, 2023).

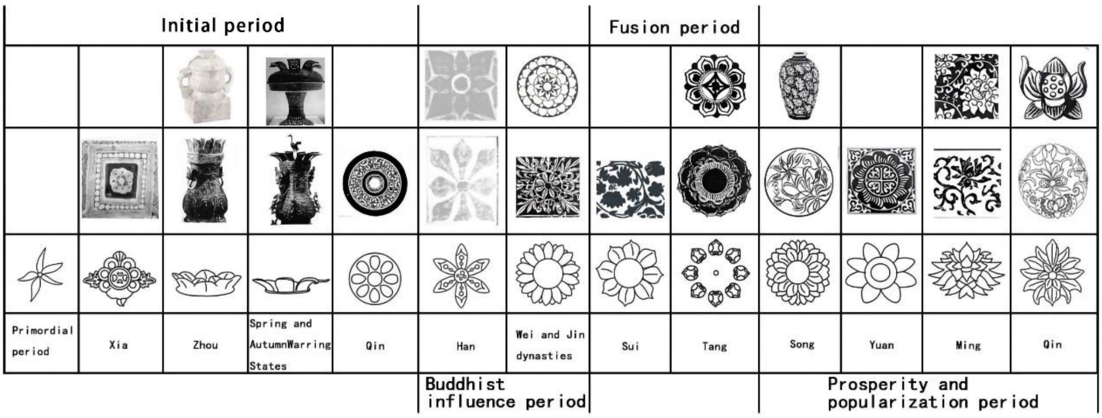


Figure 10 *Lotus pattern developed in China through the ages*
Note. Researchers draw their own, 2023

The lotus pattern is one of the classic patterns in traditional Chinese patterns that already existed in primitive times. It is an ancient cultural symbol and is widely used. The original lotus pattern in primitive Chinese society originated from the ancestors' worship of lotus as food and survival; it is the product of ancestors' sacrifices, the mysterious age of irrationality, and the balanced beauty of emotion and reason; it is an essential condition for the production of lotus patterns.

Archaeologists have discovered various species in the ruins of Xixia, such as lotus-patterned square tiles, for different purposes. Each has its characteristics in composition, which are not repetitive and are full of variety; the pattern has prominent national characteristics. This shows the ancient people's love for the lotus; people used design to express the subjective feelings of objects towards objective things. Use designed patterns to decorate various environments and apply them to the decoration of daily necessities, enhance artistic flavor, and improve aesthetic taste.

After Chinese history entered a civilized society, the earliest use of lotus patterns can be traced back to the Shang and Zhou dynasties. The lotus pattern was used to decorate bronze vessels; most have four, six, eight, or ten petals evenly arranged.

During the Spring and Autumn Period and the Warring States Period, the use of lotus patterns in art and culture gradually increased; lotus patterns mostly appear in the form of single petals, double petals, or multiple petals; the shape of the lotus pattern is more natural and vivid than before, it enhances the power and momentum of the lotus pattern posture. It mainly appears on bronzes, pottery, jade, and other handicrafts; among these utensils, lotus patterns usually appear on the base, ears, rings, etc., to increase the beauty and decoration of the utensils(Guo, 28-12-2022). In the middle of the Spring and Autumn Period and the Warring States Period, the lotus pattern was more unrestrained and natural; in the late Spring and Autumn Period and the Warring States Period, the use of lotus patterns gradually increased, close to realistic form, simple and elegant, the essential feature is its combination with other patterns. Expressing people’s pursuit of prosperity and love for life, the symbolic meaning of the lotus also began to expand gradually, and it has become an integral part of ancient Chinese culture(Daoling Chen & 2021).

In the pre-Qin period, lotus patterns were mainly decorated on the tops of utensils or buildings, representing a symbolic relationship between the sky and the sky. The lotus petal pattern also gradually transitions from the initial abstract graphics to geometric realism.

During the Qin Dynasty, Chinese culture entered a new stage, led by pragmatism and military thinking. The development of decorative arts was relatively slow; people are paying more attention to practicality and functionality. Using lotus patterns in decorating utensils is relatively rare and less common than in previous periods. The shape of the lotus pattern changes to a large form, a realistic style that doesn’t care about minor details; the most outstanding shape is the exaggerated new lotus body, a simple and concise overall image; however, realistic modeling has not yet gone beyond the freehand brushwork of the primitive period. More abstract lotus patterns are often decorated on utensils and buildings. For example, the lotus tiles from the Qin period were unearthed from the No. 1 palace site in Qindu, Xianyang, Shaanxi, and the middle represents the lotus pod. The lotus has eight petals, four large and four small, with an abstract shape.

The lotus flower in the Han Dynasty became a typical decorative pattern, the use of lotus patterns is gradually increasing, and the symbolic meaning of the lotus has also been more deeply explored and expressed. Appears in various utensils, fabrics, and buildings. The book Historical Records contains records about the lotus pattern carved on the jade used by Emperor Wu of the Han Dynasty during his southern tour, reflecting the critical position of the lotus in the religion and culture of the Han Dynasty. In the early Han Dynasty, China's native lotus pattern had fewer petals; most of them had four petals and eight petals; under the influence of Buddhism, the number of petals increased significantly, and lotus pods appeared, and the phenomenon of petals became pointed. The lotus pattern mainly occurs in the shape of a flower head in different designs; among them, the flower heads on the front are radially symmetrical, the lotus pod in the middle is round, surrounded by well-proportioned petals, the flower head on the side has a more accessible expression. This lotus pattern is often used in caisson patterns, various edge patterns, Buddhist pedestals, etc. The emergence and application of lotus patterns updated the decorative content of China's Eastern Han Dynasty. They laid a good foundation for the development of plant patterns after the Eastern Han Dynasty. As a cultural and artistic symbol, the lotus pattern is significant in Chinese history and culture.

The lotus pattern in the Wei, Jin, Southern, and Northern Dynasties was widely used in various works of art and cultural relics; the Wei, Jin, Southern, and Northern

Dynasties were a period of frequent wars, and the idea of unification of Qin and Han was disintegrated during the Wei, Jin, Southern and Northern Dynasties, Buddhism flourished in the Wei, Jin, Southern and Northern Dynasties, the lotus flower is used as a motif in some Buddhist decorations. The animal patterns that symbolized power in the Qin and Han unification thoughts were replaced by plant patterns, and China opened the door to plant patterns that celebrate life through art. The lotus pattern has become a new art form, showing its unique artistic value in paintings, sculptures, and decorative crafts. The lotus pattern is widely spread as a solemn symbol of the Buddha's appearance and nature. In the late Northern Wei Dynasty, the lotus pattern continued to change. The elegant and flexible beauty of the lotus pattern during the Wei and Jin Dynasties was integrated into the pattern design, and the lotus pattern became more and more whole; with the aesthetic philosophy of symmetry, it reflects the continuous accumulation, precipitation and sublimation of the excellent traditional culture of the Chinese nation, it shows the aesthetic significance and cultural value of lotus in the Wei, Jin, Southern and Northern Dynasties.

During the Sui Dynasty, the application of lotus patterns began to increase, and it continues to play an essential role in culture, art, and religion. The flowers are complete, gorgeous, lively, and entirely of life interest; they have more practical application value. The lotus pattern is rich in decoration, detailed and exquisite, and has become a representative of the decorative components of the Sui Dynasty. In terms of architectural decoration, lotus patterns were also widely used in palaces, Buddhist temples, tombs, and other buildings in the Sui Dynasty, for example, the architectural decorations of the Daming Palace of Emperor Yang of the Sui Dynasty, the Yungang Grottoes of the Northern Qi Dynasty, and the White Horse Temple in Luoyang all have carvings and decorative components with lotus patterns. People have used the bionic form of the lotus in their designs; later, the lotus pattern was designed to be realistic. The lotus pattern reflects secular applications and auspicious expectations in Chinese folk customs in dyeing, weaving, and architectural decoration. The use of lotus patterns in the Sui Dynasty of China has become a common element in art and architectural decoration and deeply integrated into the culture and religion of the time.

The application of lotus patterns reached its peak in the Tang Dynasty, with the influx of cultures from outside the region actively absorbed by the Tang Dynasty; the interactive integration of local culture and foreign culture enriched and improved the cultural system of the Tang Dynasty, the status of the lotus pattern is more prominent, achieved breakthrough development, many rich new styles have been produced, it is rich in shape, gorgeous and plump, rigorous in shape and diverse in style. In terms of architectural decoration, the lotus pattern was also widely used in architecture during the Tang Dynasty. Such as the statues of Guanyin Bodhisattva in the main halls of many Chinese temples, there are a large number of decorative components with lotus images and lotus pattern column base carvings, lotus-shaped eaves tiles, and flower tiles, lotus-shaped stone and wood carvings, etc., they were all common elements in architectural decoration components at that time. At the same time, lotus patterns were widely used as architectural decorative components in temple buildings during the Tang Dynasty. For example, the Qixia Temple in Nanjing and the White Horse Temple in Luoyang have many lotus-shaped sculptures and architectural decorative components(Lyu, Gong, & Li, 2021). During the Tang Dynasty, cultural tolerance and national power were strong. Gradually, auspicious graphics symbolizing the Chinese national style were formed. The lotus pattern of this period was complete and total, with colorful auxiliary decorative patterns, from simple to complex and raw to mature. Patterns belonging to Chinese national tradition are formed by borrowing and merging foreign factors.

During the Song Dynasty, the lotus pattern changed from the gorgeous and fullness of the Sui and Tang Dynasties to the delicate, concise, complex, and secular style. Appears in various artworks and architectural decorations. In terms of architectural decoration, lotus patterns were also widely used in palaces, Buddhist temples, gardens, and other buildings in the Song Dynasty; for example, the Jile Temple in the Southern Song Dynasty and the Longmen Grottoes in Luoyang have a large number of lotus carvings and decorative components. In Buddhism, the lotus pond, seat, lotus throne, etc., symbolize the lotus. The lotus is also closely connected with Buddhist teachings such as nirvana and purity. Lotus patterns are rich in form, and the level of painting and decoration is becoming increasingly mature and refined, pursuing the interest of realistic Chinese painting. The lotus pattern has simple and vivid lines, depicts liveliness, and has the style of traditional Chinese painting. In the late Northern Song Dynasty, the lotus pattern became a significant trend as a symbol of auspiciousness, and its meaning became more secular.

Political changes and social transformations occurred during the Yuan Dynasty, and the lotus pattern also underwent some new changes. The lotus pattern is no longer a mainstream decorative pattern, but it cannot resist the widespread secularization of its application in people's lives. During the Yuan Dynasty, lotus patterns were still widely used in painting, sculpture, ceramics, embroidery, etc. The lotus pattern appears frequently, and the shapes of lotus flowers are also more abundant and diverse. In the Buddhist art of the Yuan Dynasty, the lotus pattern remains an important symbol. The lotus throne of the Yuan Dynasty and shapes such as the lotus pedestal base are still widely used in Buddhist temples and towers. At the same time, The Yuan Dynasty invented a religious art form of the lotus flower. This form is centered around a lotus flower, incorporating Buddhist stories, myths, and legends, and a new spiritual art style was formed. The use of lotus patterns in the Yuan Dynasty inherited the Song Dynasty tradition; based on this, some new forms and styles were developed.

The lotus patterns of the Ming Dynasty not only inherited the traditions of the Tang, Song, and Yuan dynasties but also achieved more exquisite development in details and techniques. Compared with the Yuan Dynasty, the lotus patterns in the Ming Dynasty were more detailed and complex, showing a delicate hand-made art style. The lotus pattern was also widely used in the Ming Dynasty's architectural art. For example, in the palaces, gardens, and temples of the Ming Dynasty, lotus-shaped stone carvings, wood carvings, brick carvings, and other decorative components can be seen everywhere. The lotus flower is an auspicious symbol; it is widely used in architectural art; it not only has ornamental significance but also has profound cultural connotation and religious significance. The lotus pattern plays a vital role in architectural art, as it shows the profound influence of the lotus on Chinese culture.

During the Qing Dynasty, the lotus pattern served as a cultural and religious symbol, and he played an essential role in the Qing Dynasty's politics, culture, religion, and life. The lotus patterns of the Qing Dynasty were more refined and delicate, showing a more elegant artistic style. The renewed economic prosperity has prompted people to focus on pursuing material enjoyment; the lotus pattern appears in all walks of life; the patterns are also more diverse and colorful, and they are more complicated and refined on the original basis. In terms of architectural art, for example, in the palaces, gardens, and temples of the Qing Dynasty, Lotus-shaped stone carvings, wood carvings, brick carvings, and other decorative components can also be seen everywhere. The lotus pattern decorative components in these buildings are made with highly exquisite craftsmanship, which shows the high achievements of Qing Dynasty architectural decoration art. It not only has decorative and aesthetic value but also has cultural connotation and religious significance; it has become one of the essential symbols of Chinese culture.

2.2.2.3 THE SIGNIFICANCE OF THE DEVELOPMENT OF LOTUS PATTERNS IN CHINESE HISTORY

After comprehensively analyzing and thinking about the lotus pattern in Chinese historical documents, researchers found that the lotus pattern has been throughout the origin and development process of Chinese history; in the process of inheritance and evolution, the lotus patterns of each period reflect different era characteristics and aesthetic characteristics, The political, economic and cultural aspects of various periods, Constantly giving new artistic and spiritual connotations to the lotus pattern, Reflects the cultural psychology of different eras, China's unique lotus culture has formed. The inheritance and evolution of the lotus pattern is not only a summary and selection of the past but also a reflection of the integration of Chinese and foreign cultures and the achievements of its cultural development. It is also the artistic sublimation of the accumulation of Chinese national culture; it reflects the temperament of Chinese culture, including everything.

How to use the perspective of traditional Chinese art and culture, from the development form of the lotus pattern, transformed into a source of inspiration for creation, Re-engage with new expression media and forms, and effectively used in modern design, this research makes it extremely important to deeply study the unique stylistic features and decorative ideas of the lotus pattern. In the innovative lotus theme design, Designers should base on the theoretical basis of the evolution and development of the appearance and connotation of traditional lotus patterns, Inheriting the essence of conventional patterns, looking for lotus elements suitable for modern design, the individual patterns of the lotus pattern can be recreated, combining tradition with modernity. In this way, the lotus pattern is combined with local Chinese characteristics. Over the years, it has absorbed foreign decorative elements and retained some fixed meanings, and it has become one of the most influential traditional patterns today.

2.2.3 APPLICATION OF LOTUS PATTERN IN ARCHITECTURAL DESIGN

2.2.3.1 APPLICATION OF LOTUS PATTERN IN CONTEMPORARY CHINESE ARCHITECTURAL DESIGN

Architecture must be beautiful and practical; therefore, it has technology and artistic characteristics. Many buildings are expressions of our culture, and it is also a great artistic heritage. Lotus-themed Chinese architecture demonstrates the unique charm of Chinese architectural art and culture; it is a significant symbol of Chinese culture. Specific cases include Changzhou Wu Jin Lotus Pavilion, Hangzhou Olympic

Sports Center, Slender West Lake in Yangzhou has a lotus bridge built on the dam, Hangzhou Xin Quyuan Feng is a large park mainly dedicated to lotus appreciation, Qingdao World Museum Lotus Pavilion, Ordos Lotus Hotel, Luoyang Ling shan Lotus Park landmark building, Xinjiang Grand Theater Tian shan Snow Lotus, inner Mongolia Xiang shawan Desert Lotus Hotel, etc. The exterior forms of these buildings feature regional decoration and details, contain elements of traditional Chinese lotus culture, and tend to use lines, a combination of virtual and solid, and light and transparent materials better to reflect the cultural characteristics of regional lotus element architecture. Make the building appearance colorful and unique.

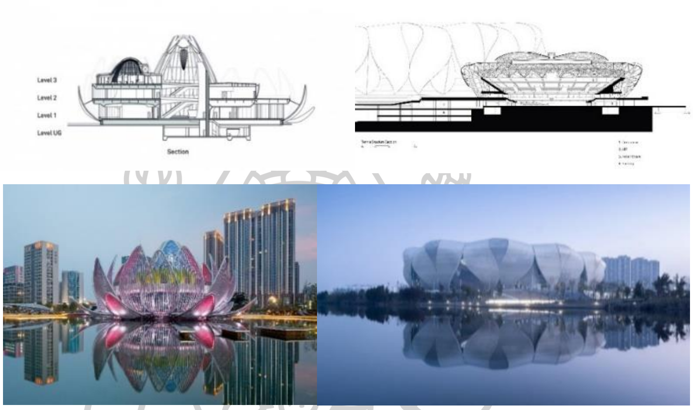


Figure 11 *Wujin Lotus Pavilion and Hangzhou Olympic Sports Center*
Note. Photographed by researcher, 2022

2.2.3.2 APPLICATION OF LOTUS PATTERN IN CONTEMPORARY CHINESE ARCHITECTURAL DESIGN

In modern design, the lotus element has an auspicious meaning customary in Chinese folk culture. It is widely used by designers in various design fields. Lotus culture has a considerable influence and robust vitality; it is not only a symbol of beautiful personality and beautiful things, but it also has the connotation of the reproduction of human life and the prosperity of the nation; it is often used in architectural decoration design. Therefore, it has become an essential manifestation of the vitality of the Chinese people and national cohesion.

In Chinese Buddhist temples, lotus flowers are used in architectural decorative components. In ancient Chinese palaces and temple buildings, lotus patterns often decorate pillars, beam heads, door leaves, and other building parts. For example, the Lotus Throne of Famen Temple, the Lotus Cave of Mount Putuo, the Lotus Throne of Lingshan Buddha, etc. The Big Wild Goose Pagoda is one of the representative buildings of ancient Chinese Buddhist temples built during the Tang Dynasty. The appearance of the Big Wild Goose Pagoda is octagonal; each floor is carved with a lotus theme, symbolizing Guru Padmasambhava and wisdom in Buddhism. Taishan Dai Temple is where emperors of ancient China worshiped Mount Tai. There are many buildings in the temple. The pavilion's wood carvings and stone carvings all have the lotus theme. It shows the superb skills of ancient Chinese architectural art.

Figure 12 *Wuxi Lingshan Giant Buddha Lotus Decorative Components*
Note. Photographed by researcher, 2022

The use of lotus patterns in modern architectural design is becoming increasingly common. When designing, the development of the lotus theme is often characterized as informative, celebratory, entertaining, educational, etc. Lotus patterns are usually processed exaggeratedly and composed of geometric shapes or can be geometrically shaped. Lotus patterns consist mainly of leaves and petals, which are very simple: abstract the lotus image, then decompose and reconstruct. In the current facade design of Chinese buildings, it can be seen that a large area of lotus patterns is used to increase the visual impact of the building; it can also be reflected in many aspects, such as building materials and building structures. Use unique materials on building facades, show the details of the lotus pattern through carving or embossing, or use the natural form of the lotus in the building structure and apply it to building columns, beam heads, and other parts; in this way, a modern building with traditional cultural charm is created. It can not only increase the beauty of the building but also express the artistic value and spiritual connotation represented by the building.

2.3 RESEARCH ON PARAMETRIC DESIGN METHODS

The parametric concept makes the design complex. However, there is a sufficient rational basis for, as a new trend of thought in the design field, it has developed rapidly in the past thirty years. The parametric design method is a parameter-based design method that introduces the relationship between parameter variables and parameter variables, making the design process flexible and efficient. With the continuous development of global digitalization, parametric design technology is constantly being used in various design fields. Compared with traditional design methods, parametric design extends people's thinking depth through the design software platform and expands the breadth of people's thinking by referring to the research results of related disciplines; this gives computer-aided design more possibilities for nonlinear design. Parametric design methods are often used with design software platform optimization algorithms to achieve automated design optimization. The parametric design method first requires defining the parameters involved in the design. These parameters can be geometric dimensions, material properties, process parameters, etc., and they describe the design object's characteristics and range of variation. With the breadth and depth of these complex systems, researchers or architectural designers need to change their single-disciplinary thinking mode and establish an interdisciplinary design methodology from a new perspective. By defining design requirements, goals, and constraints, combined with design software platform optimization algorithms, it can automatically analyze and search for optimal parameter values to obtain the best design solution that meets the design requirements. Parametric design methods can effectively support design verification and iterative processes. Changing the parameter's value allows multiple design options to be generated, compared, and evaluated. The validation of the design plan can be carried out through simulation, experiment, or other verification means; the verification of the design plan can be carried out through simulation, experiment, or other verification means.

2.3.1 PARAMETRIC DESIGN

2.3.1.1 PARAMETRIC DESIGN CONCEPT

The parameter was first used in mathematical concepts, referring to variables or influencing factors. The parametric design we are currently exposed to originated from the development of CAD computer-aided design technology in the 1990s(Chen, Zhang, Wu, Xu, & Li, 2024). Parametric design is a design method that, in modern design, Wang Shaodong's research on parametric interior space design generates design solutions through parameter combinations and uses the concept of parameters to define the design thinking process and build design prototypes; this design is defined as parametric design. The characteristics and attributes of parametric design objects are described and controlled by introducing parameters and establishing a relationship between design variables and parameters; by changing the parameter's value, the features and behavior of designs can be changed automatically. Parametric design exists in a system; the elements in each component change, and the topological relationship causes the entire structure to change. In the parametric design process, researchers pay attention to the design's logic and the design process, adjust corresponding parameters or generate rules, and finally find the ideal design result. In his discussion of parametric product modeling design, Bian Jing concluded that the parametric design process reflects dynamic, self-organizing, and irregular characteristics. Parametric design includes concepts such as fractal, emergence, self-organization, and nonlinearity; it is an essential direction in contemporary architectural design research and practice.

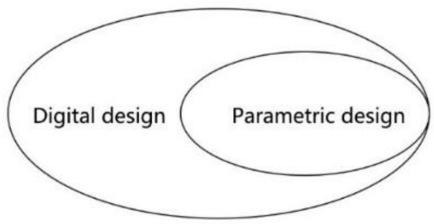


Figure 13 *Schematic diagram of the relationship between digital design and parametric design*
Note. Researchers draw their own, 2023

Parametric design is a parameter-based method that introduces parameters and relationships between parameters, promotes design collaboration and integration, and achieves design flexibility, efficiency, and reliability.

2.3.1.2 PARAMETRIC DESIGN THEORY

The theoretical foundation of parametric design originates from the foundation of complexity science, the ideological foundation of Deleuzian philosophy, and the ideological foundation of the first-generation design methodology(Rosser, 2022).

(1) Complexity science originates from studying complex systems, but academia needs to have a precise definition. Liu Yanchuan believes parametric design method thinking, the work organization model, and nonlinear theory are integral to arts. Nonlinearity means that a straight line in the coordinate system between them cannot represent the relationship between two variables. For example, in the process of playing go, with each drop, the outcome of the entire chess game presents new possibilities; this is a typical nonlinear process. Linearity in the scientific world is the classic linear theoretical discipline established by scientists such as Newton to understand natural things through linear relationships. The nature of nature is nonlinear, and linear relationships are only theoretical approximations of nature. Only complexity science can reveal complex phenomena. Topology, fractals, chaos theory, etc., are all essential theoretical sources of parametric design in complexity science.

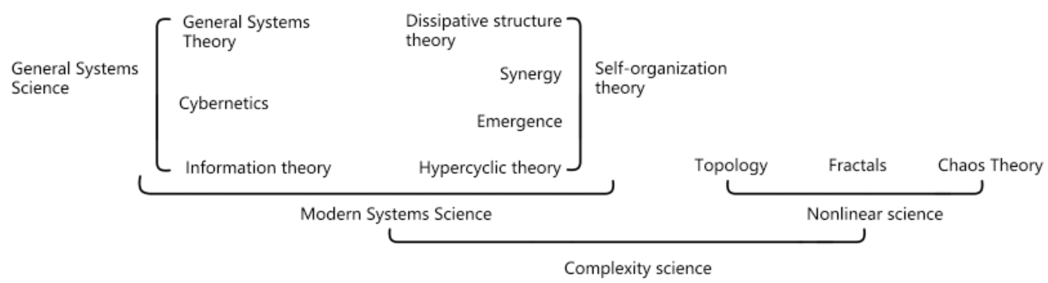


Figure 14 *Complexity Science Diagram*
Note. Researchers draw their own, 2024

a. Topology

Topology is a broad subject; it is an essential branch in contemporary mathematics, different from traditional European geometry; topology does not define actual dimensions, has nothing to do with distance and angle, and mainly studies spatial properties and spatial deformation. Topology provides a way to analyze and optimize space's shape and connection properties and realize topology optimization, analysis, and improvement of design shapes. Topology is primarily concerned with the invariant properties of space, even by stretching, twisting, and bending; as long as the basic structure remains the same, these spaces are considered equivalent.

Topology can transcend the logic of traditional Euclidean geometry and handle transformation relationships of complex shapes(Nowak, 2020). This complex transformation relationship can be described by topology; computer technology can generate rich and varied forms.

b. Fractal

Fractal science is an emerging discipline that studies fractal structures and phenomena; fractal refers to a structural shape or phenomenon with self-similarity; a fractal object can be composed of several parts, and each part approximates the overall shape and has similar characteristics. To put it another way, no matter how you look at any part of the fractal, it all has a similar shape or structure to the overall fractal. Fractal science provides these phenomena with mathematical research methods for complex phenomena(Rodríguez-Cuadrado & San Martín, 2024).

c. Chaos

Chaos theory is a discipline that studies chaotic phenomena in nonlinear dynamic systems. American meteorologist Lorenz proposed it. In complex systems, a seemingly disordered and unpredictable dynamic behavior, small changes in initial conditions, will affect the disordered state of the entire system. Chaos theory originated from the exploration of nonlinear system behavior. Such systems exhibit complex and unpredictable behavior. Chaos theory studies the seemingly random and complex behavior of systems. Deep chaos theory manifests itself as order; there are some hidden patterns and structures and fractal characteristics at different scales. Chaos theory has essential and widespread applications in weather forecasting, fluid mechanics, biology, architecture, economics, cryptography, and other fields. It prompts designers to start thinking about the complexity of design from a nonlinear perspective(Jing, Zhen, Guan, Luo, & Liu, 2022).

(2) Deleuze’s philosophical thought basis

Deleuze's philosophical thought was proposed by Gilles Deleuze, a French philosopher and cultural theorist in the 20th century. It extensively influences philosophy, political science, cultural studies, art theory, etc. Therefore, Deleuze's philosophical thoughts put forward many views and theories that differ from postmodernist philosophy in politics, aesthetics, ethics, etc(Harris, 2014).

a. Fold

The philosophy of wrinkles is one of the essential philosophical concepts pioneered by Deleuze. In the philosophy of folds, Deleuze proposed trying to eliminate the limitations of binary opposition thinking. A different point of view from the traditional concept of binary opposition, he said that the world is composed of infinite folds, surges, and changes, not defined by fixed opposing concepts. He emphasizes the importance of complexity, fluidity, and diversity. The pleat philosophy proposed by Deleuze is widely used in cultural studies, architectural theory, artistic creation, etc.; at its core, it breaks the shackles of traditional binary structures.

b. Nomadic

Nomadic philosophy is a critical concept proposed by Deleuze and Auguste in their book A Thousand Plateaus, Capitalism and Schizophrenia. Nomadic philosophy furthers Zouzi's thought and mainly studies the concepts of fluidity, variability, non-linearity, and non-hierarchy, which are the spatial expressions of folds' thoughts. The core of the parametric design is to regard design as a change process; researchers can adjust parameters, explore a broader design space, and encourage adaptation and innovation. Facing the complexity of space has important implications for studying architecture and form(Surman, Stráner, & Haslinger, 2014).

c. Diagram

Diagram is a non-verbal expression in Deleuze's philosophy, a thinking tool used to express complex ideas and concepts, and plays an important role. Illustrations serve as a supplementary form and use graphics, symbols, arrows, etc., to show the relationship, flow, and changes between concepts that cannot be described in words. In parametric nonlinear architectural design, Professor Xu Weiguo from Tsinghua University thinks that Deleuze describes the diagram as an abstract machine that connects input functions and output forms. The parametric design process establishes a dynamic and generative diagram of the relationships between various elements, described by a set of computer instructions, and Creates digital illustrations. Therefore, Deleuze diagrams, on the one hand, in simple abstract form, are interpretive tools for illustrating the design process; on the other hand, they represent the generative properties of an abstract machine between inputs and outputs.

d. Becoming

Becoming occupies an essential place in Deleuze's philosophical work. Becoming is considered by Deleuze to be the fundamental attribute of things; a thing is a state of the generating process. Deleuze proposes a way of thinking different from traditional notions of essentialism and substantiality. Yu Yang and Jia Xinfeng discussed the impact of parametric design on architectural design. They proposed relevant factors to constitute design parameters, a theory of outcomes in generative design under the mechanism of algorithms.

(3) The ideological basis of the first-generation design methodology

In the late 1950s and early 1960s, systems theory and operations research into the methodological research field of architectural design proposed models of various design processes tried to solve problems in new ways and reorganized the design process. The methodological results emerging from this stage are the first-generation design methods. Systems theory, represented by Jones, proposes that the architectural design methodology is related to elements that form a definite whole. It is a three-stage process of analysis, synthesis, and evaluation; it becomes the center of the design method. Help researchers organize, analyze, and evaluate literature, data, and information sources. Ge Junjie's research on industrial design development and methods summarizes that the Jones system design method consists of three phases.

a. In the analysis stage, the researcher collects data on all design influencing factors, organizes them into categories, helps form a clear overview, and relies and relies on diagrams to clarify the relationships between design factors. Establish a systematic data organization, expressed in terms of design performance; specific morphological and material characteristics are not considered for later comprehensive analysis.

b. In the comprehensive stage, researchers analyze all data information to integrate and synthesize it to form a thorough conclusion. Find possible answers for each performance statement and create a combined set of answers or an extensive view. The relationship between an element and the whole is between the answers and the sets they constitute.

c. In the evaluation stage, the researcher evaluates and verifies the comprehensive results. Using statistics, operations research methods, and some emerging simulation techniques, etc., assess the logic and consistency of the answer set to meet the design requirements, verify and evaluate whether the combined results can solve the design problem, and select a design solution.

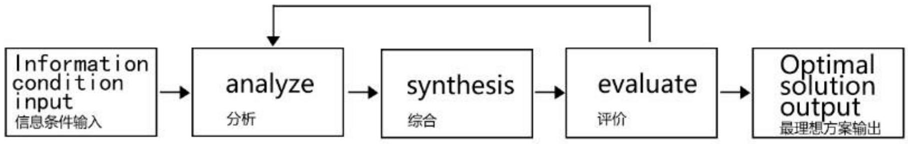


Figure 15 *Jones System Design Methodology Diagram*
Note. Researchers draw their own, 2023

Luckman added to Jones's thinking that Luckman's method is based on operations research theory, defining design as a decision-making process. Luckman believes that design is not a simple and complete linear process; designers must continuously go through the cycle of analysis, synthesis, and evaluation, rising from a general problem level to a more specific level. Then, at every level of decision-making, the solutions to all sub-problems always have relative oppositions and appropriate sub-question answers; there is no guarantee that the combination will result in a successful total solution to the problem. In his exploration of the parametric design of complex architectural shapes, Ren Zhenhua summarizes Jones and Luckman's research, Breaking the problem into smaller ones, a collection of answers to small questions that make up the entire design.

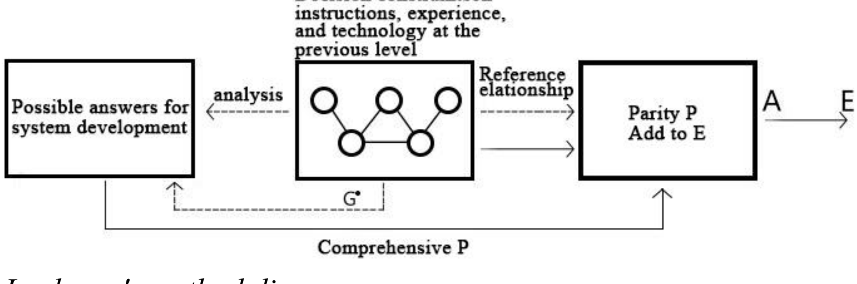


Figure 16 *Luckman's method diagram*
Note. Researchers draw their own, 2023

In the late 1960s, based on the application of systematic methods to analyze architectural design methods, many researchers introduced the results of behavioral science and psychology into the field of architectural design, which people call second-generation design methodology. Alexander believes that the design process is a process of resolving conflicts. People's behavioral activities are related, and the relationship between context and form is discussed. Therefore, contemporary theoretical approaches to research design have the following aspects.

a. Urban architecture theory is a method of studying architectural design from the perspective of the city as a whole.

b. Theoretical research on behavioral and environmental architecture is an interdisciplinary science of architecture, psychology, and behavioral science. Explore the demands of human activities on architecture and the reaction of the built environment on people's thoughts, emotions, and needs.

c. Architectural morphology theory studies methods and means of architectural design and uses psychology, sociology, ergonomics, aesthetics, and other principles to explore the nature and laws of morphogenesis.

d. The study of architectural semiotics theory starts with semiotics, combined with information theory aesthetics, understanding architecture through semiotic concepts, and forming new design thinking methods.

e. The theory of ecological architecture focuses on the two critical contents of maintaining the environment and saving energy. The above design research contains bionic parametric architectural design characteristics that emphasize elements to the whole. Objectifying the design, the research on design methods is inspiring and provides an ideological basis for parametric design.

2.3.1.3 PARAMETRIC DESIGN APPLICATION AREAS

The application of parametric design concepts currently in the design fields in China mainly includes architectural design, graphic design, industrial design, and clothing design.

(1) Architectural design field

The use of parametric design in the construction field is gradually increasing. The parametric design we are exposed to is reflected in many subject areas; the construction industry is particularly prominent. Utilizing design software platform algorithms and computer programming languages, methods for generating and controlling parametric building designs create diverse architectural design options by adjusting parameters and rules. In architectural design, based on the logic of parameterization, the design process can be translated into a digital method group, presented in a virtual three-dimensional space using computer language. Parametric design can be applied to building appearance design, structural design, functional design, environmental energy analysis, construction and manufacturing, etc. Through parametric design, architectural designers can quickly generate and control multiple design plans, compare and optimize design effects, and better meet the functional and performance requirements of the building. Parametric design breaks through the limitations of traditional architectural geometry. From a physical point of view, according to geometry and Newtonian mechanics, the original regular form and curved surface are transformed into a twisted form, with the help of computer language algorithm technology, various displays in non-standardized forms (Lotfabadi, Alibaba, & Arfaei, 2016). In China, traditional Chinese architectural elements can be combined with parametric ones to create parametric architecture with Chinese cultural characteristics. This concept has been developed to a great extent in the works of Frank Gehry and Zaha Hadid; it has almost become a symbol to identify them.

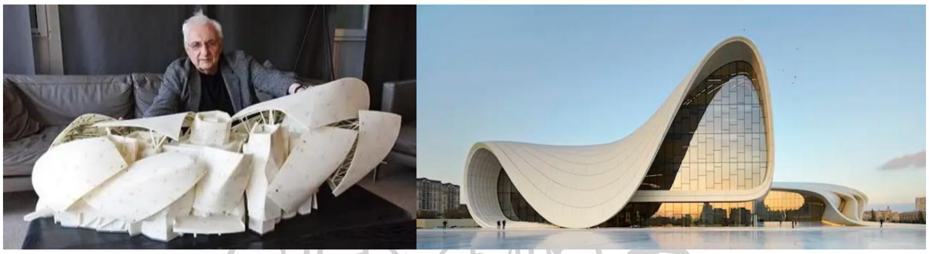


Figure 17 *Works by Frank Gehry and Zaha Hadid*
Note. https:/ soso.nipic.com/2024

China has also made considerable progress in the field of parametric architectural design. Many Chinese architects and design institutions have begun adopting parametric design methods, demonstrating their creativity and technical prowess in essential and iconic architectural projects. For example, the Bird's Nest, the National Stadium in Beijing, China, and the Water Cube, the National Aquatics Center in Beijing, were both realized through parametric design.

Figure 18 *Beijing National Stadium Bird's Nest and Beijing National Aquatics Center Water Cube, Beijing, China*
Note. https: // soso.nipic.com/2023

(2) Graphic design field

The application of parametric design in graphic design can be used for packaging design, layout design, pattern design, graphic design, user interface design, etc. Using parametric design as a tool or method inspires changes in how researchers or designers think and design concepts. Therefore, the entire parametric design process in graphic design is revolutionary. Parametric design can realize 2D graphic design, complex 3D graphic structures in graphic design, and even 4D images to extract 2D graphic designs and provide ideas for topology optimization. Applying parametric graphic design stimulates designers' creativity and brings new possibilities to graphic design. Design shapes, sizes, angles, spacing, etc., through parametric patterns, define and adjust various parameters, generate countless unique pattern designs, and enhance the user experience. User participation provides more personalized solutions; the interaction is closer to the solution's maturity. Applying parametric design in graphic design reduces the designer's long editing and unnecessary mechanical changes. It improves design efficiency and accuracy, which differs significantly from traditional graphic design. Parametric logical thinking provides innovative thinking patterns for graphic design. We can solve complex logical relationships that are difficult to calculate, innovate, and optimize the graphic design system through the overall macro thinking mode. Parametric design, as a new-era technological product of innovative development, will bring new possibilities to the development and progress of the design field. Using parametric tools and technology provides graphic design with the potential and development space for innovation, personalization, efficiency, sustainability, etc. China's anti-counterfeiting design incorporates the concept of parametric design; the currency used in China, the RMB, is a typical example of graphic parametric design.

Figure 19 *Graphic design parametric application diagram*
Note. Researchers draw their own, 2024

(3) Industrial design field

Applying parametric design in industrial design is a crucial design approach to change the rigidity and minimalist emptiness of traditional industrial design modeling. The combination of parameterization in industrial design has changed design thinking and poses new difficulties for complex industrial manufacturing and parametric algorithm translation of traditional Chinese culture. With these parametric design generation algorithms and 3D printing technologies, a comprehensive analysis and evaluation were conducted from factors such as materials, ergonomics, structural performance, production technology, etc., which guarantees industrial design products in terms of structural strength, comfort, and material performance. Parametric design can result in industrial design being process-oriented, that is, parametric variable design. That is to find logic from industrial design, use computer language to edit and combine this logical relationship, realize control of parameter variables, improve the designer’s work efficiency to a certain extent, and complexity design issues. At the same time, it also helps designers in the creative thinking process and gives them the ability to think and calculate; it is an extension of the designer's brain (N. J. H. W. H. L. X. H. W. Li, 17-19 November 2010).

Figure 20 *Industrial design parametric application diagram*
Note. Researchers draw their own, 2024

(4) Fashion design field

The application of parametric design in clothing design is also innovative research on cross-border design, as it provides fresh vitality and novel design methods for modern clothing design. Improvements in the quality of living standards have led to more and more modern clothes that seek personalized design. Traditional clothing styles are simple in structure; parametric clothing design uses unique materials and folding methods, produces rhythm and rhythm, highlights exaggerated contour shapes, gives people visual activation, and has excellent visual impact. It is unique modern clothing. This kind of parametric complexity clothing design is impossible in traditional craft clothing design. Parametric design means and methods bring higher value and interest to clothing design.

Figure 21 *Parametric application diagram of clothing design*
Note. http://www.nipic.com/2024

2.3.1.4 THE DIFFERENCE BETWEEN PARAMETRIC DESIGN METHOD AND TRADITIONAL DESIGN METHOD

There are significant differences between parametric design methods and traditional design methods. Design of any object, from the early stage of design to the production of finished products, has to go through the process of ideal construction in the early stage, media construction in the mid-term, and production and manufacturing in the later stage. Traditional design usually relies on manual operations and experience to complete the design plan; parametric design uses computer algorithms and mathematical models to generate design solutions automatically. Traditional design generally adopts a top-down linear design thinking design method. Judgment and decision-making relying on artificial intuition and experience can express the designer's design ideas intuitively; what you see is what you get; the generation process is relatively subjective; however, the design results are relatively simple, and it is unknown. Traditional design usually requires a lot of human resources and time; responding and adjusting quickly during the design iteration and optimization process is complicated. The parametric design adopts nonlinear design ideas; parameterization has the advantages of reasonable induction and encapsulation logic, can be based on specific parameters and constraints, automatically generates, evaluates, and optimizes design plans that meet the designer's expected design goals, and achieves the original purpose of the design. At the same time, during the design process, it can be modified and optimized in real-time, generating multiple design solutions more efficiently; comparative analysis of various solutions can find the best design solution. This kind of flexibility and repeatability is not possible with traditional designs.

Table 2 *Comparison table between parametric design methods and traditional design methods*

	parametric design method	traditional design methods
Theoretical basis	nonlinear theory	linear theory
design concept	bottom-up	top-down
designing process	Controllability and high fault tolerance	Low controllability and predictability
design features	rational, process	a brief burst of inspiration
Design results	complex and diverse	definite and single
Advantages reflected	Efficient and accurate, convenient for collaborative and intuitive expression of design inspiration.	Intuitively express design inspiration, what you see is what you get
Disadvantages reflected	The process of building the algorithm framework is complicated and requires certain programming basics	The workload of repeated modifications during plan adjustment is huge

Note. Researchers draw their own, 2024

Based on design theory and concepts, the parametric design method uses nonlinear theory. It is a bottom-up algorithmic logic architecture that Generates multi-dimensional design systems. Traditional design methods adopt linear design theory, a top-down end-to-end structure that generates single-dimensional design solutions. In the design process, features and results, the parametric design method enables diverse adjustments and optimizations to achieve design goals, realize controllable data for parametric models, there may be a lot of detailed calculation errors in the algorithm process, increases the likelihood of error rates, however, through the process logic adjustment and modification of the corresponding parameter data, finally, a series of parameter models with reasonable and complex data architecture logic were obtained, the traditional design method is mainly to get the initial plan of inspired design through the designer's direct or indirect design experience, this process is uncontrollable, human factors have a more significant impact, unknown factors will appear along the way, if an error occurs, it will return to a particular link in the original design process to continue modification. Therefore, the parametric design method is efficient and accurate; traditional design methods are intuitive. Taken together, no matter which design method is applicable, it can be used flexibly to find a balanced relationship in design; this is the original intention of design practice research.

2.3.2 PARAMETRIC MODELING

Parametric modeling is a technology that relies on the mighty computing power of modern computers; it is an essential technical basis for realizing parametric design. Parameterization aims to build a complex adaptive system in parametric design, using parametric modeling tools or design software platforms to build parametric models(Goncharova, 2023). Parametric modeling establishes a correlation model, a carrier for later design deepening. Relying on the mighty computing power of computers is the fundamental guarantee for realizing parametric design, allowing adjustment of parameter values during the design process, thereby gradually changing the design and implementing modification and optimization of the original design. Modifying the parameter's value allows models to be updated automatically and quickly generate new design solutions. There is currently a wide variety of design modeling tools, and many design software platforms have been installed. Most modeling tools use grid modeling, which could be more accurate; however, it is inconvenient to modify, and the field of use is also limited. Neil Leach and Yuan Feng, in the book Digital Programming in Architecture, believed that most parametric modeling tools can be design tools; they can also be design expression tools; therefore, in Yin Zhiwei's research on the parametric design and construction of nonlinear buildings, it is concluded that parametric modeling and design software platforms are divided into human-computer interaction, visual programming, and pure script programming (Grosman, Macorini, & Izzuddin, 2023).

2.3.2.1 HUMAN-COMPUTER INTERACTION CLASS

Human-computer interaction in parametric modeling is the process of parametric modeling and the methods and methods of direct information interaction between humans and computers(Costa, Barcellos, Falbo, Conte, & de Oliveira, 2022). Designers use interactive techniques such as graphical interfaces, command lines, and script programming to observe changes in the design model through Windows and make interactive adjustments; the computer provides real-time feedback on design results.

However, the threshold for such tools is relatively low, with strong operational skills. AUTOCAD design platform software, a typical example, can design and output the entire design process.

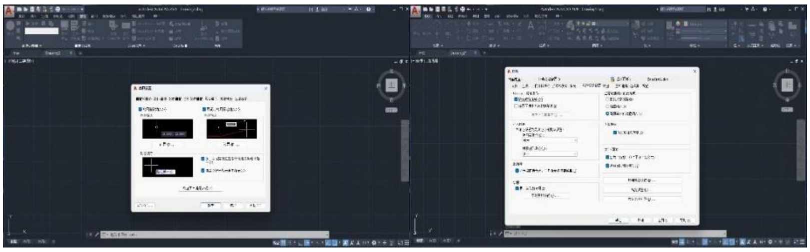


Figure 22 *AUTOCAD design platform software interface diagram*
Note. Researchers draw their own, 2023

2.3.2.2 VISUAL PROGRAMMING CLASS

Visual programming for parametric modeling is a visual programming environment provided by some modeling tools platform that allows designers to operate without coding, change code logic according to design intent, and use graphical node connections to represent model parameters and operational relationships. The writing of code is weakened, and the visual framework is emphasized. Grasshopper is a visual programming plug-in where designers build form builders without programming and scripting knowledge. It is a graphical algorithm editor tool that enables designers to explore forms using generative algorithms and can completely express the logic of parametric design. It needs to be integrated with the Rhinoceros 3D modeling tool platform. Grasshopper is a convenient, efficient, and easy-to-use design software platform(Rodríguez-Cuadrado & San Martín, 2024).

Figure 23 *Grasshopper design software platform operation diagram*
Note. Researchers draw their own, 2022

2.3.2.3 SCRIPT PROGRAMMING CLASS

Script programming for parametric modeling is the process of using a script programming language to achieve automated parametric modeling, not constrained by the user interface; designers are required to have a good foundation in computer languages, directly input the coding algorithm to generate the model, implement the construction of parametric models. The Rhinoceros 3D modeling tool platform can create 3D models for design, modeling, proposal, analysis, and implementation. Fitting curves through mathematical calculations and NURBS curve modeling supports numerous plug-ins and exports to multiple formats and facilitates subsequent conversion between different platforms. RhinoScript is a parametric script editing program that comes with Rhinoceros, requires mastery of complex scripting languages, utilizes scripting command line interactive commands, and the creation of parametric models. This pure script programming method increases the threshold for designers to use; therefore, it is not widely used.

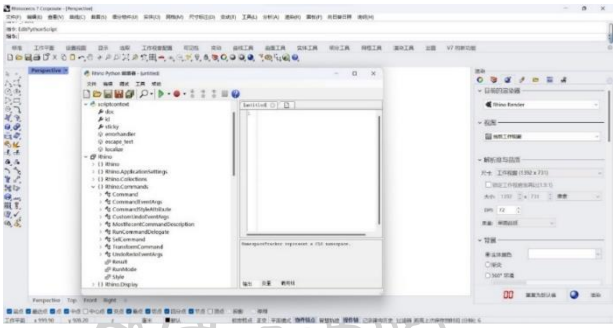


Figure 24 *Script programming diagram*
Note. Researchers draw their own, 2024

2.3.3 PARAMETRIC DESIGN VORONOI DIAGRAM ALGORITHM

The graphical form design of the Voronoi diagram relies on algorithms and parametric design methods. The Voronoi diagram, as a natural subject form, has attracted the design community's attention. The complex form of the Voronoi diagram has natural laws and artistic rhythms in natural subjects, often used in art and design. The Voronoi diagram is an important research content in computational geometry. Many natural structures in nature are very close to the Voronoi diagram; the Voronoi diagram itself has specific aesthetic characteristics. Using parametric design methods combined with the graphic topology relationship of the Voronoi diagram in natural subjects, let's study the application of the Voronoi diagram to complex architectural geometry.

2.3.3.1 VORONOI DIAGRAM CONCEPT

The definition of a Voronoi diagram is a dissection of a space plane, which is the primary data structure for spatial division; it has unique graphical relationships and mathematical properties that are closely combined. In recent years, many researchers have introduced the Voronoi diagram into design fields such as urban, landscape, architecture, interior, and art installations, forming a new parametric architectural space form. This is different from the traditional architectural space form， breaking the boundaries of conventional spatial order norms, establishing a new architectural theory that combines freedom, flexibility, complexity, and openness, paying attention to the topological relationships between things through computer-aided design, using innovative simulation to generate new model parameterizations, reusable open algorithms, dynamically generate architectural forms. This new design method cross-integrates natural science and design art to develop content beyond traditional subject studies.

2.3.3.2 VORONOI DIAGRAM RESEARCH OBJECTS

The Voronoi diagram algorithm is the object of research; the Voronoi diagram algorithm is a vital algorithm language in the field of natural sciences; with the rapid development of the computer age, researchers have begun new architectural experiments, and traditional architectural design forms cannot meet the design needs of current social development, architectural design is extended to research based on complexity science. Traditional architecture focuses on the processing of mathematical geometric forms and the control of proportion and scale and uses them as aesthetic standards and cultural concepts; at the same time, it combines materials, building structures, construction techniques, etc., to form the basis of the building. Therefore, architecture and geometry are closely related, and geometry is a vital discipline that supports the design and construction of buildings. In today's development of digital technology, Digital forms have higher requirements for complex geometric structures. From the perspective of natural science, taking the parametric design method as the starting point, whether from a two-dimensional graphic relationship or a three-dimensional spatial structure relationship, produces a new architectural geometric spatial form order. Voronoi diagram belongs to the critical category of computational geometry, and complex architectural geometry has become the basis for theoretical research on Voronoi diagram algorithms. It is very different from conventional architectural geometry and forms a sharp contrast.

Table 3 *Comparison between traditional architectural geometry and complex architectural geometry*

	Traditional architectural geometry	complex architectural geometry
Time background	Industrial production	Information and digital technology
cultural background	Rationality, context, place, diversity	Graphics, generation, folds, nonlinearity, parametric
Subject foundation	Humanities, Social Sciences	Nonlinear science and complex science
Geometry basics	Euclidean geometry, analytic geometry	Topological geometry, fractal geometry, algebraic geometry, differential geometry, computational geometry, discrete geometry, etc.
Application objects	Simple architectural form	complex architectural form
Aesthetic trends	Clarity, stillness, order Simplicity, abstraction, rationality	Dynamic, smooth, free, continuity difference, complexity, hierarchy, integrity

Design Source	Opposition or fusion of man-made rules	Imitation learning and integration of natural rules
Design method	Top-down control	Bottom-up generation or a combination of both
Operating platform	Hand drawn	computer generated
Designing process	Logical order, physical combination, proportion and scale, functional configuration, etc.	Rules for morphogenesis; geometric logic of parametric processes
Design expression	Horizontal and vertical sections, axonometric drawings, perspective drawings	Illustrations, scripts, animations
Drawing expression	Plane construction drawings	3D computer information model
Construction features	Simple, mass industrial production	Complex, CNC machining and assembly

Note. Researchers draw their own, 2024

2.3.3.3 PURPOSE OF STUDYING VORONOI DIAGRAM

The purpose of studying the Voronoi diagram is that in the information age with new scientific concepts, to meet the development needs of the current society, in addition to meeting the functional requirements of the building, we began to look for more spatial forms, using new scientific concepts and computer-aided design, it has become a trend to explore various possibilities of architectural design experimentation. The form of the Voronoi diagram has a certain degree of rationality and artistic beauty in terms of spatial form.

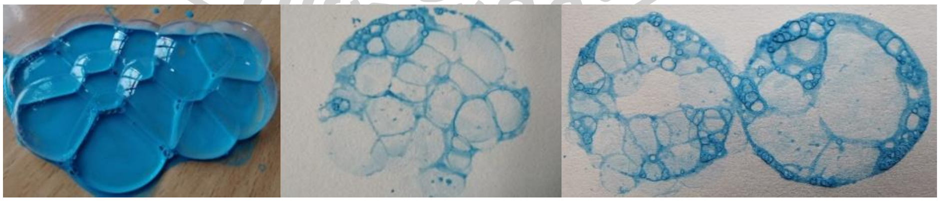


Figure 25 *Bubble theory experiment diagram*
Note. Photographed by the researcher, 2023

Combining mathematical geometric theoretical ideas such as Delaunay triangular grid, foam theory, and honeycomb structure, be inspired to explore the possibilities of new spaces. It was found that the Voronoi diagram algorithm can solve the spatial shape and the controllability of the shape, integrated with parametric design ideas. Interpreting the influence of the Voronoi diagram in design art can trigger new design trends and the emergence of new design forms. Using architectural design theory, artistic aesthetics, design structure, computer technology, etc., these powerful tools of contemporary science carry out theoretical analysis and practical research, creating new and unique architectural space forms. Therefore, the study of the Voronoi diagram is significant; it also guides the practical process of parametric design methods.

2.3.3.4VORONOI DIAGRAM MEANING

The research significance of the Voronoi diagram is mainly reflected in the interdisciplinary aspect; new trends are formed at the intersection of natural science and design art, bringing new forms to architectural design. Mathematical iterative algorithms give full play to computer autonomous algorithms, generating unexpected spatial concepts. In terms of designing experimental research and exploring new design methods, it is experimental. Mainly driven by computer-aided design technology, with the help of parametric design software, constantly try out various possibilities for building models; in the design process, it is necessary to not only meet the functional needs of the building but also find new spatial forms using the Voronoi diagram algorithm in geometry, conduct basic research on mathematical architectural space, discuss the generative significance of architectural form. In terms of the meaning of digital construction, due to the continuous development of digital construction technology, 2D cutting from CNC machine tools to 3D print three-dimensional models, to intelligent robots building concrete-printed buildings, to update and use construction techniques such as chemical synthesis. It is bringing about a massive transformation in the construction industry and pioneering emerging digital construction technologies. Get rid of the traditional construction frame form, dispelling the hierarchical concept of architecture, look at new forms of architectural space from a new perspective, and explore the building process.

2.3.3.5VORONOI DIAGRAM PRINCIPLE

The research principle of the Voronoi diagram used in lotus bionic parametric architectural design is the ordinary Voronoi diagram, a continuous polygon consisting of a set of perpendicular bisectors connecting two adjacent points. By discrete points on the plane, divide the plane into multiple regions; each region contains a point, and the area where this point is located is the set of points closest to this point(Moulinec, 2022). Carry out plane division according to the nearest neighbor principle; each discrete point has a cell polygon area associated with its nearest neighbor, and the point inside the region is the closest to the corresponding discrete point. Voronoi diagram expanded from multiple angles, and it differs from the cell structure in the plane case of the Voronoi diagram. It is the perpendicular bisector of a straight line connecting two adjacent points and is no longer a straight line. In 2006, Zhao Renliang mentioned in the book GIS Spatial Relationship Calculation based on the Voronoi Diagram that the cells forming the Voronoi diagram will transform from polygons on the plane to high-dimensional polyhedral structures. Voronoi diagram generates triangular meshes and geometric shape reconstructions. The polygons adjacent to the Voronoi region, a triangle formed by connecting related points that share an edge, become the Delaunay triangle, and the center of the circumcircle of a Delaunay triangle is a vertex of the Voronoi polygon associated with the triangle. In this case, the resulting connected and associated clustered triangles,s are the Delaunay triangle meshes. Therefore, the Delaunay triangulation network and the Voronoi diagram are dual diagrams. This can be known from the Voronoi diagram's definition. Voronoi diagram is a spatial division structure based on the principle of proximity. It comprises a collection of polygonal areas formed after spatial division; each polygonal area corresponds to a point target, and each point in the polygon area is closer to its corresponding point target than any other target. Zhao Renliang believes that it mainly depicts the adjacent area or the boundary of the influence area of the spatial point. Understanding the principle of the Voronoi diagram will help researchers better understand and apply this computer geometry algorithm and promote the development of this field.

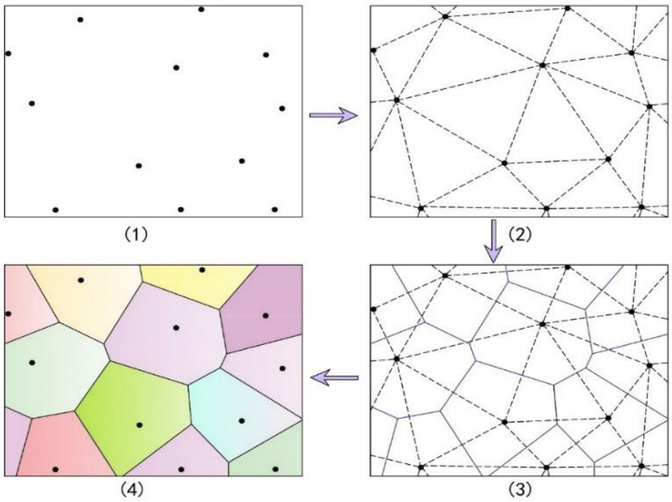


Figure 26 *Voronoi graphics*
Note. Researchers draw their own, 2024

2.3.3.6 VORONOI DIAGRAM ALGORITHM AND PROGRAM

The Voronoi diagram algorithm is also called the Voronoi segmentation algorithm, a crucial computer geometry algorithm. The concept was first proposed in 1908 and named after geologist Georgy Voronoi. In the 1970s, the application of computers to automatically generate Voronoi diagrams was closely related to algorithm generation; the imaging technology of Voronoi diagram has been extensively developed in geographic information systems; it can be used for regional division, map drawing, spatial analysis, and other applications. The Voronoi diagram algorithm takes discrete points as input and builds a Voronoi diagram based on the distance between a point and its nearest neighbor. For a given set of points, each point has one or more nearest neighbors; the point closest to that point is the nearest neighbor. The nearest neighbor is the core of the Voronoi diagram algorithm. The Voronoi diagram is a graph composed of vertical bisectors from each point to its nearest neighbor. Each point is a node in the Voronoi diagram, and the perpendicular bisector is the edge between nodes and forms the boundary of a series of adjacent areas. There are many ways to implement the Voronoi diagram algorithm, including recursive algorithms, incremental algorithms, iterative algorithms, etc. These methods have their advantages and disadvantages. Depending on application needs and scenarios, choose a suitable Voronoi diagram algorithm. The core principle of the Voronoi diagram algorithm is to calculate the distance between each point and its nearest neighbor point. Construct a Voronoi diagram based on these distances. By connecting the perpendicular bisector between each point and its nearest neighbor, the area where each point is located can be divided, forming a Voronoi diagram. This kind of nearest-neighbor search, spatial analysis, regional division, and other work provide convenience for researchers.

Currently, because computer programming is complicated for most architectural designers, architectural designers can choose the appropriate design software platform, for example, generating components for a Grasshopper application, plug-ins such as Grasshopper and Rhino Script for design software developed using parametric platforms, putting the Voronoi diagram algorithm into the design software platform, into a visual graphic script form. The Voronoi diagram algorithm is no longer complicated; it becomes easier for ordinary architectural designers to accept it and use it according to their needs. Architectural designers can choose the Grasshopper design software platform, which uses the Voronoi diagram algorithm program for graph-biased algorithms; whether it is a two-dimensional graphics or a three-dimensional space model, it is converted into a geometric data model. The process steps can be divided into the following.

a. Use computers to convert the Voronoi diagram algorithm into a geometric data model.

b. Enter the generation conditions according to the algorithm's requirements, such as the input point set.

c. After inputting the conditions, generate the Voronoi diagram or Delaunay triangular mesh required by the architectural designer.

d. The architectural designer creates a new point set within the algorithm conditions based on the design elements.

e. Algorithm software related to other algorithms or Voronoi diagram algorithms can diversify graphics.

f. Modify and adjust the generated Voronoi diagram within the controllable range.

g. Finally, output the final result.

2.3.3.7VORONOI DIAGRAM ALGORITHM STEPS

The Voronoi diagram algorithm steps can be divided into three situations: the algorithmic steps of plane drawing, the algorithmic steps based on graphics, and the algorithmic steps of Grasshopper.

(1) Algorithmic steps of plane drawing

Voronoi diagram algorithms mostly use plane Voronoi diagrams as an example, preferring interpretations of geometric drawings. It is a geometric drawing method that uses the results of the plane Voronoi diagram to infer. The key to the algorithmic steps for plane mapping is to establish the Voronoi diagram algorithm for discrete data points reasonably connected to form a triangular network, the process of constructing the Delaunay triangulation network.

a. Input a point set, with each discrete point as the original point, representing a specific location on a plane or a set of coordinates in space.

b. Using the coordinates of the maximum and minimum values in the point set to determine the boundary or circumscribed circle of the input point set helps limit the scope of the Voronoi diagram.

c. Make cross correspondences between these discrete points to connect them into triangles.

d. Make the circumcircle of the triangle form a plane grid with triangles as the primary form. If the circumscribed circle contains no original point, then the triangle that generates the circumscribed circle is retained. Otherwise, the triangle that generates the circumscribed circle is deleted.

e. Through the generated Delaunay triangulation network, according to the adjacent triangles of each discrete point, connect the centers of the circumcircles of these adjacent triangles, make a perpendicular bisector at the midpoint of the line segment on the three sides, perpendicular bisectors intersect, form a new grid pattern, finally, a Voronoi diagram forming a plane is formed.

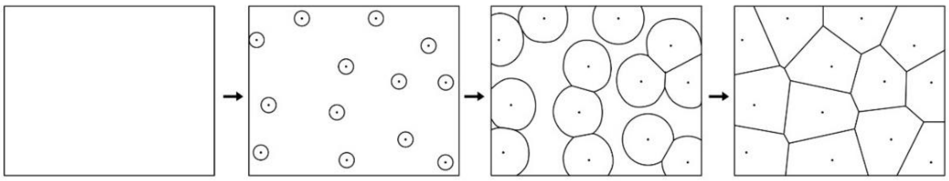


Figure 27 *Voronoi diagram based on charting algorithm step chart*
Note. Researchers draw their own, 2024

(2) Graph-based algorithm steps

The graph-based algorithm in the Voronoi diagram algorithm has many similarities with the plane drawing algorithm; graph-based algorithms input vertices or control points in the graph, the vertices can be of any shape and have other properties.

a. Draw a circle with any discrete point as the center.

b. Gradually increase the circle's radius until the adjacent circle begins to intersect and intersect until the plane where the discrete point set is located is entirely occupied by the set of circles.

c. A straight line connects two intersection points between two adjacent circles; the intersection points where these lines eventually intersect form a new set of points.

d. Connect the points corresponding to the new point set and form a line segment; finally, a flat Voronoi diagram is obtained.

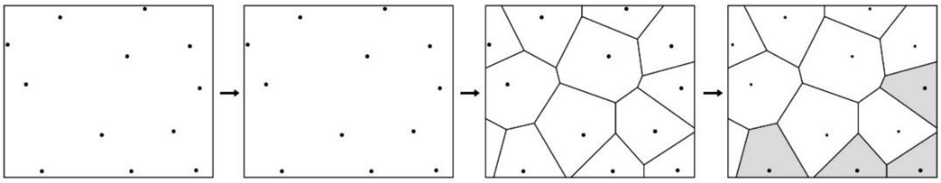


Figure 28 *Voronoi diagram based on graphic algorithm step chart*
Note. Researchers draw their own, 2024

(3) Grasshopper algorithm steps

Grasshopper's algorithm is based on the RhinoScript software platform under the parametric design platform, a plug-in that uses procedural algorithms to run generated models in the Rhino environment. Voronoi diagram algorithms are applied to design, and computer algorithm language is used to program it into a software program; this generates a series of controllable Voronoi diagram architectural spatial forms. The Voronoi diagram algorithm transforms knowledge in natural science into basic research on architectural space with mathematical properties. Based on the principles and properties of the Voronoi diagram, an extended Voronoi algorithm script is developed and designed as your own Grasshopper operator. It promoted the popularization of parametric design technology and theory.

a. Using the Grasshopper interface interaction form, the point set data for two-dimensional or three-dimensional Voronoi diagrams is set in the RhinoScript software platform.

b. The script was edited according to the Voronoi diagram algorithm, Voronoi battery input via Grasshopper software, and point set data was generated.

c. Set the point set area range for two-dimensional or three-dimensional space; adjust as needed.

d. By running the Grasshopper script, use the Rhino software platform to provide a way to visualize algorithms and output a 2D or 3D Voronoi diagram.

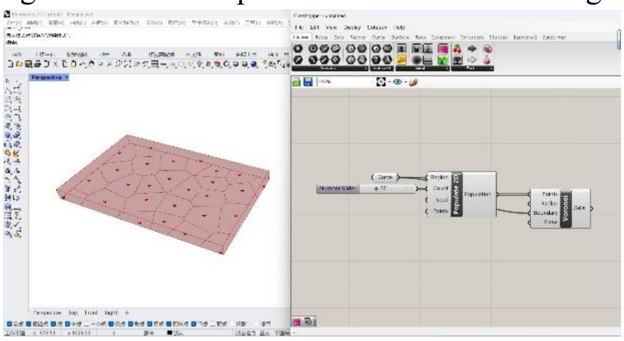


Figure 29 *Voronoi diagram plane based on Rhino platform Grasshopper program algorithm diagram*
Note. Researchers draw their own, 2024

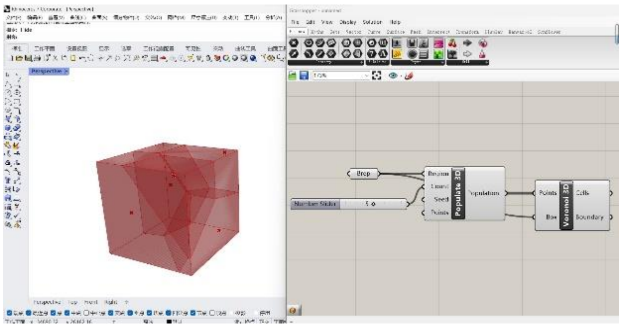


Figure 30 *Voronoi diagram 3D algorithm diagram of Grasshopper program based on Rhino platform*
Note. Researchers draw their own, 2024

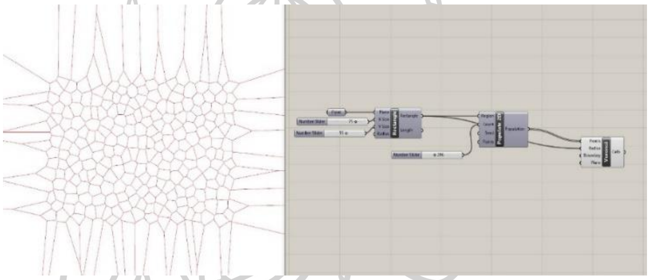


Figure 31 *Two-dimensional Voronoi effect and battery diagram*
Note. Researchers draw their own, 2024

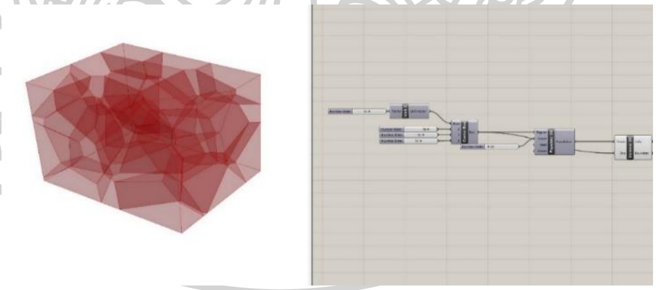


Figure 32 *3D Voronoi effect and battery diagram*
Note. Researchers draw their own, 2024

2.3.3.8VORONOI DIAGRAM APPLICATION IN CONSTRUCTION FIELD

Digital technology was used to develop the geometric properties of the Voronoi diagram algorithm, and a series of effective spatial forms and complex geometric surfaces were produced to apply the Voronoi diagram in the construction field. From the dimension of the Voronoi diagram used in the design field, divided into two sizes and three dimensions, the Geometric expansion of the two-dimensional Voronoi diagram can be applied to building skins, facades, curtain walls, plane decoration, etc. The three-dimensional Voronoi diagram is mainly about a similar cell structure's spatial structure and plausibility. It can be used in building structural framing systems, and it can also be used for urban furniture, spiritual fortresses, public installations, industrial product models, etc. The Voronoi diagram's proximity property and linear principle can be applied to land plot analysis and planning, landscape planning, building space outline, and shape planning, interior functional layout differentiation, polygonal or polyhedral structural configuration, etc. Applying the Voronoi diagram, combined with topology, fractal, iteration, tessellation, and other algorithms, is widely used in graphics language diversification and model optimization.

Architecture is an integral part of the urban development process. It was created to meet the needs of human beings and affect the development of urban form. Architectural environment with the development of science and technology, the form of buildings has undergone significant changes. Many innovative architectural experiments have attracted much attention in today's society. The form of the building becomes continuous, smooth, flowing, complex, chaotic, overlapping, dynamic, twisted, hollow, plastic, conflicting, floating, uncertain, light, and other ideological characteristics. In their research on parametric environmental design teaching, Zhan Heping and Xu Jiong, to sum up, the pioneering architectural designers, using mathematics, geometry, design, physics, and complexity science, using science and technology as new design styles and trends, breaking the traditional architectural geometric form of architecture, using ultra-avant-garde architectural design concepts, using parametric design and algorithmic design methods, create a unique architectural ideology, to try to solve their problems. Under the influence of this design, the Voronoi diagram design generates a relationship between the properties of the Voronoi diagram and the graph, letting researchers or architectural designers get inspiration and inspiration, and there is an increasing focus on disciplines other than those of architecture. By studying theories and methods from the natural sciences, a construction theory that relies on geometric logic to construct complex architectural forms, develop various design art theories and practices related to the Voronoi diagram. Researchers and architectural designers use the Voronoi diagram in space analysis and division of many architectural designs to achieve optimal resource allocation and divide the space without overlapping. Therefore, it is widely used in construction science and engineering, urban planning, environmental design, design art, etc.

In 2000, Arup Associates established the Advanced Geometry Department ACU, committed to in-depth research on various types of nonlinear geometry and its application in architectural design, analysis, and construction; later, there were advanced geometry and structure research departments such as Balmond's nonlinear systems research institute NLSO, partly founded by Hanif Kara, and Buro Happold's GGU. Then, some companies researched geometry and algorithms, for example, Foster's Special Model Group and Zaha Hadid Architects' Code Research Group, and for architectural design proposals, a company that provides consulting and analytical optimization modeling and other programs, in 2008, Helmut Portman founded the Evolute company, the Swiss DesigntoProduction company, etc. Their research covers geometry and computer graphics on multiple surface, space, and form topics, including two- and three-dimensional mosaic systems, as well as spatial organization forms such as folding, branching, tangles, and topology. This provides a powerful design platform for designing and constructing the Voronoi diagram; through these platforms, various forms of iterative design architectures derived from the Voronoi diagram algorithm can emerge.

Researchers have recently summarized the practical application of the Voronoi diagram in architectural design.

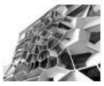
State	Project pictures	Project name	Area	Time	Place	Designer	Application Part	How to apply	Place
Invention project		Net.Lab		Year 2006	Virtual	G_Nome	Appearance and space design	Component or form	A continuous space with blurred boundaries of walls, floors, and structures
Development and Design		Tulum Heritage Museum (TLLUM SITE MISEUM）	1350 ㎡	Year 2006	Mexico map of Mayan ruins	Andrew Kudless	Wall (structure) design	Ingredient analysis	Cell structure layout and overall layout
		National Kaohsiung Performing Arts Center (National Kaohsiung of the Arts)	100000 ㎡	Year 2007	Taiwan Weiwu Urban Park	Zaha Hadid	Land subdivision and program setup	Basic parameter extraction for environmental analysis	Overall planning integrated into the landscape
		Victorian college of art (Victorian College of the Arts)	5000 ㎡	Year 2001	Melbourne Dodds Street South Bank	MvS Architectural Design Office	Flora silver plated interior space layout and planning	Graphic elements are extracted and topologically shaped into shallow cones and orthogonal windowing forms.	The wrapped shell wants to be integrated with the architectural space
		Li Bo Beauty Salon Center		Year 2005	Maka, Tonami City, Mount Fuji, Japan	Matsukawa Shohei	Building exterior and building interior space layout and planning	Properties application, algorithm space simulation experiment and construction	Algorithm intervention in architecture and discussion of effective space configuration
		Mikimoto, Ginza 2	2205 ㎡	Year 2005	Tokyo, Japan	Toyo Ito	Building facade skin	Extraction and application of geometric elements	The building's façade serves as both skin and supporting structure
		Tokyo Cell Building, Japan	3000 ㎡	Year 2007	Tokyo	M/Hajime Masubuchi workshop	Building facade multi-layer skin	Graphic element extraction	complex layered epidermis
		China National Aquatics Center (water Cube)	79532 ㎡	2003.12-2008.1	Beijing China	China Construction Design, together with Hugh and PTW Architectural Design Office of Australia	The structure of the space steel frame	Optimal space architecture analysis	Unique space architecture system
Built		Harpa(Reyk javik Concert Hall and Conference Centre)	28000 ㎡	Year 2011	Reykjavik, Iceland	Henning Larsen Associates	Building facade space structure, interior space	Crystal architecture analysis	The overall planning of the building is both regular and changeable
		Cordoba Center for Contemporary Art	12287 ㎡	2008-2013	Cordoba, Spain	Nieto Sobejano Arquitectos	Landscape planning, building space layout, precast concrete structure building facade	Basic parameter extraction for functional space analysis	Architectural space cell structure diagram
		Taichung Metropolitan Opera House	57685 ㎡	December 2009-November 2014	Taiwan, China	Toyo Ito	Basic plane space generation	Topological extraction of two-dimensional Voronoi properties	Spatial complexity and diversity
		Football stadium in Borisov city, Belarus	8925 ㎡	2011-2014	Belarus	OFIS Architects	Aluminum clad metal skin	Graphic element extraction and surface optimization	The spatial architecture complements the skin
		台湾大学社会科学院图书馆	53231 ㎡	Year 2013	Taiwan, China	Toyo Ito	Integrated design of architecture and landscape	Graphic element extraction, optimization, and topology shaping	"Generative tree-like" lines created by design algorithms
		Cultural and Sports Center Shenyang	123000 ㎡	Since 2011	Shenyang, Liaoning, China	EMERGENT Tom Wiscombe LLC	Architectural spatial form and skin	Element form finding and mathematical model calculation	Form integration, overall harmony and unity

Figure 33 *Application table of Voronoi diagram in architectural design*
Note. Compiled and analyzed by the researcher, 2023

As a result, there have been many research cases where the Voronoi diagram algorithm has been used in building construction and planning. Through the process of experimentation and practice in architecture through the Voronoi diagram, the researcher, it is found that in this Voronoi form generation algorithm based on the mid-perpendicular line between two points, the following results are possible:

Through the concept of information analysis and feedback space of the built environment, data-parameterized process models are created.

Environmental information can be created in various forms through Voronoi diagrams to create parameterized structures, and the induction type can be controlled based on expectations.

The Voronoi diagram and other algorithms are implemented through various methods, and the multiple types of potential arising from a change in the system's algorithm must be exploited.

Extend from the two-dimensional Voronoi diagram to the reference point in the three-dimensional space to create a three-dimensional view of the space. This can progress to space construction, combining structural geometry to optimize polyhedral space architecture and space utilization in architectural design.

Voronoi diagrams are introduced in many fields because they find a way and the possibility that some alternative configurations will work. However, if there is no finite geometric information remaining, and generates variables given only by functions and control characters, further research with large amounts of controlled data is needed.

2.3.4 PARAMETRIC DESIGN GENETIC ALGORITHM

A genetic algorithm was developed in the 1960s and proposed by Professor Holland from the University of Michigan, USA, in the early 1970s; he suggested the fundamental theorem of genetic algorithms, a model theorem, that laid the theoretical foundation of genetic algorithms. Genetic algorithms draw lessons from the evolutionary laws of biology. That is, the random search method developed from the survival of the fittest mechanism. It is a search algorithm with an iterative process of survival and detection. Subsequently, experts such as De Jong, Goldberg, and Davis did much calculation and application work. This algorithm has been widely used in combinatorial optimization, machine learning, artificial life, and other fields; it is a crucial technology for modern intelligent computing. Since the late 1980s, there have been frequent international academic activities on genetic algorithms; genetic algorithms are booming. Fan Huiyuan and Wang Shangjin believed in genetic optimization design that, in the early 1990s, China had just begun to study genetic algorithms. Although it started late, it developed rapidly, and remarkable results have been achieved in many fields. John Frazer introduced the algorithm into architectural design in the 1990s and created the evolutionary architectural algorithm. Make buildings as adaptable as species in nature; evolution yields the best results. Genetic algorithms can perform curve and surface fitting, which are used for structural analysis design(Cavallaro, Cutello, Pavone, & Zito, 2024).

Algorithms require editing of programming languages and scripts. Common scripting platforms in architectural design and construction include RhinoScript, MAYA Mel, and Python based on C language, processing based on JAVA, and editing platforms such as CATIA based on CAA. During the execution of the script, Processes such as conditional statements, loop statements, and situational statements can express different algorithm logics, which enables complex calculation processes. Fractal iteration and recursion, cluster intelligence, and multi-agent systems are essential tools for digital architects to perform form generation. Many algorithms also serve essential computational functions in analyzing and optimizing curves and surface forms.

Many algorithms also serve essential computational functions, Summarizes the genetic algorithm as an optimization method, the basic theory is that the mathematical model consists of design variables$X = (x_1, x_2, \dots \dots, x_n)^T$, The objective function F(X) and the constraint conditions g_i(X)≥0 (or ≤0), i=1,2,…,n are composed. The basic concepts, main characteristics, and algorithm structure of genetic algorithms are as follows.

2.3.4.1 BASIC CONCEPTS OF GENETIC ALGORITHM

Chromosome, a tiny compound contained in biological cells, is the primary carrier of genetic material, made up of multiple genetic genes.

Fitness, in the process of inheritance and evolution, is used to measure the degree of adaptation of species to the living environment.

Individual, collection of design variables.

Population, collection of individuals.

Encoding, genetic information is arranged in a pattern, and mapping from phenotype to genotype.

Decoding, mapping from genotype to phenotype.

Selection, the operation of selecting several individuals from the population with a certain probability, generally based on survival of the fittest based on fitness.

Crossover, where the code is cut off at the same position on both chromosomes, is the process in which the two strings before and after are crossed and combined to form a new chromosome, also called genetic recombination.

Mutation, when cells replicate, may produce replication errors with a very small probability, thereby changing the characteristics of the cell and producing new chromosomes.

2.3.4.2 MAIN CHARACTERISTICS OF GENETIC ALGORITHM

Universality, the genetic algorithm only needs to use the objective function to obtain information; there is no need to calculate high-order information. Therefore, it is suitable for large-scale, highly nonlinear discrete multi-peak and objective function optimization without analytical expressions.

Parallelism, the genetic algorithm operates on multiple feasible solutions. Many trajectories are used to search for the target point, so it has parallel characteristics.

Globally, the selection mechanism of the genetic algorithm is based on the entire population, coupled with its good parallelism, which gives it an excellent overall character and robustness.

Simplicity, the set of feasible solutions for a genetic algorithm operation is encoded, and the objective function can be interpreted as the fitness of the encoded feasible solution.

2.3.4.3 GENETIC ALGORITHM CONSTRUCTION PROCESS

First, the design parameters of the decision variables and their various constraints, that is, the individual phenotype X and the problem's solution space, are determined.

Second, an optimization model must be established to determine the type of objective function and its mathematical description form.

Third, the chromosome encoding that represents the feasible solution and the corresponding decoding method is determined; the relationship between individual genotype X and individual phenotype X is determined.

Fourth, the quantitative evaluation method of individual fitness is determined, and the specific operation method of the genetic operator is designed.

Fifth, determine the relevant operating parameters of the genetic algorithm.

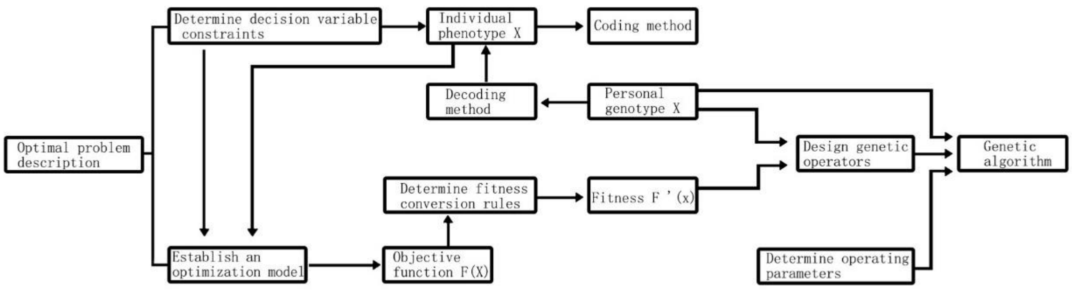


Figure 34 *Construction process diagram of genetic algorithm*
Note. Researchers draw their own, 2022

There is an excellent connection between digital design and genetic algorithms; genetic algorithms can optimize parametric design's parameter selection and adjustment process. In parametric design, we can use parameters to control the object's shape, size, location, and other attributes. Through different parameter settings, we can get different design results. The genetic algorithm is an algorithm that simulates the natural biological evolution process through operations such as selection, crossover, and mutation to select the optimal solution from the initial population. We must first determine the objective function and parameter range when applying genetic algorithms for parameter optimization. We can then use a genetic algorithm to randomly generate an initial set of parameters and calculate the corresponding objective function value. Next, we can use select, crossover, and mutation operations to create new parameters continuously optimized by calculating the objective function value. Finally, we can get the optimal parameter combination for the optimal design result. Therefore, parametric design can be combined with genetic algorithms, thereby achieving automation of the global optimization design process, and the design efficiency and optimization degree are greatly improved.

2.4. RESEARCH ON PARAMETRIC ARCHITECTURAL DESIGN

2.4.1 RESEARCH BACKGROUND

In the mid-1990s, architectural parametric design teaching began to appear at Columbia University in the United States. MIT School of Architecture, the Architectural Alliance College in the UK, has set up teaching courses on parametric design. The early experiments of avant-garde architects, represented by Greg Lynn, Hani Rashid, and Jason Lesser, promoted a form of expression known as fluid architecture. Fluid architecture is an architectural style that is streamlined and organic; the works created by Greg Lynn in this expression are the original representative of parametric architectural design and have become classic works.

Most people questioned parametric architectural design at the beginning. For a long time, computers were only used as tools for drawing and rendering, and their powerful automatic generation function was ignored. Over time, digital design technology has gradually become more popular worldwide. More and more designers and offices are beginning to apply digital technology to their work. In 1997, the Guggenheim Museum, designed by American architect Frank Gehry, was completed in Bilbao, Spain, just boldly used aerodynamic computer software to create the overall structure of the museum on the computer; this is also one of the early parametric architectural designs practices.

2.4.2 THEORETICAL BASIS OF PARAMETRIC ARCHITECTURE

2.4.2.1 FRACTAL THEORY

Fractals can be represented as geometric figures, such as the Koch curve, a geometric curve shaped like a snowflake, and the Mandelbrot set of point sets in a complex plane(Su et al., 2024).

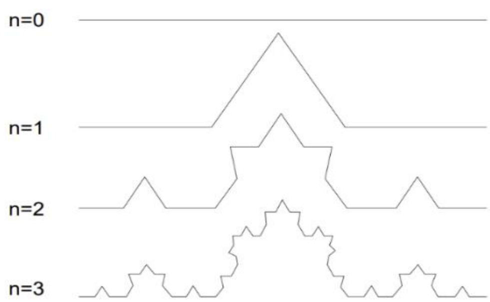


Figure 35 *Koch fractal graph*
Note. Researchers draw their own, 2024

There are also widespread fractal phenomena in nature, such as winding coastlines, melted snowy ground, winding mountains, intertwined rivers, strange animal and plant textures, natural phenomena of clouds and lightning, etc.; these all have typical characteristics of fractals. Fractals manifest as geometric figures and natural fractal phenomena and can also reflect numerous fractal behavioral phenomena. For example, in a society, the social fractal of human social performance is at different scales in the country, province, city, and family.

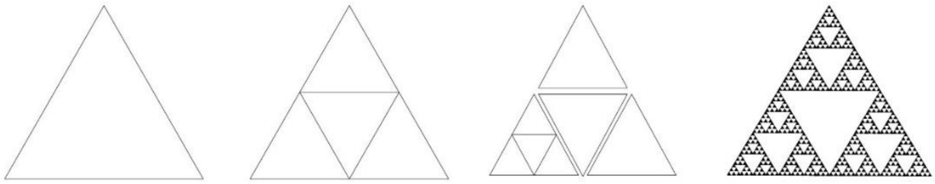


Figure 36 *Sierpinski triangle diagram*
Note. Researchers draw their own, 2024

The fractal theory reveals the simple rules behind complex phenomena; designers consciously apply fractal thinking to architectural design, interior decoration design, etc., and generate design works with complex rhythm and order.

2.4.2.2 THE IMPACT OF FRACTAL GEOMETRY ON ARCHITECTURAL DESIGN

The emergence of fractal art, which brings new developments to the aesthetics of architecture, lets people pursue the irrational beauty of chaos. Published by China construction industry press, the book Kurokawa Kisho, translated by the author Zheng Shiling, mentioned that Japanese architect Kisho Kurokawa once said, with the help of Heisenberg's quantum mechanics and Einstein's general theory of relativity, fractal geometry hinted at the possibility of a new order. There is a fractal order in natural phenomena; it was previously rejected due to its complexity. Fractal geometry, located in the middle realm between order and chaos, is the principle of life itself; architecture in the age of life will be developed based on fractal geometry.

Figure 37 *Fractal art design drawing*
Note. http://www.nipic.com/2023

The fractal theory allows people to realize the nonlinear beauty contained in nature and biological organisms, changes people's previous aesthetic views, and makes people more willing to get closer to all natural things. At the same time, it also affects people's aesthetic appreciation of architecture; people no longer need the same standard geometry boxes and eagerly look forward to the emergence of a new architectural form. Under this idea's guidance, architects began to use new aesthetic perspectives and design a unique architectural form—Danish architect Jorn Utzon designed Australia's famous landmark, Sydney Oper957. The Sydney Opera House building is like a piece of substantial white shell like a sailboat. It was created by architects using the mathematical principles of fractal geometry.

Figure 38 *Jorn Utzon Sydney Opera House renderings*
Note. http://www.nipic.com/2024

2.4.2.3 PHILOSOPHY OF PARAMETRIC ARCHITECTURAL DESIGN

French postmodern philosopher Gilles Deleuze's non-centrality, non-totalization, a philosophical perspective that advocates immediacy and contingency. Especially for wrinkles, explaining concepts such as nomadism, diagramming, and becoming directly influenced the parametric architectural design and found the basis of ideas, a point of convergence of ideas. In other words, parametric architectural design is a technology and method that, according to the philosophy of Gilles Deleuze, provides a framework for understanding and creativity. Diversity in the philosophical thought of Gilles Deleuze, difference and repeatability, enables researchers to use design methods based on algorithms and parametric models to adjust parameters and rules to generate diverse architectural design plans, provide new ways for complex forms, encourage researchers' knowledge and understanding, provides a philosophical perspective.

First, fold philosophy explains the complexity of relationships and changes between things through abstract concepts and mental models such as folding, splitting, and twisting. Matter is subject to various internal and external forces to produce creases, causing multiple morphological characteristics. The philosophy of fold advocates viewing reality as a continuous process of change; various elements interact and fold; this kind of two-way folding includes time and space; the wrinkles are curved, dynamic, and intertwined in a non-linear, non-hierarchical way. The germination of a seed and the rise and fall of the earth's surface are all pleats. Inspired by this idea, various forms of expression have appeared in architecture that break the traditional view of time and space—presented from a complex, diverse, and fluid perspective.

Second, nomadic philosophy comes from thinking about the fluidity of living space and the differences between nomadic and sedentary lifestyles. The nomadic lifestyle has no fixed residence, relying on cultural groups that constantly migrate and adapt to environmental changes; nomadic space is topological. Nomadic philosophy sees this fluidity and variability as a philosophical pattern, trying to transcend traditional binary opposition thinking and fight against settled and fixed ways of thinking. The core of parametric architectural design is to regard design as a change process, explore a broader design space, and face the complexity of space; the study of architecture and form has important implications.

Third, Diagrams serve as tools for expanding the boundaries of thinking, explanation, and analysis in architecture. Deleuze diagrams are not simple images or photographs but symbolic systems with deep philosophical thinking. Traditional diagrams are static, explanatory forms of diagrams, while new diagrams are dynamic, generative diagrams. It can explain the inner relationship of things and the expression of the architectural designer's design inspiration intention.

Fourth, the generation concept makes traditional design search for specific results; it establishes a dynamic process, and the result is the design work. In parametric architectural design, relevant factors constitute architectural design parameters, and architectural design results are generated using algorithms.

2.4.3 PARAMETRIC ARCHITECTURAL DESIGN ANALYSIS

In parametric architectural design, two types of factors affect the design results: one is a variable factor, and the other is an immutable factor. Various results can be obtained when variable factors change as a parameter in architectural design. Therefore, parametric design is an architectural design method that produces different results based on changes in variable factors. The variable characteristics of parametric design make architectural design more flexible. Compared with traditional design methods, the processing of complex shapes becomes more accessible and more accurate. The architectural designer only needs to change the parameters in the operational relationship, and you can modify or change the final architectural design result.

Parametric architectural design, broadly, refers to all architectural forms conforming to parametric characteristics. Covers architectural design before the advent of nonlinear theory. In a narrow sense, in the information age, with the help of complex architectural shapes processed by digital technology, this building uses computer technology in its design and construction, parametric architecture. Parametric architecture is a building with continuous and flowing shapes; its physical characteristics are affected by architectural performance and surrounding environmental factors; it is an abstract reflection of natural forms in architecture. In the Architecture of Jumping Universes, published by China Construction Industry Press, author Charles Jenks once said that complexity in architecture is loosely based on scientific complexity and has reached maturity. Some architects consciously accept the basic ideas of complexity science and its many generative and design methods. Due to the complexity of factors affecting construction, this determines the irregular appearance of the parametric nonlinear building.

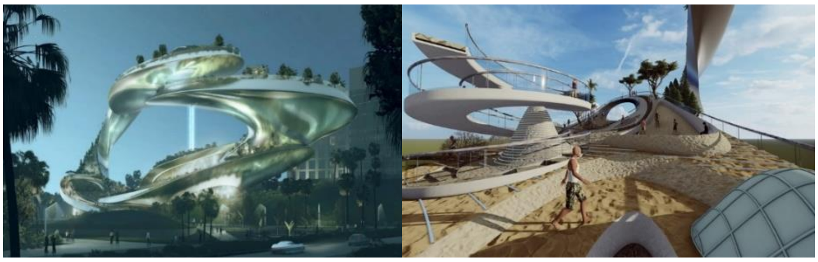


Figure 39 *Reloading Lands diagram*
Note. http://www.archcollege.com/2024

Therefore, we call this design method parametric architectural design, that is, parametric nonlinear architectural design in a narrow sense. In the final analysis, the parametric architectural design originated from digital technology innovation. Therefore, it is subject to the development level of computer technology. At the same time, parametric design provides an integrated production process from design to construction, changing the traditional construction production model. It is a new trend that emerged after deconstruction; it is currently in its initial stages. There are presently two situations in parametric architectural design. One is computer-aided design, which is to complete the scheme design by hand, and then the parametric design method is used to produce the model. The other is to thoroughly apply parametric design, combine architectural design ideas and design tools, and generate new architectural forms.

2.4.4 DEVELOPMENT OF PARAMETRIC BUILDING MATERIALS AND CONSTRUCTION TECHNOLOGIES

The shape of the building depends to some extent on the structural form and material selection. Alejandro Zaera Polo once said that architecture is not a plastic art; it's the engineering of the material itself. Due to the cross-development of multiple disciplines, the digital age triggered a massive change in building materials, and new composite building materials are constantly being manufactured. Unlike traditional masonry materials, these new composite materials are difficult to classify based on typical mechanical properties; they are affected by the structure and the location of the structure and exhibit different characteristics; this also requires architects to have the ability to deal with the complexity of materials(Chacón et al., 2024).

Furthermore, since the skin of the complex building is independent of the traditional building facade, it becomes a free and continuous skin surrounding the entire building, thus getting rid of the load-bearing function and other functions, making it more abstract and expressive(Yuan et al., 2017). Therefore, the materials that can be used as building materials are more comprehensive; for example, copper plates, zinc plates, metal plates, ceramic plates, acrylic, cards, ETFE plates, etc., can be used to express the effect of building skin. Through computer technology, traditional materials also have different forms of expression than in the past.

Parametric design has also brought about considerable changes in how buildings are produced. With the development of electronic technology, computer-aided manufacturing technology has been gradually applied to engineering construction, and achieving the construction of complex shapes is no longer a problem in architectural design. At present, computer numerical control machine tools are commonly used tools in the construction industry. They control the system through a computer program, perform various operations on the objects to be processed, and finally, complete the processing of building components. This method removes excess parts from the blank and keeps the required model, Computer Numerical Control. In contrast, another CNC machining technology is rapid prototyping technology prototyping, which includes fused deposition modeling, three-dimensional printing molding method, selective laser sintering method, and 3D printing method. This technology uses additive or subtractive molding principles, and the raw materials are gradually stacked and formed.

2.4.5 THE IMPACT OF PARAMETRIC ARCHITECTURAL DESIGN ON ARCHITECTURAL ART

Architectural art is a three-dimensional art form; it is the reflection of aesthetic laws in architecture; the most significant difference from other categories of art is that architectural art is an art that combines practicality and aesthetics. Architecture becoming an aesthetic object is a product of history; it is a development process from practicality to aesthetics. Due to the constraints of material materials and physical structure, the aesthetic character of a building is influenced by its practical function, and there are certain limitations in the form of expression.

The functions of architecture and art interact, which are two inseparable characteristics. The quality of the building's use function directly affects people's judgment of architectural aesthetics. If a building has a lovely shape, but the usage function is not satisfactory, it is also a failure in people's lives. For an architectural work, functionality is essential, but the artistry of architecture must be addressed. In architectural reality applications, functionality and artistry are often intertwined; it's hard to tell which part is functional or art.

Parametric architectural design is an architectural design method that emerged after deconstruction; it is the inevitable result of the development of computer technology. It uses parametric technology and effectively solves many problems in architectural design. Zaha Hadid is one of the leading representatives of the post-deconstruction design period; her designs' eternal theme is to arouse the viewer's curiosity constantly. In the Chanel Mobile Art Exhibition Hall, she uses the latest architectural design language through coherent and well-organized design concepts, giving the building a sculptural sensual beauty. This new building uses the latest data modeling technology, breaks the limitations of traditional design, and promotes the design development of flowing shapes. Zaha Hadid explains the process, complexity, and advancement of data imaging software and construction technology make the construction of mobile art exhibition halls possible. We use new data design and manufacturing processes to generate a naturally flowing architectural language. We created the organic form of the entire exhibition hall, and it is no longer a repetitive building from the industrial era of the 20th century.

The improvement of architectural technology level has promoted the development of architectural art, allowing architectural art to express people's aesthetic needs more fully. At the same time, the development of architectural art also requires continuous progress in construction technology. The unique charm of architecture is displayed in the perfect combination of technology and art.

2.5. 3D ARCHITECTURAL PRINTING TECHNOLOGY AND PRODUCTION

With the development of China's economy in recent years, 3D concrete printing has gradually emerged as a new construction technology. The industrialization of Chinese construction, intelligent manufacturing, and green construction have become significant development trends in China's construction industry. The unique intelligence of 3D concrete printing, automation advantages, etc., provides a new development method for the industrialized construction of buildings. Based on the development situation of China's domestic building modernization construction, researchers for the development of 3D concrete printing, 3D concrete printing equipment, printing concrete materials, research on printing technology optimization, and some typical successful project cases in China. In the construction industry processing and production, 3D printing can be used according to architectural needs and specific attributes such as specific shapes, textures, colors, etc. Create personalized buildings. For the smooth development of intelligent construction in China's construction industry, provide beneficial reference value and promote the development, transformation, and upgrading of China's digital sector.

2.5.1 DEVELOPMENT HISTORY OF 3D PRINTED CONCRETE

As an innovative technology that subverts traditional building construction methods, 3D-printed concrete is expected to play a more critical role in the construction industry in the future and promote the development of the construction industry in the direction of digitalization and intelligence(L. Wang, Wang, Li, & Wang, 2024). The earliest concepts of 3D-printed concrete emerged in the 1990s. At that time, researchers began exploring machine control methods to print concrete according to predetermined design templates. Only at the beginning of the 21st century did 3D printing concrete technology start to make breakthroughs; some research institutions and universities have begun to conduct more in-depth research and proposed various printing technologies and prototypes. In 2004, Professor Behrokh Khoshnevis of the University of Southern California developed Contour Crafting's 3D printed concrete technology. Use large robotic arms to control concrete spraying and build the entire building layer by layer. Contour Crafting is an essential milestone in developing 3D printing concrete technology and provides innovative solutions for large-scale construction. At the same time, many research teams and companies began to work on developing commercial 3D printing concrete machines and completed a series of construction projects. Among them, a research team from the University of Eindhoven in the Netherlands successfully printed the world's first fully habitable 3D-printed concrete house in 2014; this marks the practical application of 3D-printed concrete technology. By 2015, Chinese building materials company Winsun and American technology companies such as Apis Cor had successfully printed some buildings such as houses and office buildings, further promoting the development of 3D printing concrete technology. 2016 French technology company XtreeE developed the BOD2 3D printing concrete machine. BOD2 uses a mobile robotic arm to print various shapes and sizes of concrete components, including walls, columns, and beams. The emergence of this equipment has promoted the application of 3D printing concrete technology in the construction industry and received widespread attention. France's XtreeE company has printed the world's first 3D-printed concrete bridge prototype, demonstrating the potential of this technology. In 2017, China Construction Corporation's Architectural Innovation Institute successfully printed a garden in Shanghai. It has the characteristics of traditional Chinese architecture. This further highlights that 3D printing concrete technology can retain traditional culture while the advantages of personalized construction can also be realized. In the same year, a 3D printing concrete machine was developed by Italian 3D printing company WASP. Provides a variety of WASP printer series models and configurations, with the ability to adapt to construction projects of varying sizes and complexity. These printers use unique injection systems and control technology, high efficiency can be achieved, precision and sustainability can be achieved, and they have become critical players in the 3D printed concrete industry. In recent years, 3D-printed concrete technology has become more widely used worldwide. From building homes and bridges to urban infrastructure, it drives the construction industry toward digitalization and intelligence. 3D printed concrete is also expected to enable larger-scale building printing, reduce construction waste, increase construction speed, etc., bringing new possibilities for future construction innovation.

2.5.2 TYPES OF ARCHITECTURAL 3D CONCRETE PRINTERS

(1) D-Shape printer

The D-Shape printer was initially designed and invented in 2008 by Italian architect Enrico Dini. The D-Shape printer is a tool suitable for large-scale construction, with a larger printing area and accuracy, and can print concrete elements of immense dimensions. The d-shaped printer uses a high-precision control system and specially designed inkjet heads, so excellent printing accuracy and detail performance can be achieved. The ability to print complex geometric shapes and delicate textures brings more creative inspiration and personalized design possibilities to the building. The D-shape printer uses a unique cantilever printing principle. Unlike traditional support structures, buildings can be printed without additional support structures. This simplifies the printing process and reduces post-construction cleanup work. In addition, D-Shape printers can utilize renewable materials, such as recycled concrete, to improve sustainability and promote environmentally friendly development in the construction sector. Customization capabilities are also a significant advantage of D-Shape printers. Customized printing can be carried out according to the requirements of architectural designers, and individual building components and structures can be created. This enables creative design and personalized architecture and provides greater freedom.

Figure 40 *D-Shape printer*
Note. Researchers draw their own, 2023

(2) Frame printer

The frame-type 3D printing concrete machine is a widely used 3D printing concrete equipment made of sturdy metal or steel construction; the stability and rigidity of the equipment are ensured. This structure can provide accurate positioning and guarantee precision and accuracy during printing, thereby printing a solid structure and stable buildings. Modular design is often used to connect the print head, injection system, and separation of components, such as the feeding system, to facilitate maintenance and replacement; this design makes equipment maintenance and updates more convenient and improves reliability and maintainability. Frame printers usually use multi-axis motion systems; Accurate movement can be achieved in three or more directions. This design allows the print head to be precisely positioned on the x, y, and z axes to achieve architectural printing of complex shapes and structures. At the same time, the frame-type printer is equipped with an automated control system; through automated control, it can precisely control the movement of the print head and concrete spraying, achieve a high-precision and high-efficiency printing process, and increase productivity. The injection system is a critical component of the frame printer. For controlling concrete spraying and realizing architectural printing stacked layer by layer, the injection system includes elements such as a concrete feeding system, nozzles, and control valves, which can accurately control the amount and speed of concrete spraying to meet various printing needs. Frame-type printers have a certain degree of flexibility. Ability to adapt to construction projects of varying sizes and complexity. It can be customized according to the designer's requirements and has flexible printing parameter adjustment capabilities, such as adjusting the printing speed, concrete layer thickness, etc. To meet the needs of different construction projects.

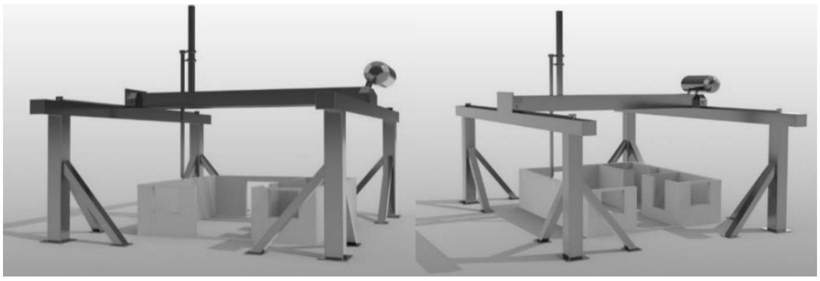


Figure 41 *Frame printer*
Note. Researchers draw their own, 2023

(3) Gantry printer

The gantry 3D printing concrete machine is a highly flexible and efficient 3D printing concrete equipment with adjustable print height; the height of printed objects can be flexibly adjusted as needed. Gantry printers usually have large printing areas, can print larger-sized concrete components, have greater flexibility in the construction industry, and can achieve large-scale and volumetric building printing, providing feasible solutions for large construction projects. Gantry printers also have a stable frame structure constructed from sturdy steel or aluminum materials, which have excellent rigidity and stability. This structure ensures the stability and accuracy of the printer during the printing process, ensuring the accuracy and quality of printed objects. A high-precision motion control system is one of the essential features of gantry printers. It enables precise positioning and motion control on the X, Y, and Z axes, providing excellent printing accuracy and layer flatness. Gantry printers often support multiple printing tools, such as numerous nozzles or applicator tools. This design allows various operations to be performed simultaneously, improves printing efficiency and flexibility, and speeds up building printing and completion times.

Regarding open systems, some gantry printers have open architecture and software systems that can be integrated with other devices and software. The gantry-type 3D printing concrete machine is a height-adjustable, large printing area, stable frame structure, High-precision control system, and advanced printing equipment with features such as multi-tool support and open systems. It has crucial application potential in the construction industry; it will support efficient printing and personalized design of buildings.

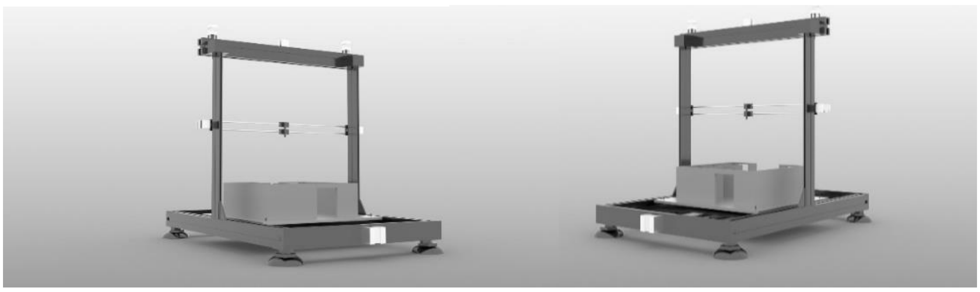


Figure 42 *Gantry printer*
Note. Researchers draw their own, 2023

(4) Robotic arm printing system

The robotic arm 3D printing concrete system is an advanced printing equipment with high flexibility and precision. The system uses a robotic arm as the leading printing tool, accessible and flexible movement, and printing operations can be performed in three-dimensional space. This design enables the robotic arm printing system to adapt to the printing needs of buildings of different sizes and heights, from small components to entire building structures. Robotic arm printing systems usually have an extensive printing space, a large working radius, and a printing range. This feature enables it to cover a wide range of spaces and achieve printing of buildings of various sizes. Whether a small residential or a large commercial building, robotic arm printing systems can meet the needs. The robotic arm printing system has precise positioning and motion control capabilities. I achieved exact positioning and accurate movement on the X, Y, and Z axes using high-precision positioning and motion control systems. The robotic arm printing system is equipped with real-time sensors and feedback mechanisms, with the ability to monitor changes and corrections during the printing process in real time. Through real-time data feedback, the system can adjust printing parameters and correct posture in time to ensure the accuracy and stability of printing results.

Regarding material selection, robotic printing systems are generally appropriate for various concrete materials. It can use ordinary concrete, reinforced concrete, or even specially formulated concrete materials for printing. The robotic arm 3D printing concrete system focuses on sustainability and environmental protection. The system minimizes material waste and energy consumption with accurate concrete spraying and fine print control. This ecological awareness is significant in the construction industry and contributes to sustainable development. The robotic arm 3D printing concrete system is also mobile and removable. Due to its independent mechanical structure, the system can be quickly deployed and moved between different construction sites or construction sites. This flexibility makes the robotic arm suitable for temporary buildings and particular scenarios such as emergency disaster relief and hard-to-reach terrain. In addition, robotic arm 3D printing concrete systems also have innovative potential in the construction and engineering fields. It can realize the printing of complex geometric shapes and curve structures, promoting innovation in architectural design and construction. This new printing technology brings sustainability to the construction industry and provides customizable and efficient solutions.

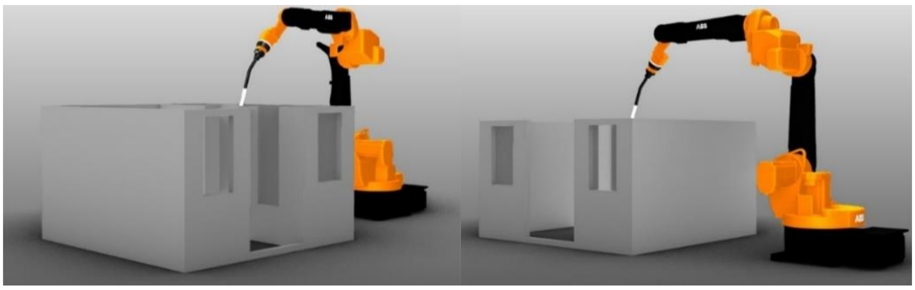


Figure 43 *Robotic arm printing system*
Note. Researchers draw their own, 2023

Table 4 *Equipment comparison data of 4 concrete printers, a D-shape printer, a frame printer, a gantry printer, and a robotic arm printer*

Features/Types	D-Shape	Framework style	Gantry	Mechanical arm
Structure type	Multi-dimensional framework structure, providing support for large-scale printing.	Featuring a framework structure, providing stability for the equipment.	Equipped with a gantry structure, it provides stability and support for the equipment.	The robotic arm structure provides flexibility and multi-directional motion capability.
Print range	Large printing range 12m*12m*10m	Medium printing range 2m*1m*1m	Large printing range 12m*12m*10m	Medium printing range, 5m*2.5m*4.5m
Accuracy	High precision, capable of achieving precise stacking of concrete layers. 10mm	Medium precision, able to meet the requirements of many building applications. 15mm	High precision, capable of achieving precise printing of complex structures.10mm	High precision, able to achieve precise printing paths and layer stacking. 8mm
Speed	Medium to slow speed 0-150mm/s	Faster 0-160mm/s	Medium speed 0-150mm/s	Faster 0-160mm/s
Applicable scenarios	Mainly used for building structures, sculptures, etc.	Mainly used for small and medium-sized building structures, walls, foundations, etc.	Mainly used for large-scale projects such as building structures and bridges.	Mainly used for small and medium-sized building structures, decorative elements, artworks, etc.
Manufacturing costs	High	Medium	High	Medium
Advantage	Large printing range, high precision, suitable for complex structures.	Stable structure, wide applicability, and relatively high printing speed.	High precision, suitable for large-scale projects, stable structure.	High flexibility, suitable for complex structures, and relatively high printing speed.
Disadvantage	High cost, large volume, relatively slow.	High manufacturing costs and limited applicability.	High manufacturing cost, large equipment volume, and slow speed.	The manufacturing cost is high, and the accuracy is limited by the structure of the robotic arm.

Note. Researchers draw their own, 2023

2.5.3 3D PRINTING CONCRETE REINFORCEMENT TECHNOLOGY

The key to 3D printing concrete optimization technology is combining computer-aided design with concrete materials and injection technology through machine automation processes and translating architectural designs into concrete structures(J. Wang, Zhang, Feng, & Cai, 2024). 3D printing concrete optimization technology aims to improve printing efficiency and printing quality and the feasibility of 3D printing concrete optimization technology.

Figure 44 *3D printing concrete technology diagram*
Note. https://www.cram.com/2023

Optimization of 3D printing concrete material formula is a critical factor in the printing process; optimizing material formulations can improve print performance and strength. By adjusting the composition, particle size, and fluidity of concrete, better layer adhesion, stability, and flow can be achieved, thereby improving the print quality. Optimizing printing parameters is an essential step in improving 3D-printed concrete. Adjusting the nozzle diameter and printing speed can control parameters such as layer thickness and temperature, print quality, and structural strength. Optimization of 3D printed concrete also requires consideration of structural design. Reasonably designing the structural form, internal support structure, and spatial layout can improve the stability of the building and the utilization of internal space. Reducing unnecessary overhangs and increasing internal hollow structures can reduce printing load and save materials. Path planning plays a crucial role in 3D printing concrete. Reasonably arranging the printing path and reducing the print head movement distance can improve efficiency and stability. In addition, mastering printing skills, such as controlling the nozzle posture, choosing the appropriate printing speed and nozzle movement method, print quality, and process control can also be improved. Optimizing 3D-printed concrete involves quality control and inspection mechanisms. Introduce sensors and detection devices and monitor the temperature, pressure, flow, and print quality during printing; you can adjust printing parameters and correct errors in time, ensuring print quality and consistency. Considering the cost and environmental sustainability of concrete slurries, optimization technology also involves recycling and reusing materials. Developing renewable concrete materials and recycling systems and reusing discarded materials can reduce costs and reduce waste.

2.5.4 APPLICATION OF 3D PRINTING TECHNOLOGY IN CHINESE ARCHITECTURE

Currently, China's prefabricated buildings continue the traditional construction model by transferring the cast-in-place work to factory prefabrication, and there is no qualitative change. With the rapid development of science and technology, 3D printing prefabricated buildings with digital models, 3D printing concrete technology has received widespread attention and application in the construction industry. 3D printing concrete technology, with its efficient, sustainable, and personalized characteristics, has brought an innovative change to the development of China's construction industry.

The application of 3D printing concrete technology in Chinese construction and disruptive technology has revolutionized China’s construction industry, Opening up new possibilities for architects and engineers. 3D printing concrete technology is processed through automated machines, able to print building structures quickly and efficiently, and the construction time is significantly shortened. This not only reduces the manual burden but also effectively lowers construction costs. They are providing housing solutions with good living conditions to more people. 3D printed concrete technology makes building construction more sustainable, with the ability to precisely control the amount of material used; waste is reduced. The limitations of traditional construction techniques often limit the realization of creative and complex structures. Through 3D printing concrete technology, architectural designers can achieve more complex and unique architectural forms and structures.

Figure 45 *3D printing construction case diagram*
Note. https://3w.huanqiu.com/a/667415/42PCtQdacA6, 2021

Currently, there are an increasing number of application cases of 3D printing concrete technology in Chinese construction; in an innovation park in the Shanghai Pilot Free Trade Zone, a curved office building was printed using 3D printing concrete technology; it shows the combination of future technology and art. Like these science and technology innovation parks, more and more people use 3D-printed concrete technology to build unique buildings. In a low-cost community called Sunroom in Hunan Province, China, dozens of tiny houses were built using 3D printing concrete technology, significantly reducing construction costs and providing residents with a high-quality living environment. 3D-printed concrete technology offers innovative solutions for low-cost housing projects in China. In terms of cultural architecture, this technology was used to print an exquisite and detailed garden building with cultural significance and artistic value in a traditional garden scenic spot in Zhejiang Province. Combining traditional and modern design concepts shows the charm of Chinese traditional culture. In terms of urban infrastructure construction, such as bridges in large Chinese cities, tunnels, and other structures, this technology can be used for quick, efficient construction, saving time and cost.

These cases demonstrate part of the application of 3D-printed concrete technology in Chinese architecture. With the continuous advancement of technology and the expansion of applications, more innovative cases will emerge, bringing more opportunities to develop China's construction industry.

2.5.5 CURRENT PROBLEMS IN 3D PRINTING CONCRETE TECHNOLOGY

China has made impressive progress in 3D printing concrete technology. Still, it faces challenges and problems that must be gradually solved through continuous research and practice. Equipment selection and equipment system design are essential key points. Current equipment could be faster in printing speed, limiting the efficient construction of large-scale buildings. The scale expansion of equipment also faces challenges; effective methods must be found to increase productivity. The accuracy and stability of the equipment directly affect the printing quality. Unstable equipment can lead to wastage of materials and poor bonding between layers, thereby affecting the overall strength and appearance of the building structure. Since 3D printing concrete technology uses a layer-by-layer stacking method, it may cause problems such as poor bonding between layers, cracks, etc., which may affect the structure's consistency and stability. Complex structures and details may be challenging to achieve accurately through layer-by-layer stacking technology, limiting design creativity and architectural geometry(Y. Chen et al., 2024). About 3D printing slicing software processing, slicing software plays a key role. Because the need to process large amounts of data may cause software performance to degrade, especially when dealing with large construction projects. In addition, file format standardization and compatibility may lead to problems with data transmission and processing. Slicing software must support complex building structures to ensure the accuracy and quality of the printing process. The construction process characteristics of concrete 3D printing technology require in-depth research and verification. One of the critical issues is the strength and durability of the structure. Sufficient experiments and practical applications are needed to verify. Construction safety is also an issue that needs to be re-examined to ensure the safety of workers and sites during the 3D printing construction process.

Regarding the entire construction industry, 3D printing concrete technology still needs to overcome some challenges. The development of standards and norms is necessary to ensure the safety and quality of technology. The construction industry needs to cultivate professionals with knowledge and skills in concrete 3D printing technology; this requires joint efforts from the education system and industry. With the continuous development and progress of science and technology, these limitations and shortcomings in all aspects will be gradually solved, bringing innovation and change to China's construction field.

2.6. DIGITAL DESIGN

The meaning of digital design is relatively broad. Since the 1970s, the introduction of computers and the digitization of design methods began, and CAD computer-aided design has developed rapidly. In actual design practice involving computer use, it is called digital design. In the 1990s, when architectural designers used computing software and algorithms to generate new architectural forms that no one had seen before, many people started cheering because it presented a new form of neighborhood; the architectural era of digital design was beginning. The latest generation of information technology, represented by the internet of things, big data, cloud computing, and artificial intelligence, is giving birth to a new round of industrial revolution. E-commerce has subverted traditional business models, social networks have put pressure on the conventional communication publishing industry, autonomous driving makes people look forward to the future of intelligent transportation, and Blockchain is reshaping the financial sector, in particular, the manufacturing revolution with intelligent manufacturing as its core is sweeping the world, become the focus of competition, such as Germany's Industry 4.0, the United States Industrial Internet, the United Kingdom's high-value manufacturing, Japan's Industrial Value Network, and the Made in China 2025 strategy, etc.

2.6.1 RESEARCH ON THEORIES AND METHODS OF DIGITAL ARCHITECTURAL DESIGN

The exploration of digital architectural design started the transformation of digital computing images into materialized actual construction; it is a smooth channel from digital design to digital construction. With the rapid development of computer technology, digital technology is widely used in various disciplines. Computers unify reality and virtuality, as well as humans and machines, time and space. Negroponte said in his book Digital Survival that computing is no longer just about computers; it determines our survival. The new 3D design software can quickly present non-orthogonal and non-linear shapes on the screen, and the NURBS modeling system allows architects to control surface modeling as soon as they can control European geometry. With those non-standard and complex graphics, from virtual graphics to the construction of physical entities, architectural designers seek the possibility of experimental building construction in novel forms.

An essential feature of the built environment in the digital age is the dispersion and reorganization of space; the dispersion and reorganization of space has caused some traditional building types and use spaces to shrink or even disappear; at the same time, other building types and use spaces have been strengthened and combined. Neil Leach said in his monograph Designing for a Digital World, published in August 2002, In the digital age, people have less and less need for fixed or designated spaces; what is more needed is electronic, interesting, diverse, and humane living spaces. The boundaries between different building types are becoming blurred; space becomes more multifunctional, a space with more depth, permeability, and continuity will meet the increasing density of communication, and a new dynamic system will satisfy accelerated structural reorganization and flexible space allocation at the same time, an open and uncertain environment that allows for real-time interpretation and borrowing will satisfy the transition from a command-and-control management style to a self-organizing style.

2.6.1.1 PHILOSOPHY OF DIGITAL ARCHITECTURAL DESIGN

In people's daily lives, People tend to ignore the most common natural phenomena by observing everything in nature; none of their shapes are regular. Most artificial objects are geometric shapes with regular rules; architecture is even more so. It may be that human science, technology, and production capabilities are limited; it may also be that Euclid's geometric theory greatly influences people.

Figure 46 *3D printing construction case diagram*
Note. https://www.cram.com/2022

In the mid-20th century, nonlinear scientific theories continued to be invented, breaking through the shackles of linear science on humans; people doubted the authority of Euclid's geometric system, and Products in non-standardized forms began to be produced. The establishment of fuzzy theory, chaos theory, dissipative structure theory, emergence theory, non-standard mathematical analysis, and other theories shows people the dynamic stabilized ordered structure far from the equilibrium state, revealing nature's rich potential for complexity, eliminating the binary opposition between time and space, showing the unified state of time and space, it celebrates a high degree of continuity and fluidity. Professor Xu Weiguo, in nonlinear architectural desiproposessing that buildings, like other artificial objects, are affected by these new scientific theories and begin to eliminate the shackles of regular and standard geometric shapes towards a nonlinear development path.

2.6.1.2 THE CREATION OF DIGITAL ARCHITECTURAL DESIGN

In 1988, Columbia University pioneered digital design; Bernard Tschumi, dean of Columbia University School of Architecture, using his unit structure education model at the British Architectural League, changed the structure of the college, using computer software technology and replacing tools such as paper, pen, ruler, etc., carry out architectural design, putting architectural design on the path of digital development. 1994, the Columbia University Graduate School of Architecture established the paperless design studio. They combine research and teaching, specializing in nonlinear digital design theory research and design. It mainly uses Maya's embedded language (MEL) as the programming language. Students must use (Cellular Automata, CA), L-system, Genetic Algorithmic (GA), and other theories used for design generation. Try to make connections between different things, use graphic language to express the internal logical characteristics of different things, and use models to explore the possibilities of form. Finally, the graphic language formed in the above process is transformed into a computer three-dimensional shape; each design studio has its personality and different design methods, and the possibilities of digital design are explored in various directions.

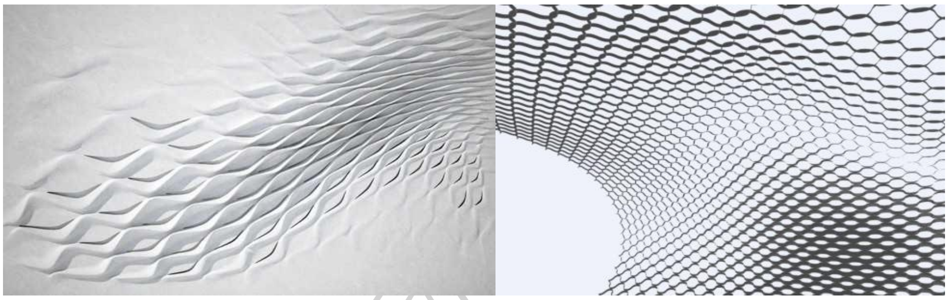


Figure 47 *Paperless Design Drawing*
Note. Researchers draw their own, 2022

In 2000, Peter Testa from the Department of Architecture at the Massachusetts Institute of Technology collaborated across disciplines with several computer experts to form a new matrix of disciplinary collaboration. Developed a plug-in Morphogenetic Surface Structure that uses the L-system to generate free-form surfaces; software development is based on Alias/Wavefront Studio software as the platform, based on MOSS, Peter Testa Emergent Design Group continues research into digital generative design, added genetic algorithm GA, improving connections between design methods through digital means, further emphasizing the combination with architectural design, In 2001, the GENR8 plug-in running on MAYA was launched. The Hemberg Extend Map L-system controls GENR8's surface generation. GENR8 introduces Grammatical Evolution based on genetic algorithms; this algorithm can generate program grammar and realize program evolution; architectural designers can export and analyze surfaces or modify the parameter environment at any time during the evolution process. This allows architectural designers to control the shape of the surface generated more effectively. He pioneered digital architectural design theory and methods.

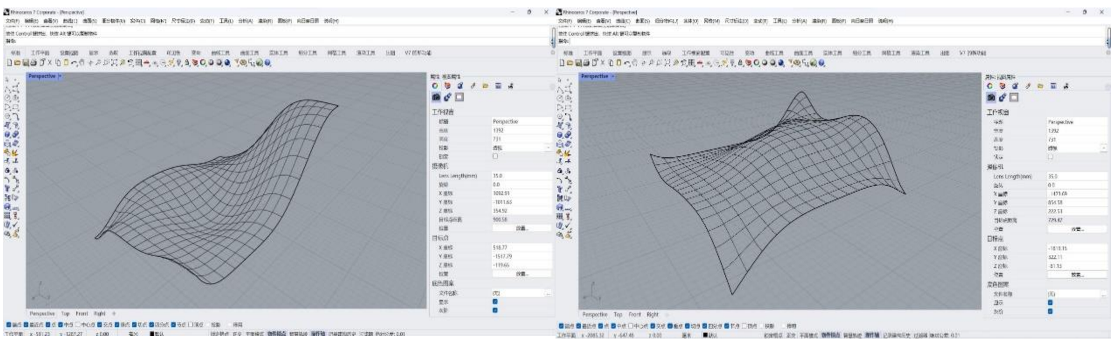


Figure 48 *Free form plot*
Note. Researchers draw their own, 2024

From December 2003 to March 2004, the non-standard architecture exhibition at the Pompidou in Paris displays built or experimental works by 12 international architectural design offices, shows the achievements of nonlinear theory in the field of architectural design and research, also showcases the construction industry that is being redefined.

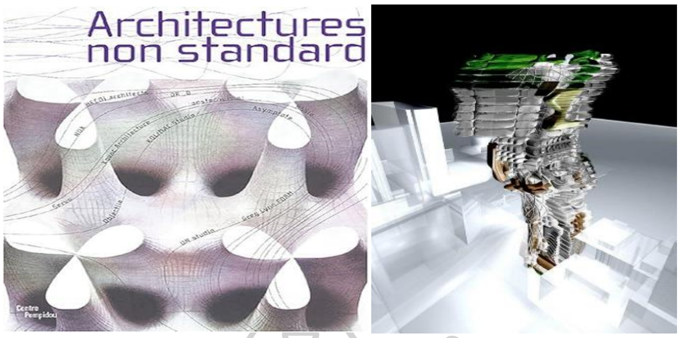


Figure 49 *Non-standard architecture exhibition at the Pompidou in Paris*
Note. https://www.abbs.com.cn/bbs/2023

From September 2004 to October 2004, Xu Weiguo, a professor at the School of Architecture at Tsinghua University in China, and Neil Leach, a British architectural theorist, co-curated the exhibition, an international exhibition of avant-garde architects' works titled Fast Forward, HotSpot, brain cells, the latest works of 12 pioneering architects who are currently the most influential in the international architectural community are on display. Not only was it the first time that China held a world-scale avant-garde architecture exhibition, but it was also the first time that this kind of non-standard architectural idea and work was introduced to the field of Chinese architecture.

Figure 50 *Tsinghua University Fast Forward, Hotspot, Brain Cells curatorial image*
Note. Photographed by the researcher, 2023

2.6.1.3 THE MATERIAL CONSTRUCTION OF DIGITAL ARCHITECTURAL DESIGN IN THE WORLD AND CHINA

In the 1990s, digital design still relied on algorithms and programs to generate virtual forms and the resulting graphics while having graceful features on the screen. Still, far from being a possible building, avant-garde architects were not only interested in morphogenesis but also turning to these generated complex forms to conduct physical construction research on material structure and structural performance.

British Architectural Association, School of Architecture, emerged as a technology group Semtech through teaching, research, and design practice, exploring how to comply with the structural diversity and performance variability of natural systems in design, research on forms that are suitable for the environment, form-finding methods, and behavioral characteristics of material systems related to CNC manufacturing, and under geometric or topological definitions, establishment of digital parametric models of material structures and production of full-scale models, etc. Explore the feasibility of irregular shape structures in actual projects. This research explores using biological structures as prototypes to illustrate biological tissue structures, analyze force characteristics through full-scale models, write a numerical parameter model of the structure and form, and use it as a design approach for nonlinear bulk structural systems. The 10th-anniversary pavilion of the Architectural League School of Architecture DRL is an example of the combination of digital design and CNC machining. The pavilion's form was determined through a rigorous process; it was built by directly cutting the structural ribs with CNC machine tools. The practice mentioned above of CNC construction and research on CNC construction methods fully demonstrate the possibility of realizing complex irregular architectural shapes with the help of digital production tools. Neri Oxman from the Media Lab of the Massachusetts Institute of Technology in the United States explores the relationship between the form, material, and structure of nonlinear bodies based on the structure of biological tissue. In 2007, Ni Xin's work Raycounting is a complex body of light and shadow in a specific environment.

Figure 51 *Pictures of Nixin's works*
Note. https://www.nipic.com/2023

The most representative digital architectural design project in recent years is the Beijing Phoenix Media Center hosted by Shao Weiping of the Beijing Institute of Architectural Design. The Phoenix Media Center project design uses the mathematical concept of the Möbius circle to generate a complex curved shell. Wrapping the magnificent atrium space, a structural steel diagrid supports the shell glass curtain wall. The Chinese entirely independently designed this project. China Construction Company CNC Machining and Construction, parametric modeling, BIM, 3D scanning, and other digital technologies were used throughout the process. The built result is high in completion and exquisite in construction quality, with features such as perfect building performance, and it has become a new landmark in Beijing. In addition, the

Qingdao Garden Expo service facilities designed by Wang Zhenfei Architects, Sichuan Niubei Mountain Volunteer House designed by Li Daode, Lanxi Pavilion in Chengdu, Sichuan designed by Yuan Feng of Tongji University, Shenzhen OCT Design Museum designed by Zhu Pei, the Foshan Art Village building designed by Song Gang, Hangzhou Alibaba Exhibition Center designed by Zhang Xiaoyi, Xiamen T4 Terminal designed by Lin Qiuda of Hedao Company, etc., they are all representative cases of digital architectural practice in my country.

Figure 52 *China Digital Architecture Practice Case Map*
Note. https://www.nipic.com/2023

2.6.1.4 THEORY AND METHODS OF DIGITAL ARCHITECTURAL DESIGN

Digital architectural design is inseparable from education, and its rapid spread worldwide is attributed to school education, media dissemination, exhibition displays, construction projects, etc. It started at Columbia University in the United States in the 1990s, organized teaching in the paperless design studio of Columbia Univethe city in the United States; almost every spring and autumn semester, more than 15 professors open design studios for students to choose from, and each professor's design topics are combined with their own research and design practice, and all have their different perspectives. Digital architectural design education in China began in 2003 with the non-linear architectural design course of Tsinghua University School of Architecture; this course takes ideas such as emergence, fractals, and clusters as the basis of design uses Rhino, MAYA, and other software as standard tools, explore design through material experiments, biological morphological analysis, site simulation, etc. How to find form after that, many domestic institutions such as Southeast University, Tongji University, South China University of Technology, Hunan University, and Xi'an Jiancheng University have opened design or technology courses related to digital design.

In 1993, Greg Lynn edited the AD magazine's special issue, folding in architecture; in 1995, he published Bubble in the Journal of Philosophy and Visual Arts and published the monograph Animate FORM, thus starting the research on digital architectural design theory and methods.

In 2004, Neil Leach edited and published Digital Tectonics; some papers explore combining digital design and construction.

In 2006, Reiser and Umemoto published the Atlas of Novel Tectonics. Combine the knowledge system you have established with architectural design examples and the vision of new construction is opened through scattered discussion.

In 2011, Mark Burry's book Scripting Cultures, Architectural Design, and Programming researched standard methods and technical routes of digital design. The digital design process also allows routine and repetitive work to be replaced by computers; designers can spend more time on design thinking.

The Autopoiesis of Architecture, published by Patrik Schumacher in 2011 and 2012, elaborates on a new parametric architectural style.

The most representative work in the field of digital architecture in China is the series of books co-edited by Professor Xu Weiguo of Tsinghua University and British architectural theorist Neil Lynch; hot spots, the think tank group, brings together international and domestic research results and design works from various periods in the field of digital architecture, it laid the foundation for the development of digital architectural design and research in China.

Based on learning from Western digital design ideas, Chinese researchers, considering China’s primary national conditions, look for theories and methods suitable for developing Chinese architectural design practice.

a. The combination of nonlinear system theory and digital architectural design. Euclidean geometry and Newtonian classical mechanics are no longer sufficient to explain diverse natural phenomena and complex artificial systems. As a result, a series of nonlinear systems and theories were born, such as fractal theory, chaos theory, cellular automaton, multi-agent, artificial neural networks, etc.

b. These include fractal theory, chaos theory, cellular automaton, multi-agent, artificial neural networks, etc. The acquisition and processing of information and information-based system control have become the core content of current natural sciences and engineering. It has also affected architectural design in many aspects.

c. The influence of Deleuze’s philosophical ideas on digital architectural design. Gilles Deleuze's philosophical concepts directly and profoundly impact digital architectural design. His philosophical concepts include Fold, Diagram, Striate & Smooth, etc. They have been repeatedly cited by architects and reflected in their works. Changed the way architects view and solve problems.

d. A theoretical study of digital Construction. The core idea of traditionally constructing Tectonics is that the building should express its structural and material construction logic. Digital Construction is its development and extension, the use of digital technology to generate architectural shapes in computers, and the Construction of buildings with the help of CNC equipment. Becoming is for actual Construction, and Construction should follow the generated logic. The final architectural form will express structural and Construction logic to the greatest extent; simultaneously, the results will express a new poetic quality.

e. Parametric architectural design and algorithmic prototyping. In the article Parametric Design and Algorithm Generation, Professor Xu Weiguo of Tsinghua University systematically explains the theoretical methods, implementation links, and design examples of parametric design and algorithm generation. The definition of parametric architectural design regards various influencing factors as parameter variables, and based on the research on the site and building performance, find the rules that connect the multiple parameters, then establish a parametric model, use computer technology to generate building volumes, space or structure, and can obtain multi-solution and dynamic design solutions by changing the values of parameters. It is one of the most essential theoretical methods of digital architectural design. Algorithmic modeling uses algorithms or rule systems, uses a specific computer language to describe the algorithm to form a program, and generates architectural prototypes through computer calculations; it is a specific technical means to realize the parametric design method.

f. Research on systematic methods for controlling errors in digital building design and construction processes. The difference between the designed form and the built building is the error; minimizing mistakes is a sign of high-quality Construction. Researching error control methods in the digital building design and construction process will help reduce mistakes and improve quality.

2.6.2 COMPLEXITY SCIENTIFIC ALGORITHM MODEL IN DIGITAL DESIGN

Complexity Science Algorithm Model in Digital Design Digital Design, using computers as essential tools using methods such as computer programming, can be based on theories from complexity science; models and algorithms are used to generate forms.

Complexity science is developed from system science; the research object is complexity and complex systems. In the 1940s, complex systems saw the birth of systems science, dominated by organizational theories such as systems theory, cybernetics, and information theory. It is the beginning of the development of system science. In the 1970s, systems science theories based on dissipative structure theory, synergy theory, catastrophe theory, and o, o and their organizational theories were born, and it became the second stage of systems science. In the 1980s, chaos dynamics, fractal theory, complex adaptive system theory, and complexity science theories such as open complex systems theory emerged and became the third stage of the development of system science. In addition, complex network theory, combination system theory, optimization theory, mathematical theory, etc., enrich the content of complexity science.

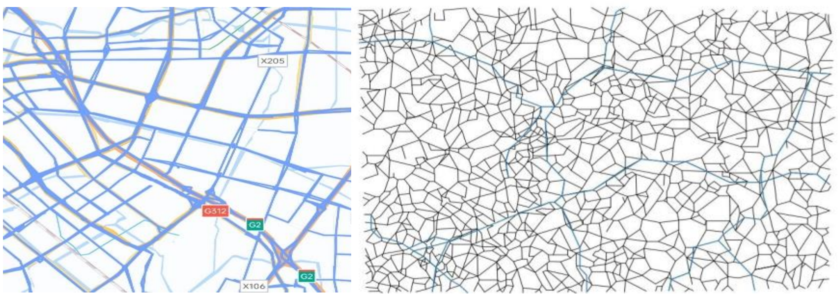


Figure 53 *Schematic diagram of complex network theory*
Note. Researchers draw their own, 2024

2.6.2.1 BIRD MIGRATION MODEL

The agent model of bird migration aims to simulate the cluster morphology of bird flocks during migration. During the migration of birds, the actual situation is more complicated; bird flight is a continuous process, and the interaction between birds also occurs continuously and affects the flight process, which constantly affects the actual flight of each bird. However, the above process has been simplified and changed during the simulation. First, the process of influence and change is discretized, dividing it into several time points. At these specific points in time, the current status of each bird is determined, and the reactions are accordingly. Secondly, the coping modes are also simplified into three types; that is, the three significant countermeasures are to avoid collisions, move in the same direction as neighbors, and stay close to the center of the flock. In addition, each bird in the flock is simplified to a point, thus completely ignoring the influence of the individual itself and only focusing on its position change in the flock. From a microscopic perspective, each bird in the flock is primarily concerned with its relationship with neighboring birds; its macro performance sometimes gathers and sometimes scattered birds, resulting from the continuous interaction between several monomers.

Based on the above principles, constructing a simulation algorithm for bird migration mainly includes five parts: generating an initial flock of birds, separating, aligning, approaching, and moving forward.

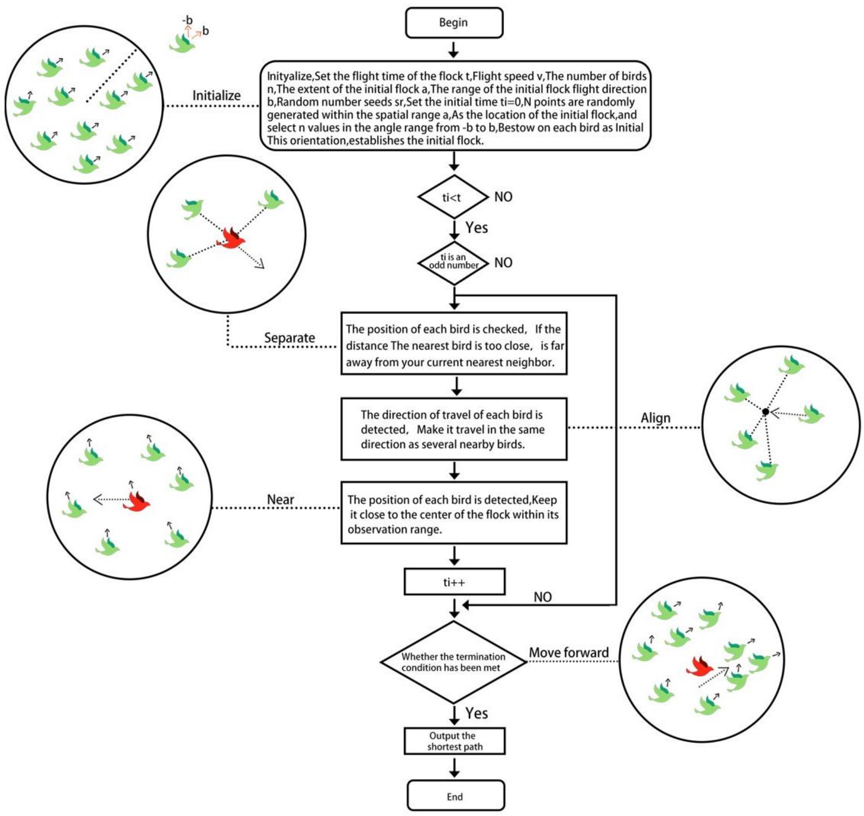


Figure 54 *Simulation algorithm and diagram of bird migration*
Note. Researchers draw their own, 2024

The model contains a large amount of data and rich dimensions, and different analysis results can be obtained from various angles. Therefore, the bird migration model generates morphology rather than directly using the simulated morphological results. Instead, you can use the data information in the simulation results to process it, and then the morphological generation results can be obtained. This result may show the characteristics of bird migration. Still, it may also be different from its morphological generation, which relies only on the simulated data results rather than the intuitive morphological results of the simulation. Therefore, the simulation results are processed differently, and different complex forms can be obtained.

2.6.2.2 CELLULAR AUTOMATA

Cellular Automaton is a computing model first proposed by Von Neumann and Ulam, using the concept of Cellular Spaces. These cells change state in discrete time steps through the same basic rules, as a realization possibility of biological systems, used to simulate the self-replication process of organisms. Cellular automata are widely used to simulate complex systems and natural phenomena, including physics, biology, sociology, and other fields.

The core content of cellular automata is the rules of interaction between units. The setting of rules is relatively free. As long as the basic rules remain unchanged, even without the influence of external conditions, only changes based on the two states of life and death, different initial shapes will also evolve into entirely different morphological results. For example, it will die if the unit cluster is used as the initial shape and has 1, 3, or 5 neighbors. 2, 4, and 6 neighbors survive as a basic rule; as time progresses, the body gradually grows and becomes spherical. However, different initial states will also produce different morphological results during the evolution process; in trying to find a natural transition between them, a cellular automaton was chosen as the biomorphic algorithm to generate this transitional shape.

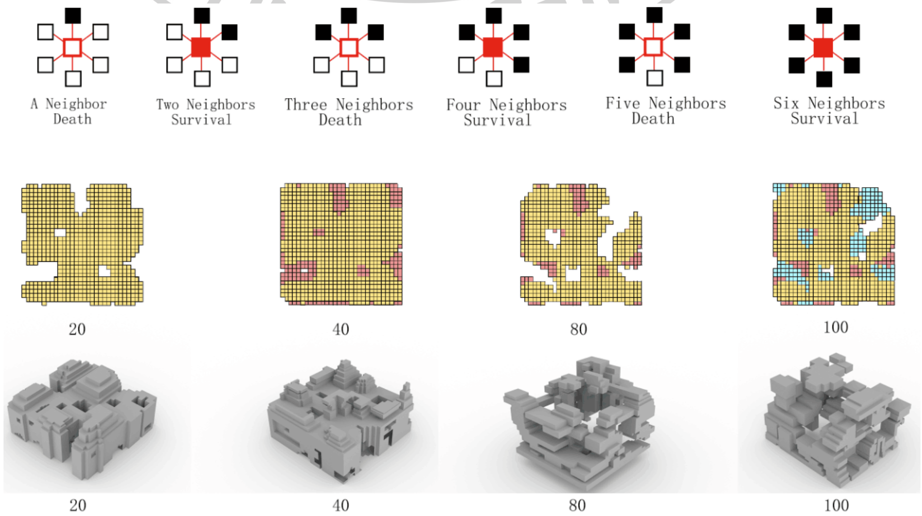


Figure 55 *Cluster processes in different initial states under the same basic rules*
Note. Researchers draw their own, 2024

Cellular automata provide a simple and robust method; complex overall behavior can be produced by simple repeated application of local rules; this helps us understand and study the dynamics of natural and artificial systems.

2.6.2.3 BEE HONEY COLLECTION MODEL

The bee nectar collection model involves interactions between individual bees, Environmental factors, and individual behavioral patterns. The bee nectar collection model is algorithmically more complex than the bird migration model or the ant colony algorithm. The bee honey collection model is similar to the ant colony algorithm but different. The honey-gathering model of bees can simulate the honey-gathering behavior of bees, and the simulation process can obtain a large amount of spatial information about bees and flowers. Further processing of these data can generate form. Different simulation models will produce different data results.

The bee honey collection model is a new intelligent optimization algorithm consisting of three parts: honey source, hired bees, and non-employed bees. The honey source is a feasible solution to the optimization problem; it is the primary object to be processed in the bee colony algorithm. The quality of the nectar source is the quality of the feasible solution; the amount of nectar evaluated in the source is the fitness. There is a one-to-one correspondence between the hired bees and the location of the honey source. Non-hired bees are follower and scout bees, providing nectar source information to select nectar sources and making greedy choices. Scout bees search for new nectar sources to replace their original nectar sources.

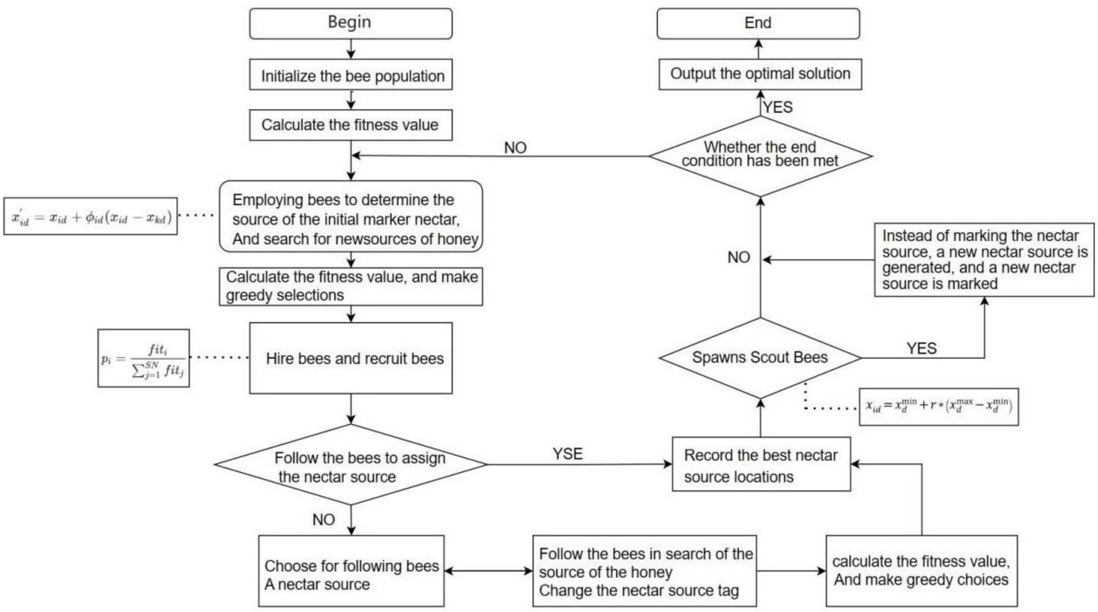


Figure 56 *Flow chart of honey collecting model algorithm for bees*
Note. Researchers draw their own, 2024

2.6.2.4 FIGURE

The graph is a standard computer science and mathematics data structure that represents the relationship between elements within a particular set. It can be used to construct polyhedrons or more complex spatial networks. It means a network and a structural relationship, and the types of graphs are infinite; each different network relationship can generate a corresponding graph. Based on the graph, the shortest path between two grid nodes can be found. Algorithms and operations on graphs help solve various problems, such as the shortest path problem, the minimum spanning tree problem, etc.

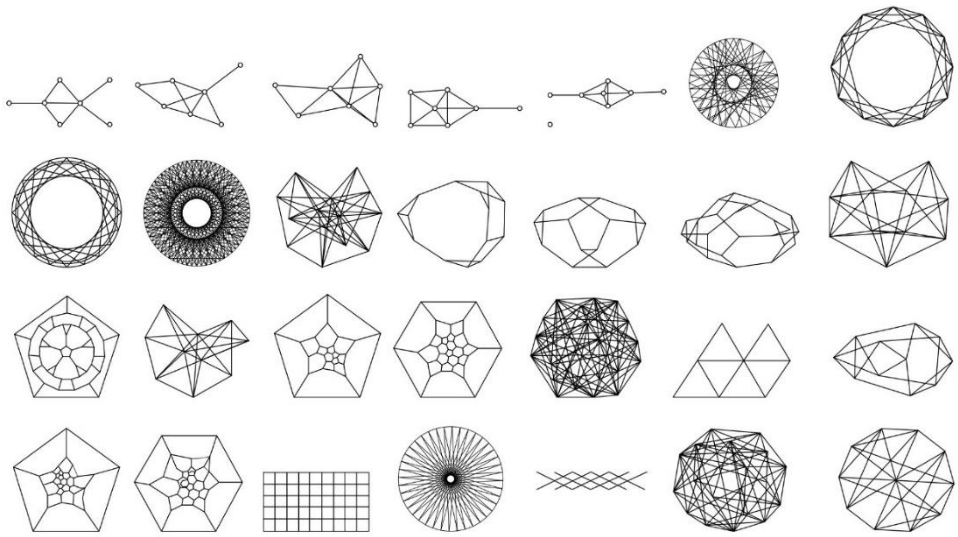


Figure 57 *A variety of diagram examples*
Note. Researchers draw their own, 2024

The morphological result based on the shortest traversal is a continuous curve; there is no self-intersection, and it is a closed curve, which may be a plane curve or a three-dimensional curve, depending on the distribution of initial points. The shortest traversal solves the morphological results.

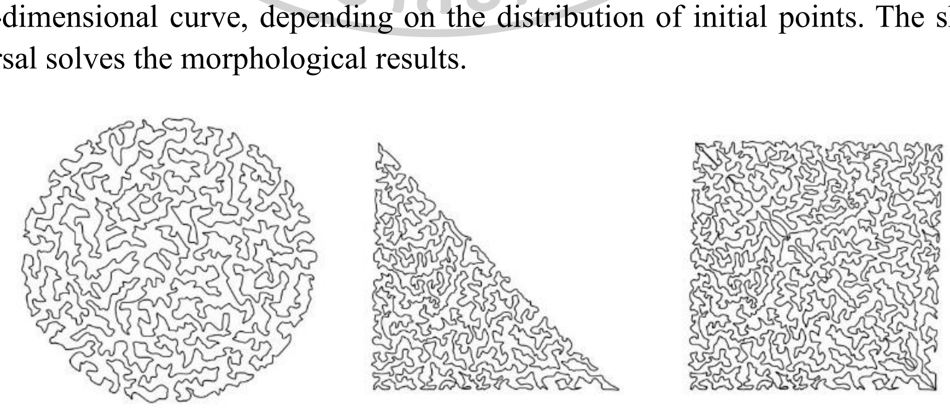


Figure 58 *The shortest traversal solves the morphological results*
Note. Researchers draw their own, 2024

2.6.2.5 STRANGE ATTRACTOR

Strange Attractor is an attractor with a complex geometric structure and has some hyperbolicity. Strange Attractor describes the trajectory of a system in phase space, showing a strange and complex structure. A Strange Attractor is a particular attractor observed in chaotic dynamic systems. This structure is usually aperiodic and cannot be described by simple geometric shapes or trajectory equations. Strange attractors are complex reflections in chaotic dynamic systems, mathematical structures of nonlinear behavior. Not all attractors are strange attractors; the simplest of these is to attract fixed points. For attracting fixed points, all orbits have the same asymptotic properties; therefore, they are not sensitive to initial conditions, and small changes in initial conditions do not affect their asymptotic results. The strange Attractor is different; small changes in initial conditions can significantly impact the results. In addition, the peculiar Attractor also has a fractal structure, and it exists widely in power systems. The strange Attractor can generate a series of shapes with a sense of circular motion; it can be used for the morphological design of construction sites or individual buildings. Multiple morphological results are superimposed through different attractors and parameter settings to form the site's overall form. When generating a building unit, the spatial curve based on the strange Attractor generates a linear structural skeleton and a planar building skin; the two combine to create an architectural form.

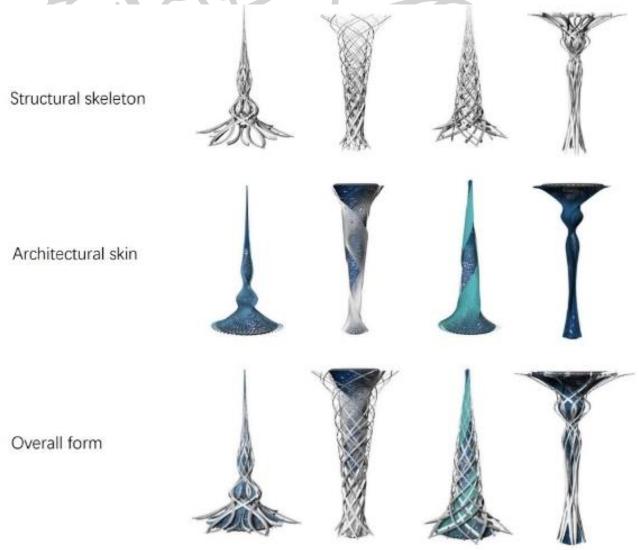


Figure 59 *Building blocks of strange attractors are formed*
Note. Researchers draw their own, 2024

2.6.2.6 SHORTEST PATH ALGORITHM

Algorithms for finding the shortest path include the Deegers algorithm, Floyd algorithm, SPFA algorithm, etc., and these algorithms focus on the final result; the application value for morphogenesis is small. The original ant colony path-finding model simulates the path-finding behavior of ants to obtain the shortest path. Its algorithm contains more data and is more suitable as a model for morphogenesis.

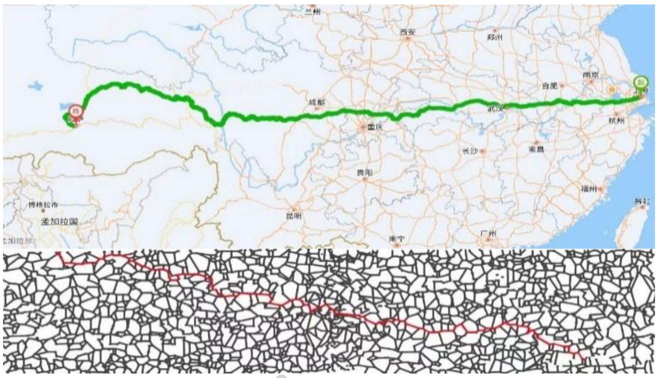


Figure 60 *Shortest path diagram*
Note. Researchers draw their own, 2024

In the most primitive ant colony model, how ants find their way, usually there are more than two ants of different lengths, and paths to food are available. In the initial state, the probability that ants choose various paths is the same, but ants that choose the shortest path can travel faster between food and their nest. Therefore, the frequency of round trips is higher. Ants also leave more pheromones along the shortest path than on other paths. This will affect the ant's choice; therefore, after some time, most ants will consciously choose the shortest path under the influence of pheromones, thus completing the self-organizing process.

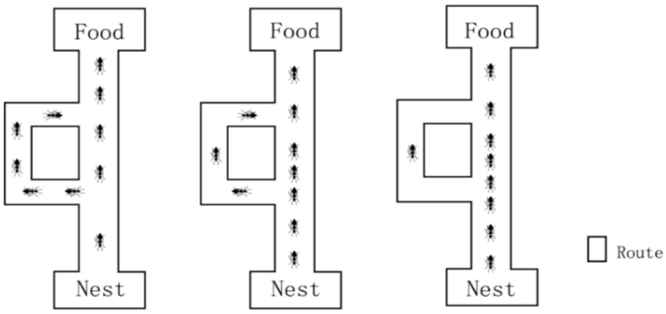


Figure 61 *A simulated map of ant colony pathfinding*
Note. Researchers draw their own, 2024

2.6.3 COMPUTATIONAL SIMULATION OF BIOLOGICAL FORMS

The study of biological forms by architectural design scholars is not like the scientific exploration of biological forms by biological scientists; architectural research is, to some extent, more valuable than the design profession; its primary interest is in biomorphic forms, the internal structural relationship of biological body and biological form, the laws of biological morphogenesis and development, biological dynamic behavior trajectories, etc., the forms displayed by these biomorphs have endless appeal for architectural design and Provide rich form creation prototypes for architectural design.

The core of computational simulation is an algorithm or rule system. The algorithm describes the characteristics of the form to be generated, and algorithms determine the results of morphologies generated through calculations. Therefore, if the design firm is to be generated by borrowing biological form, first, we need to identify the characteristics of biological forms and embody these characteristics in the algorithm, then write the algorithm into the program through calculation and graphics with specific biomorphic characteristics that can be generated. The program can simulate biomorphic prototypes, and new design shapes can also be generated based on different conditions. Therefore, the computational simulation of morphology mainly lies in studying morphology algorithms and algorithm-by-algorithm case studies through varying levels of morphology; finally, a biomorphic simulation algorithm library can be established.

Biomorphic design simulation, starting from the observation and recording of biological forms, uses language to describe the characteristics of biological forms, uses analysis diagrams to represent its characteristics, creates algorithms and writes algorithms into computer programs, runs the program through the computer, generates simulated biological forms, and use this program to generate architectural design shapes. Forms of simulation will be developed from this process.

I am taking the phyllotaxis of plant organ morphology as an example, algorithmic research into biomorphology, and the process of using digital graphic design methods for architectural design. The phyllotaxis is divided into alternate phyllotaxis, opposite phyllotaxis, whorled phyllotaxis, and clustered phyllotaxis. Alternate phyllotaxis means one leaf grows on each node, born through interaction. Opposite phyllotaxis means two leaves growing on each node, born relatively. Whorled phyllotaxis is three or more leaves growing on each node, radiating arrangement. Clustered phyllotaxis is the growth of leaves in clusters on short branches(Yu, Zhang, Zhang, & Han, 2023).

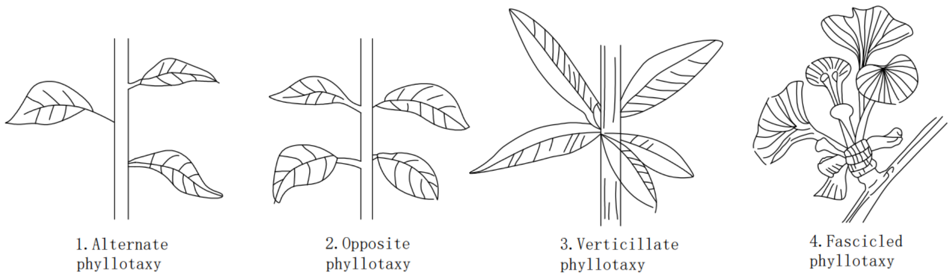


Figure 62 *Leaf order morphology map*
Note. Researchers draw their own, 2024

The morphological characteristic of alternate phyllotaxis is that one leaf grows on each node; the plane projection angle between adjacent leaves is 137.5º; observed on a flat surface, The leaves form two sets of Archimedean curves in opposite directions; the number of adjacent two-term curves in the two sets of Fibonacci numbers is regular, The spiral coil formed by the leaves and the number of leaves growing in the coil are also regular, It can be represented by two adjacent terms of the Fibonacci sequence.

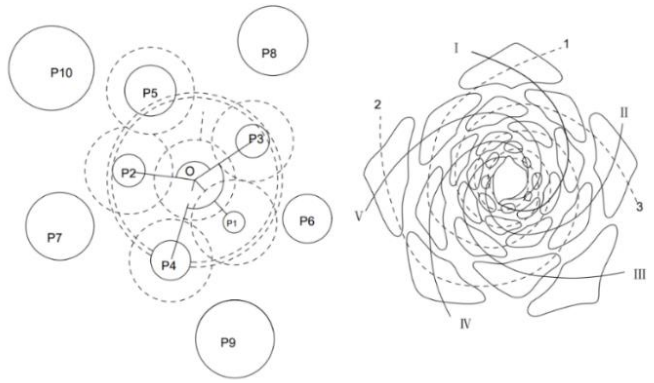


Figure 63 *Morphological analysis of alternate leaf order*
Note. Researchers draw their own, 2024

If you use a program to implement the morphological algorithm of alternate phyllotaxy, it can be implemented using various software or computer language programming. Rhinoceros' built-in Python language programming is one of these methods.

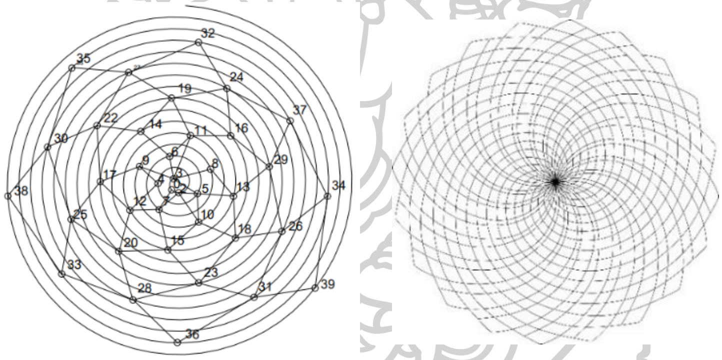


Figure 64 *Alternate leaf order morphology of Archimedes spiral linear calculation simulation*
Note. Researchers draw their own, 2024

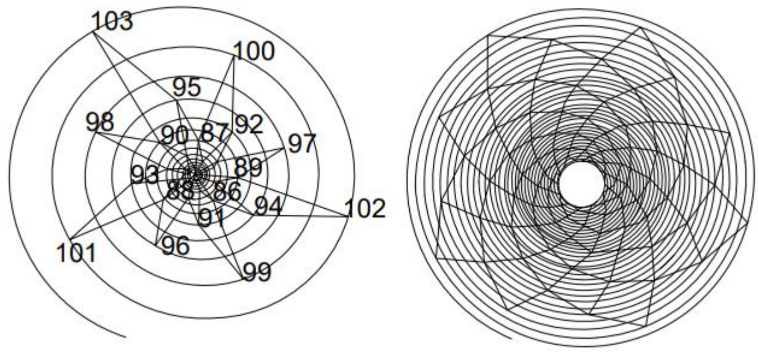


Figure 65 *Simulation diagram of logarithmic spiral linear calculation of alternate leaf order morphology*
Note. Researchers draw their own, 2024

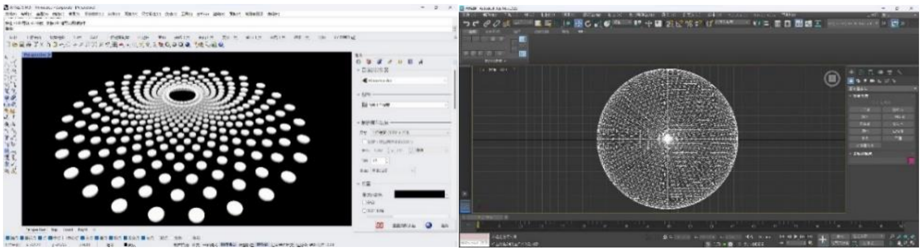


Figure 66 *Alternate leaf order morphology was calculated to generate the shape map*
Note. Researchers draw their own, 2024

Figure 67 *Alternate leaf order morphology was calculated to generate the construction form map*
Note. Researchers draw their own, 2023

2.6.4 DELEUZE’S PHILOSOPHICAL THOUGHT AND DIGITAL DESIGN

Gilles Deleuze graduated from the Philosophy Department of the Sorbonne University in Paris. Deleuze's classic anti-philosophy theory aligns with the development of nonlinear science in the same period; Deleuze's philosophy can be called a new nonlinear philosophy. Deleuze's theories have become the bible of today's architectural designers. Gilles Deleuze created a series of distinctive poststructuralist philosophical and aesthetic concepts. He is a nomad in the realm of ideas. There is a natural fit between Gilles Deleuze's thought and digital architecture. It has important implications for the development of architecture as a whole.

2.6.4.1 DELEUZE’S PLEAT THOUGHT

Gilles Deleuze's creative interpretation of Monadology by G. W. Leibniz, 1646-1716, combined with the Baroque style, Developed and perfected the important pleat French Pli, English Fold concept and was published in the book The Fold, Leibniz and the Baroque in 1988, this concept also leads to the idea of nomadism. Monads and folds and their nomadic thoughts explain the unity of one and many and how the world is constituted, manifold, automaticity, etc. Deleuze coined the concept of pleats; for Deleuze, folds are everywhere, everything in the world contains folds, there are wrinkles everywhere, and some things can fold, unfold, and cycle over and over again; things are also composed of monads spiraling into pleats. It cannot be seen as just a fold of reality; it represents several philosophical characteristics. We need to have an overall understanding of pleats by understanding their characteristics.

Pleats have broad universal principles. Gilles Deleuze believes that as small as the microscopic world, as big as the universe, there are wrinkles everywhere; it is not an ordinary pleat of clothing or fabric; it’s an image; it symbolizes the coexistence of differences, universal harmony, and overlapping, folds are difference and repetition.

Deleuze's pleats influence contemporary architectural designers; they play a vital role in the research and practice of digital architecture in today's world. A large number of architectural offices and architectural design companies present Deleuze's pleated philosophy in architectural practice.

The idea of wrinkles is one of Deleuze's core concepts. The architectural intention of pleated thought is a response to the cyclic theory and infinity theory in pleats; Deleuze says that the pleats of pleats are only possible in Baroque architecture. Professor Xu Weiguo of Tsinghua University said that the size and performance of buildings in reality are limited, and Architecture can never fully achieve actual infinity. The wrinkles in architecture express the hierarchy and shape changes of architectural space to meet contemporary society's ideological, cultural, and information needs.

2.6.4.2 DELEUZE’S NOMADIC SPACE

Gilles Deleuze is the creator of nomadic thought; even the concepts he writes about are nomadic. Nomadic space corresponds to his nomadic thoughts; while discussing nomadic space, he proposed smooth space and striped space; both spaces define the characteristics of nomadic space. Nomadic thought reflects anti-thought, opposing rationality and advocating pluralism; it resists the universal thinking subject and allies to specific individual races. It no longer resides in the ordered interiority, free movement among external elements. Nomadic thought rejects a universal thinking subject. Instead, it allies itself with a single race. Nomadic space has multiple attributes: dynamic, smooth, continuous, multiple, abstract, multi-tactile, multi-dimensional, heterogeneous, topological space. The nomadic space of the building shows a dynamic and possibility; there is no room for specific and clear goals, no predetermined structure, and no stated purpose. The nomadic space of architecture is an irrational space. But it can be controlled through rational analysis. It emphasizes human emotional factors and respects people’s emotional changes, which can be reflected in the state of space. The nomadic architecture space emphasizes difference and generation; nomadism is becoming, and nomadism aims to eliminate strict symbolic restrictions. The complex relationships between people make nomadic spaces complex, dynamic, and diverse.

2.6.5 PARAMETRIC DESIGN METHOD

Parametric design is the product of parametric design and digital technology; they are all based on digital modeling technology; parametric design is obtained through computer software calculations and building parametric models. A parametric software model is an overall logical relationship system that uses parameter variables to control the model's shape; various factors and parameters that affect the model's shape are linked together through a rule system or algorithm. Different rule systems can build different model forms; when changing the input value of a parameter, the model's shape generated by the calculation will change. The input parameters can be numerical values, and they can also be graphics.

Parametric design methods have been used in architectural design in the early days before the advent of computers. At the end of the 19th century and the beginning of the 20th century, when Gaudi was designing the Guell Church, determine the shape of the church vault through the catenary physical model, adjust the length of the rope, the weight of the suspended object, a series of data such as the position of the fixed point, produces results consistent with the morphological gravity relationships of church vaults. In this design process system, the length of the rope, fixed node position, the weight of suspended objects, etc. These are variable parameters, and the invariant parameter is the specification wire of the rope material, the fixed node knotting method, the material of the suspended object, etc. Therefore, the foundation of parametric design is the design of variable parameters. Constant and variable parameters control the design process to change the design results. Mark Burry, a professor at RMIT University in Melbourne, is the architectural director of Sagrada Família. He has a very in-depth study of Gaudí's designs, and he believes that although it is not clear whether Gaudí was influenced by mathematicians and scientists who studied parameterization, traces of parametric design methods can be seen in Gaudí's built projects.

Figure 68 *Gaudi designs the church of Gouel*
Note. https://m.mafengwo.cn/i/2883687.html/2022

2.6.5.1 PARAMETRIC DESIGN MODEL CODING METHOD

The generation of buildings is diverse; there is a geometric composition from the building itself, functional requirements, rules required for streamlining analysis, etc.; there are also other bionic forms of systems, microstructural or algorithmic transformation rules. Therefore, the encoding methods used by different parameterized models are also different.

Christopher Alexander's Formal Synthesis proposes that a design problem can be decomposed into a series of sortable sub-problems, and the design work is completed by solving these sub-problems. Based on the design process, this approach is the earliest way of encoding parametric models. Stiny proposed the concept of formal grammar Shape Grammar, which defines the rules that describe the transformation of one form into another. According to formal syntax, a specific architectural form can be generated by specifying a series of regulations for form transformation and solving a series of design sub-problems sequentially. Wright-style prairie houses, Palladian classical architecture, Siza-style independent houses, Chinese wooden structures, etc., these cases are researchers trying to use a series of parametric models, decompose the design problem into a series of process-orderable sub-problems, automatically generate specific architectural shapes, they are all modeled based on the parametric model coding method of the design process.

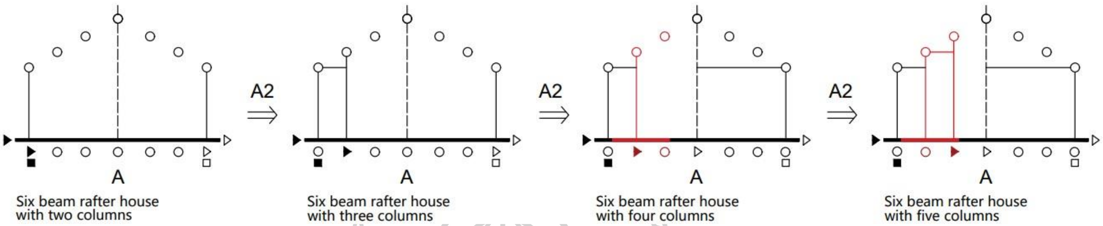


Figure 69 *Chinese wooden structure architectural drawings*
Note. Researchers draw their own, 2023

2.6.5.2 DIGITAL DESIGN MODELS BUILD LOGICAL METHODS IN PARAMETRIC SOFTWARE

There are currently many parametric software platforms; mainstream parametric software is object-oriented, and different levels of development, operating interfaces, and construction logic are also other; the more typical ones include process relationship logic, model tree hierarchical logic, and primitive association logic.

The process relationship logic in parametric software is a set of commands corresponding to a series of sequential steps in the geometry modeling logic. Software commands include input ports and output ports. The input port is mainly used to input the constituent elements of the geometry and related parameters, and the output port mainly displays geometry and related geometric attribute information. The entire process involves parameter definition of many geometries, and when the parameters are modified, the geometry changes accordingly.

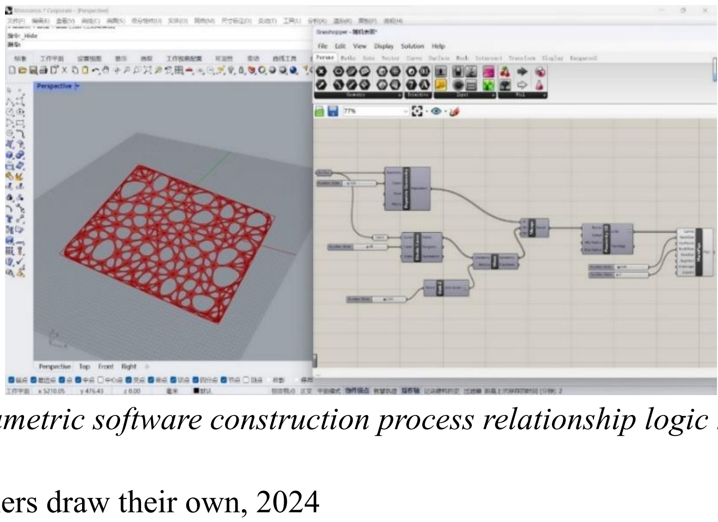


Figure 70 *Parametric software construction process relationship logic method diagram*
Note. Researchers draw their own, 2024

Parametric software model tree hierarchical logic is in the software modeling process, using a tree-like branch structure relationship, expanding layer by layer to construct the geometric model. Rhino BIM plug-in was developed on the Rhino software design platform, and CATIA developed digital Project DP. It is managed according to tree hierarchical logic.

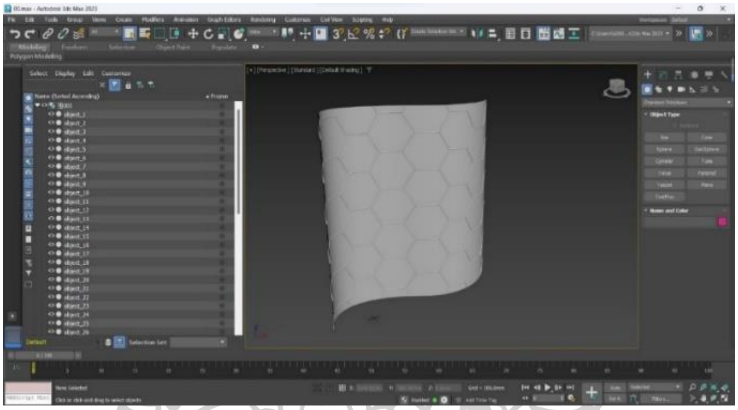


Figure 71 *Parametric software construction model tree hierarchical logic method diagram*
Note. Researchers draw their own, 2024

The parametric software construction element association logic is a set of modeling methods specially customized for architectural construction in Revit. The logical organization structure of all geometry in this software is based on building construction logic; there is no need for various geometric information and operation processes in process panels and tree structures. Because the axes, walls, doors, and windows are part of architectural design, components such as structures directly face users through graphics elements. Geometric logic is hidden in the definition of building components.

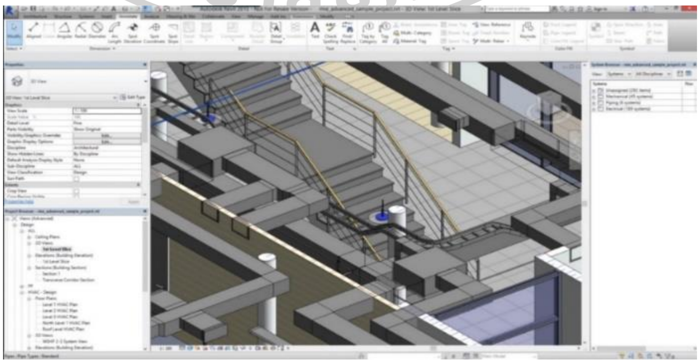


Figure 72 *Parametric software construction diagram element association logic method diagram*
Note. Researchers draw their own, 2024

2.6.5.3 PARAMETRIC ARCHITECTURAL SCHEME DESIGN CONTENT IN ACTUAL PROJECTS

Standard parametric architectural design is realized through the digital design process. Connect the digital architectural plan design process, from conceptual and preliminary to detailed design. Then, we went to the various stages of construction drawing design. Design using digital tools and computer software technology ensures a seamless connection between all design stages and provides accurate digital design and CNC processing models for parametric building materiality realization.

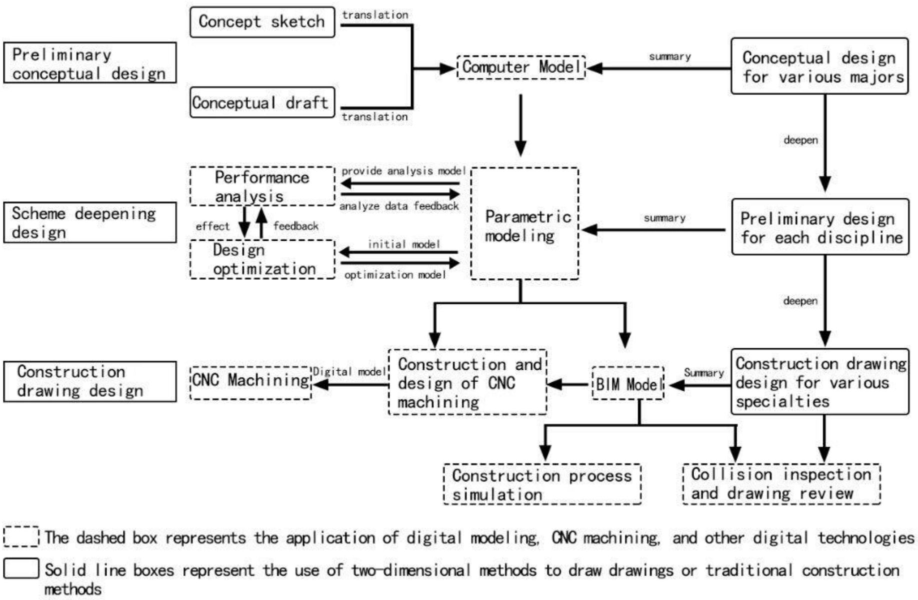


Figure 73 *Digital architectural design flow chart*
Note. Researchers draw their own, 2024

Parametric modeling is the most crucial step in digital architectural design. All work in the design phase is carried out around parametric models. Parametric modeling has three core steps: parameter translation, establishing constraints, and establishing relationships. Parameter translation translates the factors that affect the design into computer-readable data or graphics, and inputs into parametric models influence the design. There are many ways to translate parameters, mainly through programming and simulation. Establishing constraints is to establish the relationship between graphics and graphics. When modeling, establish limitations on the outer surface of the wall and the outer surface of the column; no matter how the position or shape height of walls and columns changes in space, the outer surfaces of the wall studs are all aligned. Establishing associations is establishing connections between graphics and data. For example, establishing a relationship between the size of epidermal openings and the amount of solar radiation, the higher the radiation dose, the smaller the windows, the lower the radiation, and the larger the windows. Use this to establish the principle of association when designing the texture of the epidermis.

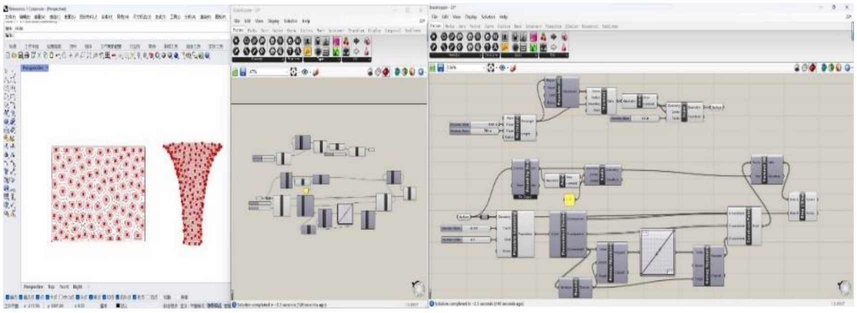


Figure 74 *Parameter translation association diagram*
Note. Researchers draw their own, 2024

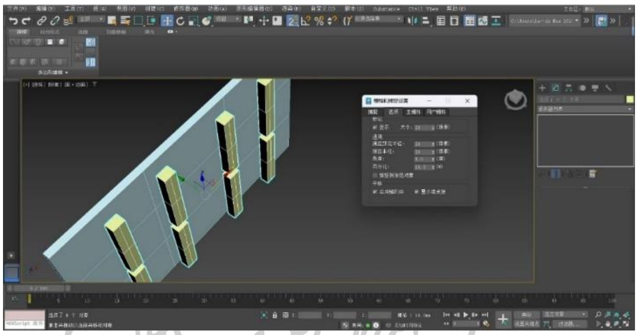


Figure 75 *Create constraint diagrams for the outer surface of the wall and the outer surface of the column*
Note. Researchers draw their own, 2024

Figure 76 *Correlation diagram between epidermal openings and solar radiation amount*
Note. Researchers draw their own, 2024

Through parameter translation, establishing constraints, and establishing associations to build a parametric model, the design results can be changed by adjusting parameters; in this way, the parameterized model data and graphics, graphics, and graphics are interrelated and constrained, so when changing the value of a parameter, parametric models will change in conjunction with each other. This enables design optimization and comparison and selection of multiple solutions.

Table 5 *Commonly used parametric design software*

Software Name	Development Company	Practical type	Software features and application content
Rhino& Grasshopper	Robert McNeel		Simple to operate but complete, it is suitable for architects to carry out simple

Microstation & Generative Components	Bentley	Parametric 3D modeling software	programming to build parametric models and has good applicability in the process of shape finding, simulation and analysis, design optimization, and digital model output. This method connects CAD/ CAE/ CAM design, analysis, and machining in series.
Processing	MIT	Visual progrramming language platform	A new open-source computer language with a simple syntax and strong graphical visualization capabilities, where programs uploaded to the web by other designers can be downloaded and modified, suitable for use by architects for simulation and building shape finding.
MAYA	Autodesk	Parametric modeling and rendering software	Very powerful and convenient sculpture modeling capabilities, mainly used for architectural shape finding, through the embedded Mel language can be programmed to generate more complex forms. Rendering fractionation at a later stage.
3Dmax			The most commonly used 3D modeling and rendering software in the past, very powerful and convenient sculpture modeling capabilities, mainly used in architectural shape finding, rendering, and animation.

Note. Researchers draw their own, 2024

After the digital building performance simulation results are completed, it is necessary to enter a design optimization stage for the architectural plan. Design optimization reduces the difficulty of building construction and improves construction quality; it plays a crucial role in controlling costs and construction schedules. The digital building performance simulation results should be accurate to the built form; Functions should be optimized. Correlate the data results obtained from building performance simulations with the form of building components and change the shape of components through data drive, achieving better building performance. In traditional design and performance simulation methods, multiple plans are usually created manually. The optimal solution among these solutions is selected through performance simulation, but this method may need to include the optimal solution. However, if the parametric design method is combined with the genetic algorithm, the optimal solution can be found directly by computer. Design optimization for construction, subdividing complex surfaces through parametric programming, adjusting the shape of the surface, refining subdivision units in terms of material and process selection, shape optimization design, component optimization design, connection node optimization design, corner optimization design, etc., a vital link to improve construction accuracy, CNC processing, and construction under the requirements of reducing building construction costs and shortening the construction period.

Software parametric models bring flexibility to architectural design to meet the requirements of the organic characteristics and dynamic continuous complexity of the design process; when the size of the parameter changes, it can be used on existing parameter models, change input information to get new results, in this way, the design results become controllable. Computer parametric design provides an abstract modeling machine; it allows the design process to be repeated repeatedly with constant feedback. You can enter different conditions to get multiple results, and Design results can be modified numerous times; this cannot be done manually. The rule system and the language for describing rules in the parametric design process, software parameter model, parameter variable, and the generated shapes are all visible; it is a logical and controllable scientific design process.

To summarize the above, according to the digital construction design book by Professor Xu Weiguo of Tsinghua University, Digital Architectural Design Theory, and Methods, it is concluded that the parametric architectural scheme design process includes six key links.

First, the design requires the digitization of information.

Second, the establishment of design parameter relationships.

Third, the establishment of a software parameter model.

Fourth, the evolution of the design prototype.

Fifth, the final design of the parametric structural system and construction logic of the form.

Sixth, testing and feedback on design results.

2.6.6 DIGITAL DESIGN DEVELOPMENT TRENDS

Digital design can be understood as a digital design oriented to the design process, a further extension of digital design. Digital design surpasses the function of computer-aided design in the internal logic of design and shows the inner workings of the design process. China's construction industry must seize the historical opportunities of the new round of scientific and technological revolution, deeply integrate modern information technology with engineering construction, with greening as the construction goal, industrialization as the industry path, and intelligence as technical support, improve the construction and management level of the construction industry, from the extensive form, fragmented construction methods move toward refinement, transformation, and upgrading of integrated construction methods, achieve high-quality development of engineering construction.

2.7. CASE ANALYSIS INTERNATIONAL MEDIA CENTER, BEIJING DAXING INTERNATIONAL AIRPORT, WATER CUBE

2.7.1PHOENIX INTERNATIONAL MEDIA CENTER

Phoenix International Media Center is the headquarters of Phoenix TV in Beijing; it was designed and built against the background of the most rapid urban development in China. Phoenix International Media Center shows a new direction in Chinese architectural creation. There were many good buildings before, and most of them are based on history and culture. Getting inspiration and enlightenment from tradition, the foothold and directionality of the design of the Phoenix Center are entirely different. It meets the needs of modern social life.

Phoenix International Media Center is located between the third and fourth rings in northeast Beijing, in the southwest corner of Chaoyang Park. The construction land is irregularly shaped, and the location is located at a non-orthogonal urban road intersection. To the east are the park’s natural vegetation and water. On the north side is a 20-story early high-end residential building in Beijing. On the south side, you can overlook the constantly renovating Beijing CBD; with the new development of Beijing CBD, the geographical location shows its superior and scarce location advantages.

Figure 77 *Map of Phoenix International Media Center and area map*
Note. https://www.bing.com/2024

The clues contained in the site became the beginning of the design. Specific terrain environments and new architectural forms need to be imagined, dilute the sense of direction of the building, and design an intimate spatial form. Let the rounded and blurred form adapt to the characteristics of urban blocks and natural forms; it has become a harmonious urban landscape in Chaoyang Park and Beijing. The shape of the building and the irregular road direction, the corner, and the park should form a harmonious relationship. Therefore, phoenix International Media Center starts from the research environment, the logic of the overall design; it has an ecologically functional shell with a rounded and unique wrapping space, and developing and advancing along this design direction creates a large number of interactions full of dynamics and vitality, shared public experience space. Let the architecture, environment, and participating public form a natural blend of urban space atmosphere. As a result, the Phoenix International Media Center has evolved from a traditional media building into a cultural building open to the public, really letting the architecture take root in urban places and make an essential contribution to the quality of Beijing city.

Phoenix TV is one of the most influential Chinese-language media in the world. Phoenix TV takes innovation, openness, and integration as its core corporate values; it is an information link connecting Chinese people worldwide. Its programs have covered 75 countries and regions in Asia-Pacific, Europe, America, and North Africa. Phoenix Center is the headquarters of Phoenix TV in Beijing; after completion, it will realize the integration of Phoenix TV's resources in mainland China, echoing the Phoenix TV headquarters in Hong Kong, China.

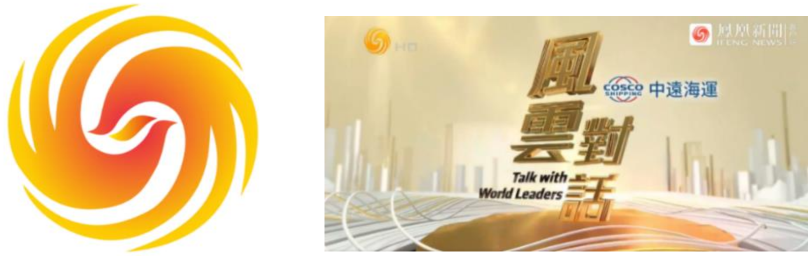


Figure 78 *Phoenix TV logo/ Phoenix media column*
Note. https://pic.ntimg.cn/2008-03-06/200836104855511_2.jpg,2024

The architectural design creativity of Phoenix International Media Center comes from the Möbius strip in mathematics. The design concept of the Möbius strip is not to find some formal symbol attached to the building; instead, I hope to convey the more profound meaning in Mobius, based on the world view of yin and yang in Chinese culture, combined with the most contemporary topological space shaping techniques, the essence of Chinese culture, explained using cutting-edge international space and technical means. Always in motion, never stop, full of changes, the appearance is like a bird's nest, it means the phoenix's nest. Mobius's positive and negative morphological characteristics and repeated cycles are innovative in Phoenix TV's open and integrated corporate culture. The Phoenix Center uses the continuous form shaped by the Möbius concept, integrating the towering main office building and the low studio podium into a whole; a large number of public spaces are formed between the continuous roof and the two functional bodies, this is the contribution of design creativity to future public event opportunities. To embody Phoenix Media's philosophy of open innovation, many visiting experience spaces open to the public are built into the design, inadvertently forming a very open experience environment. Let the architecture, environment, and participating public form a natural blend of urban space atmosphere. As a result, the Phoenix Center has evolved from a traditional media building into a cultural building open to the public. Since the completion of the Phoenix Center project, we have received visitors from all over the world almost every day; no one can fail to marvel at the magical charm of architecture. Phoenix Center has become Beijing's most famous fashion center; the world's and China's top fashion brands have chosen Phoenix Center as their new product launch venue.

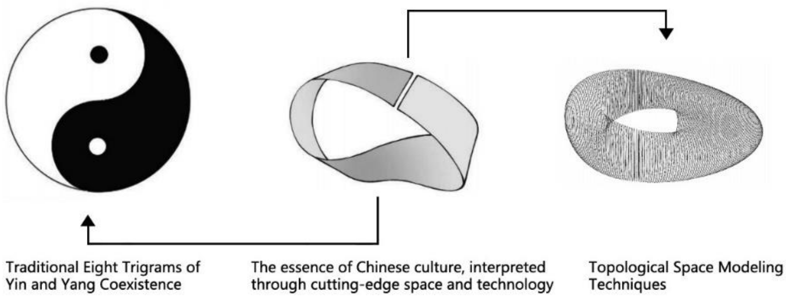


Figure 79 *Phoenix International Media Center design idea source map*
Note. Researchers draw their own, 2024

The twisted steel and aluminum plates of Phoenix International Media Center are integrated into the solid curtain wall part; the 8,000m-long steel structural ribs follow a path defined by high-order curves, precisely outline complex architectural geometries, their rotation angles, spatial positions, and floor supports are all the same. The glass curtain wall part between the solid curtain walls comprises 3180 glass curtain wall units; all units contain hundreds of thousands of components and continuously expand along the gaps between them; their size and spatial location are also the same. The same organizational logic controls all these seemingly diverse details. Controlled diversity not only brings a richness that traditional architecture never displays but also conveys the complexity of architectural design results from a more profound, invisible level. The Phoenix International Media Center has become a world-class benchmark for today's digital construction technology. As pointed out in a signed review article in Architect magazine, the journal of the American AIA Association, the Beijing Phoenix Center, completed by a local Chinese architect, proved that Chinese architects had entered the international stage, sending a signal of the transformation from Made in China to Create in China, it means that the baton of modern architectural innovation has been passed to the Chinese people. Ban Ki-moon, the then Secretary-General of the United Nations, once lamented when he visited the construction site, the Phoenix Center allowed him to see the future of architecture.

Figure 80 *Phoenix International Media Center renderings*
Note. Researchers draw their own, 2024

Corbusier once said that architecture is a manifestation of willpower, and design is to create an order. We have always felt that such words are still practical for us when doing architecture in the current context. In the Phoenix International Media Center project, we want to use a more advanced means to establish an order for architecture, make buildings more in line with people's needs, and better satisfy a holistic need for beauty; this is also our understanding of the Phoenix International Media Center architecture.

Phoenix International Media Center embodies the creative freedom given to designers by the most cutting-edge architectural design control technology, and it reflects the beauty of architectural order that is full of tension. The creative path of Phoenix International Media Center and its cultural effects on society will inspire the broad architectural design community. Complete autonomous knowledge, original design, Chinese technology, and the design team's most valuable thinking and experience under China's bright conditions provide a model text for the future creative direction of Chinese architecture. The design motivation of Phoenix International Media Center is related to exploring the unknown. Directionality is future-oriented.

2.7.2 BEIJING DAXING INTERNATIONAL AIRPORT

Beijing Daxing International Airport is the center of the Party Central Committee, and the State Council decided significant national landmark projects. It is a new source of power for national development. The project is located on the north bank of the Yongding River, in the middle of Beijing, Tianjin, and Hebei. The single building area is 1.43 million square meters, costing 80 billion yuan, 46km from Tiananmen Square. It is 54km from the Beijing sub-center and 55km from the Xiongan New Area. It is 81km away from Tianjin city. Beijing Daxing International Airport has a capacity of more than 100 million passengers per year; it is divided into two terminal areas, north and south; the northern terminal and supporting facilities can accommodate 45 million passengers in advance after the subsequent construction of the satellite hall on the south side, the capacity target of 72 million passengers can be achieved.

Figure 81 *Beijing Daxing International Airport map/ Beijing Daxing International Airport area map*
Note. Researchers draw their own, 2024

The external transportation of the airport consists of the newly built airport expressway, the northern transverse connection line of the airport and four expressways, with the north-south subway Daxing New Airport Express Line and the Beijing and Xiongan intercity lines, the east-west Langzhuo intercity line, S6 line, and many other rail lines, together they form a five-vertical and two-horizontal transportation network, gather in front of the terminal building. A total of 1,320 sets of isolation devices are used in the terminal building. It is the world's most significant single isolation building, constructed with its most enormous single concrete slab, and the seismic fortification intensity reaches 8 degrees. The maximum speed of the high-speed train when passing through the underground terminal is 350 kilometers per hour. This crossing and speed design is the first for an airport in the world. It has solid civil aviation transportation capabilities and accessible external transportation conditions; Beijing Daxing

International Airport has become a new and comprehensive transportation hub, giving full play to its comprehensive functions of serving Beijing, radiating surrounding areas, and promoting coordinated regional development.

Beijing Daxing International Airport is the world's first dual-entry airport, double exit, terminal building, and terminal building F1-F4 with two arrival floors and two departure floors: international arrivals, domestic arrivals, domestic departures, and international departures. Beijing Daxing International Airport is building four runways; the terminal area is between the east and west runways, 2380m apart, and their parallel taxiways. The terminal area is the core functional area of the airport, directly serving air passengers; the primary issue in its planning and design is how to cope with the passenger flow of more than 100 million passengers per year; this is the current maximum design capacity for one-time construction of terminal facilities, it must not only meet the comprehensive arrangement of a large number of aircraft parking, transportation connections, passenger processing, baggage handling, and other facilities, it is also necessary to reasonably control the overall architectural scale of the terminal, the scale of technical systems and the walking distance of passengers, there is no previous experience of an airport of this size to draw from.

The final exterior design plan for Beijing Daxing International Airport is a phoenix spreading its wings in a shape that echoes the Capital Airport's. The shape implies that the phoenix spreads its wings, and the Capital Airport forms a dual hub pattern of dragon and phoenix. It consists of a centralized main terminal building and six radial corridors at an angle of 60° to each other; it includes five waiting corridors and one supporting service corridor; it explains the concept of centralization in a simple and direct, almost graphical way, and set a new record for the design capacity of a single terminal. The lighting throughout the airport is perfect because there is a highly transparent glass as the roof. All the light bulbs used for airport lighting use intelligent light bulbs, and you can adjust your brightness according to the brightness of natural lighting in the airport. The U-shaped elevated road encloses the main work area of the airport and adopts a dense road network and small plot division; in the central part, the track cover area is used to centrally arrange the service facilities of the work area, civil air defense parking facilities, and landscaped green spaces.

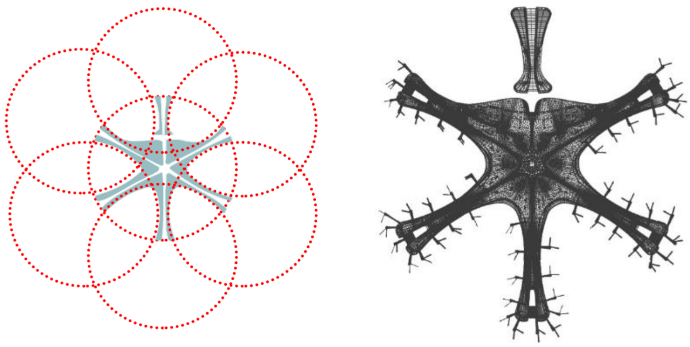


Figure 82 *Beijing Daxing International Airport generated map and Beijing Daxing International Airport floor plan*
Note. Researchers draw their own, 2024

The outer contours of the six corridors of the terminal building and comprehensive service building are positioned by an outer circle and six perfect circles that cut each other. The diameters of the seven circles are all 1200m, controlled by the length of the center line of the corridor of 600m, and according to the internal space requirements, the minimum signage corridor width of 44m and the signage corridor end width of 110m are controlled. Five waiting corridors divide four parking bays, coupled with the enlarged end of the corridor, a total of 50 boarding bridges are arranged, connected to 79 near-aircraft seats. Each harbor has three Category E aircraft taxiways and operates in a one-in, two-out manner; the intersection of adjacent sign corridors is chamfered with a large radius arc of 100m, alleviating the cramped sharp corners at the bottom of the harbor and can arrange E-class large aircraft, in the five waiting corridors, one on the south side is international. Four on the east and west sides are domestic, and the allocation of near-airport seats is in line with the capacity forecast of 20% global and 80% domestic; internationally, there are switchable aircraft positions at the root of the southeast and southwest corridors at the domestic junction, for the future growth of international near-aircraft seats and domestic, provide conditions for the process connection of international connecting flights.

Figure 83 *Beijing Daxing International Airport map*
Note. https://th.bing.com/th/id/R,2024

Beijing Daxing International Airport Terminal is such a comprehensive and complex super project that its design work has exceeded conventional architectural design's scope; it requires the coordination and cooperation of many design teams from different majors and fields to complete together. Integrate external design consulting resources and coordinate the design results of each node, wholly submitted to the construction unit, to further guide the construction, avoiding disconnects and inefficiencies between multi-unit designs, ensuring the logic and coherence of the design results, laying the foundation for efficient construction.

The internal design team of the consortium is divided into majors such as architecture, structure, water supply and drainage, HVAC, electrical, green building, steel structure, BIM, economics, art, etc., with more than 150 people. The entire system involves many aspects such as planning, contract, organization, progress, quality, etc.; for digital design work, the core point is establishing a collaborative design platform. Collaborative design, figuratively speaking, means everyone draws a picture together. The particularity of airport architecture determines two points. First, it is large-scale and highly complex, requiring many people from different professions to work together. The second is functional continuity; airport architecture is based on passenger flow lines, and the overall building is highly interconnected and cannot be broken down into several small individual buildings like conventional buildings. Therefore, in airport collaborative design, critical thinking is systematic design.

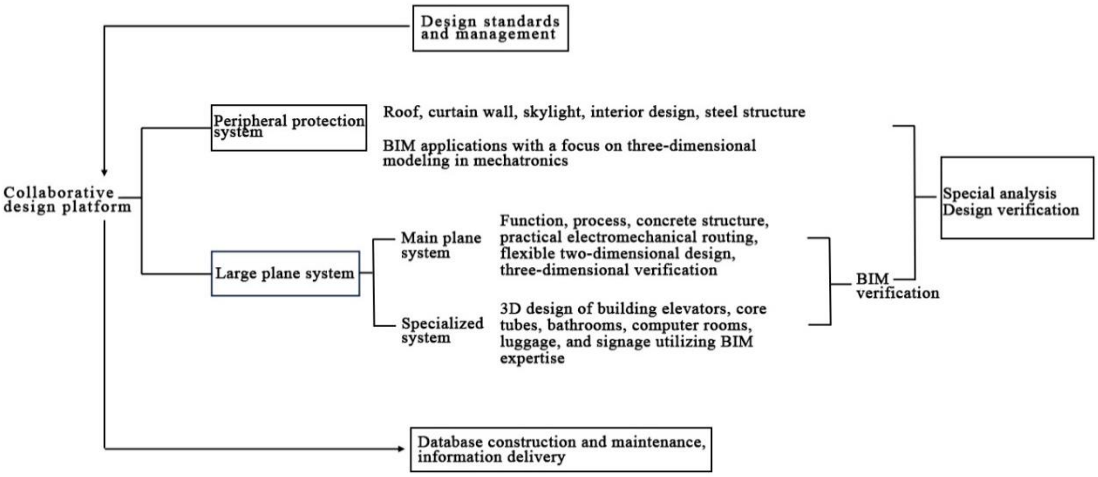


Figure 84 *Beijing Daxing International Airport Project Collaborative Design Platform Framework*
Note. Researchers draw their own, 2024

The design task of the terminal building of Beijing Daxing International Airport, faced with such a dilemma, the scale and complexity of this project exceeded previous experience; in 2015, no existing design software or digital platform could independently undertake its digital design work. In this situation, the design team can only be based on a suitability-oriented strategy, utilizing our existing collaborative design platform, decomposing a super system into several relatively independent systems, and for different systems, adopting different digital design strategies, then integrating the design results of each system, form the final complete digital design.

For the building envelope system mainly composed of curved surfaces, using Rhino as the core platform for design, integrating multiple 3D software results, the extensive surface system uses the traditional CAD platform, ensuring design efficiency and timeliness, and completes the Revit model construction in stages, for independent systems that BIM software is capable of, For example, independent standard components such as floor elevators, core tubes, bathrooms, and machine rooms, we use the Revit platform, taking advantage of building informatization, carry out standardized design, improve design efficiency, all while ensuring the three-dimensional accuracy of these complex components. All design results pass through the collaborative design platform, integrated into large flat systems like Live Update. At the same time, building space information should be regularly integrated under the Rhino platform to ensure space effect. This collaborative working method ensures that the entire building design is advanced simultaneously, coordinated, and unified.

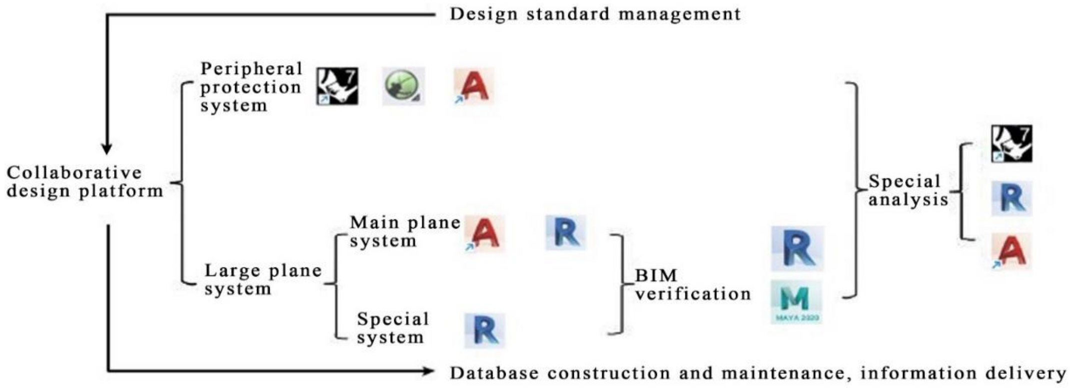


Figure 85 *Beijing Daxing International Airport digital collaborative design platform*
Note. Researchers draw their own, 2024

Beijing Daxing International Airport relies on computing power for design, a fundamental concept that has existed since the beginning of parametric design. Many experimental and small-scale applications are also constantly being verified and accumulated. Beijing Daxing International Airport's digital design is the first time it has been thoroughly applied and implemented on such a large scale. This declares that the era of computational design has truly arrived.

Luckily, I made it to the finish line from human intelligence to computer computing power. But to reach the destination, it's simple and efficient enough. New methods will inevitably produce new forms. On the road to computational design, the application at Beijing Daxing International Airport has yet to mature. We are just getting started and hope to bring travelers a slightly different architectural space experience than before. The architecture we have relied on for so long is just the accumulation and summary of experience in the field of the human brain. Today's society is undergoing drastic changes. Digital technology, the Internet, big data, and artificial intelligence are constantly changing and subverting various industries. With the improvement of design algorithms, the accumulation of primary data, and the popularization of artificial intelligence, silicon-based intelligence will inevitably become more and more deeply involved in architectural design work.

2.7.3 CHINA NATIONAL SWIMMING Center

The National Aquatics Center, also known as the Water Cube, is located in Beijing Olympic Park, one of the landmark buildings of the 2008 Beijing Olympic Games. It and the National Stadium are located on both sides of the northern end of Beijing's city central axis. The planned construction land of the National Aquatics Center is 63,000 square meters, the total construction area is 80,000 square meters, and the construction area of the underground part is no less than 15,000 square meters.

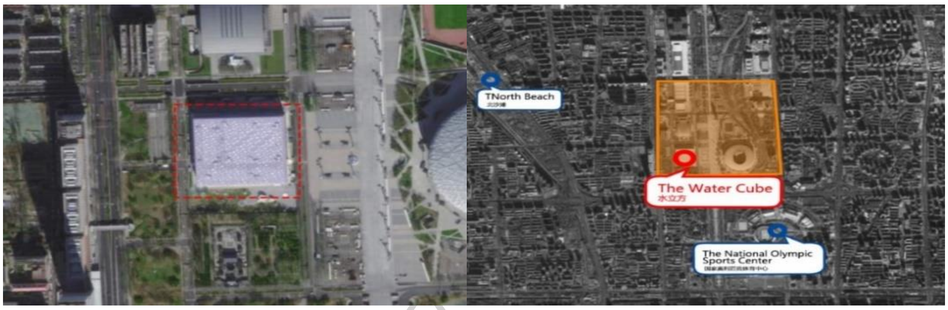


Figure 86 *National Aquatics Center map/ National Aquatics Center area map*
Note. Researchers draw their own, 2024

The design plan of the National Aquatics Center is a water cube proposal produced through a global design competition. In Chinese culture, water is an essential natural element and stimulates joyful emotions in people. Designers target people of all ages when designing and exploring the various forms of recreation water can provide, thus developing multiple uses for water; this design concept is called the Water Cube. The square shape is the most basic form of ancient Chinese urban architecture; it embodies the rules of social life represented by ethics in Chinese culture. Traditional Chinese design philosophy gave birth to the conceptual design of the Water Cube, and this square box can well reflect the multi-functional requirements of the National Aquatics Center. As a result, traditional culture and architectural functions are perfectly combined. It integrates Chinese traditional culture and modern technology with a light, quiet, and poetic atmosphere. The designers hope it inspires and inspires people, enriches their lives, and provides them with a carrier of memory. Integrating architectural and structural design into one, in harmony with the national stadium environment, fully meets the requirements for swimming, diving, synchronized swimming, water polo, and other events in the 2008 Olympic Games. It can accommodate 17,000 seats. At the same time, it is easy to train and operate the National Swimming Center later. Construction of the National Aquatics Center started at the end of 2003. The total investment was over 100 million US dollars, completed in 2007.

Figure 87 *National Aquatics Center logo/ Renderings of the National Aquatics Center*
Note. Researchers draw their own and Photographed by the researcher, 2023

Water Cube is the largest membrane structure project in the world. The world's most advanced, environmentally friendly, energy-saving ETFE Ethylene tetrafluoroethylene membrane material is used around the building(Lamnatou, Moreno, Chemisana, Reitsma, & Clariá, 2018). ETFE film is a transparent film; it can bring more natural light into the venue; its interior is a multi-story building, the symmetrically arranged grandstand has a broad view, the milky white building and the blue pool in the museum complement each other beautifully, ETFE film is also fireproof, leave the fire, and it goes out. This material has excellent corrosion resistance, thermal insulation properties, and self-cleaning solid ability. Foreign anti-aging tests prove it can be used for 15 to 20 years. This material is solid. It is said that People jumping on it will not damage it. At the same time, due to its waterproof properties, you can use natural rainwater to clean yourself, an emerging environmentally friendly material. The ETFE membrane, which looks like water bubbles, has better pressure resistance, and an air pillow made of ETFE film that is only as thick as a piece of paper can even bear the weight of a car. Air pillows, depending on their placement, the outer film is distributed with an uneven density of plating spots; these points will effectively shield the direct sunlight entering the museum, playing the role of shading and cooling. Currently, the Water Cube is the largest membrane structure project in the world; not only does it reflect the power and beauty of the structure, but it also fully expresses the architect's vision, enjoying the romantic space of nature. The Water Cube is light blue during the day. The Water Cube at night contains infinite possibilities; the colors can be changed and combined into various patterns.

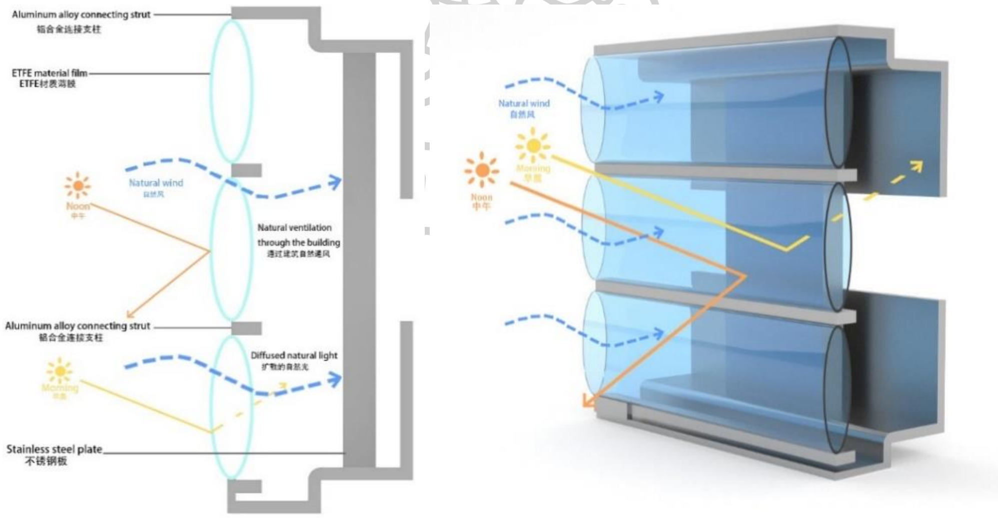


Figure 88 *National Aquatics Center ETFE Material Environment Map/ National Aquatics Center ETFE membrane material structure diagram*
Note. Researchers draw their own, 2024

The leading advanced energy-saving technologies in the construction of the

National Aquatics Center include the selection of heat pumps, utilization of solar energy, comprehensive utilization of water resources, advanced heating and air-conditioning systems, control systems, and other energy-saving and environmentally friendly technologies, if internal and external wall insulation is used, reduce energy loss. Adopt high-efficiency energy-saving light sources and lighting control technology. Adopting these new standards, technologies, and materials has set an excellent example for China's future building energy-saving construction, further driving and promoting the development of industrialization of China's energy-saving technology.

The National Aquatics Center is the largest in Beijing, a multi-functional swimming, sports, fitness, and leisure center with international advanced levels; it has become a valuable legacy left by the Olympic Movement to Beijing and a new highlight in Beijing's urban construction.

2.8. RELATED RESEARCH

2.8.1 ADVANTAGES AND CHALLENGES OF PARAMETRIC DESIGN

Parametric design methods have certain advantages in contemporary architectural design and can lead the future personalized architectural design trend. However, due to the current social, cultural, economic, political, scientific, and technological challenges, parametric design methods are still in their infancy and are relatively avant-garde design methods. At the same time, it is precisely because of this immaturity that pioneering this has led more and more researchers to conduct in-depth research.

2.8.1.1 ADVANTAGES OF PARAMETRIC DESIGN

The advantages of parametric design methods are evident in contemporary architectural design; parametric design brings changes in experience and can improve design efficiency, flexibility, and reliability.

For architectural designers, changes in experience in traditional architectural design ideas, when designing buildings, first, the overall architectural image will be produced in mind, then start designing a plan, continuously strengthen and deepen the design plan to pursue the realization of the architectural image. It was full of passion during the design or modification process at first, but slowly, as the number of revisions increased, it lost its love and became boring. In contrast, when designing buildings, parametric design sets some design rules according to the design conditions; if these rules need to be more detailed to control the entire design process, we must add more restrictions or regulations. Run the parametric model; after running many models, the result is a dynamically generated iteration; this is very different from the traditional design process; if the result is not what we want, you can change parameters or adjust rules, parameter changes, adjustments to the rules will produce completely different results, even some parameter models have different results every time they are run. Architectural designers have discovered the joy of parametric design in the process of these adjustments.

The main reason for changes in experience for the user or observer is that parametrically designed buildings can bring them visual impact and different feelings in space and activate their visual centers. The sense of flow brought by parametric design, interaction, etc., is impossible to achieve by traditional geometric architecture.

Due to the characteristics of parametric design, the requirements of new technology for new materials are different from those of traditional building materials and technology. The texture, color, light, and shadow of new materials also bring different feelings to users.

Through parametric design, designers can quickly generate multiple design solutions, accurately complete the design of complex architectural shapes, convenient for various plan modifications, and automatically search for the optimal solution during optimization. At the same time, parametric design can support design reuse and variant design and improve design reliability and consistency. Parametric design, a digital technology booming in Chinese architecture, provides a rare opportunity for advancement. Digital technology is not just a fashion for architecture but also a design attitude and progress in architectural thinking.

2.8.1.2 CHALLENGES OF PARAMETRIC DESIGN

Parametric design methods also present some challenges and limitations. Developing a new design technique in architecture will bring about two sides. The same goes for parametric design methods, has their advantages but are also under the influence of social, cultural, economic, political, scientific, and technological factors, etc., and challenging, and that's why only a few architects are using them.

Parametric design thinking is different from traditional Chinese architectural design thinking. Conventional Chinese architectural design follows the aesthetic rules of centrality and complete form that people have been accustomed to for thousands of years. Parametric design follows the philosophy of post-structuralism in complexity science and post-modern thought. Parametrically designed works in China mainly focused on small-scale personalized buildings and architectural sketches, such as stadiums, opera houses, airports, train stations, libraries, art public building facilities, etc. These outstanding buildings represent emerging architectural philosophies and ideas. At present, China's economy is in a stage of vigorous development, the field of humanities in China is still very backward, and the people's ideological consciousness is still relatively low; for the pioneering introduction of parameterization, many Chinese architectural designers are difficult to understand. Many people in China understand architecture as European style equals Roman columns; the Chinese style is equivalent to the architectural symbolic aspect of the big roof.

In terms of parametric science and technology, one of the challenges is to build accurate mathematical models and parameterized algorithms. This requires architectural designers to know computer programming and mathematical modeling.

At the same time, a deep understanding of material processing technology is necessary for construction technology. In China, many traditional construction processes are done manually, failing to meet design requirements regarding accuracy and efficiency. In addition, the success of parametric design methods also depends on the designer's accurate definition of design goals and constraints. If parameters are set improperly or constraints are too complex, this may lead to unbalanced or ineffective design solutions.

The most significant limitation is Chinese architecture's influence on politics and economy. Currently, parametric buildings in China are mainly used in places that represent typical cities, such as this city's business card engineering building. The cost of parametric architecture is often several times or even dozens of times higher than that of traditional architectural works. In many circumstances, party A can accept the concept and form of architectural design; however, due to the high budget, party A will give up on the parametric design of the building.

2.8.2 RESEARCH APPROACHES AND RELATED THEORIES ON ARCHITECTURAL FORM ISSUES

The problem of architectural form is one of the fundamental problems of architecture. It's a theoretical question; it is also a matter of practice. In design practice, various complex needs, technical solutions for multiple types of work, thoughtful thinking about the environment and place, and even profound thinking about society and the living environment, the final architecture must be implemented in some shape and form.

Architectural firms have many meanings and content when studying contemporary architecture. To summarize, there are two research approaches to the problem. First, form is regarded as a research object with clear connotations and independence based on the autonomy of form. The second is to focus on the correlation between examination form and other factors. Explain the origin and meaning of form and the coordination of many design factors. However, many studies do not distinguish between these two pathways; they are related. For example, architectural semiotics, regarding the connotation and extension of architectural form, have made significant research on linguistics and architectural semiotics, signifiers defined in architecture; this can be seen in part as an emphasis on formal independence, which refers to in architecture, it can be regarded as other factors related to the form and the denotative meaning and symbol of the form, etc. For example, the classic slogan of functionalism regarding architectural form is that form follows function, seen as a discussion of the correlation between form and function factors, explaining the origin of form.

2.8.2.1 ARCHITECTURAL SEMIOTICS

Swiss philosopher Ferdinand de Saussure is considered one of the founders of Western semiotics; the other was American Charles Sanders Peirce.

Saussure talked about the nature of linguistic signs in his general linguistics textbooks; a distinction is made between sign, signified, and signifier.

A basic premise of architectural semiotics is that all buildings inevitably carry meaning; some buildings also contain symbolism in some way. This understanding is, to a large extent, complementary to functionalism, even antagonistic.

Semiotics was introduced into architecture to understand how architecture carries meaning and symbolizes. The word symbol is replaced with building or architectural symbol; clearly, what do the signifier and the signified specifically refer to in architectural symbols? As a professional theorist of architecture, Charles Jenks states this question in more detail. Architectural symbols can be compared to other symbols; the signifier is the level of expression, and the referent is the level of content. The first level of signifier is form, space, surface, volume, etc. They have rhythm, color, texture, density, and more qualities. The second signifier level is the architectural experience part, such as sound, smell, touch, kinesthetic sensation, heat, etc. The referent is simply a meaning or group of meanings, concepts, and ideologies about space.

Table 6 *Charles Jenks's distinction between the signifier and the signified source, Signs, Symbols, and Architecture*

	First level	Second level
signifier (expression code)	form hypersegmentation	sound
	space characteristics	smell
	surface rhythm	touch
	Volume Color	kinesthetic
	Other textures and others	other
refers to (Content code)	iconography	iconography
	intentional meaning	converted meaning
	The meaning of aesthetics	potential symbol
	architectural concept	Anthropological
	space concept	evidence
	social/religious beliefs	Implied functionality
	Function	Somatics
	Activity	land value
	lifestyle	other
	business goals	
	Technology System	
	other	

Note. Researchers draw their own, 2024

The architecture uses various means, structural, economic, technical, and mechanical, to make tangible signifiers, such as physical materials and enclosures, clearly express the lifestyle, value, function, etc., it refers to. Saussure claimed in linguistics that architectural symbols form a dual unity of signifier and signified. The process of integrating the signifier and the signified is what semiotics calls the signification function(Pellegrino, 2006).

The primary purpose of Charles Jenks' introduction of semiotics to architecture was to emphasize the diversity and multivalence of architecture. On the one hand, the meaning of architectural form is within the exact scope of time and space; it's diverse. On the other hand, in different historical periods and different regions, the meaning of formal symbols is also constantly changing. Different audiences and perceivers target the same architectural symbols; other meanings and value judgments may also be derived. Charles Jenks distinguished between famous architecture and professional, avant-garde architectural work. The two appear to be in a state of division. Jenks tried to reconcile the two; he advocated that architects should be aware of their dual role, designed with elite pioneers and popular codes. At the same time, architecture is intentionally over-coded. Popular, elite, vernacular, and synthetic symbols can all form overloaded codes, thereby obtaining the polyvalence of architectural meaning.

Venturi's emphasis on symbols has stemmed more from direct observation of urban architecture. Venturi advocated that architecture should not just serve planes and structures; structure plus plane cannot determine form, and sturdy and practical do not mean beautiful. Decorated buildings have rationality for their existence. It is also reasonable to refer to buildings in historical styles. They evoke immediate associations and historical romantic metaphors and convey various symbolic meanings.

American architect Peter Eisenman gave another direction on architectural symbols, opposite to the Venturi. In Eisenman's early series of numbered residential works, points, lines, surfaces, bodies, and abstract elements become the minor marks for architectural objects and shapes. They are displayed in a Cartesian grid space background; after all, a building cannot be anything, leaving minimal entities, and the relationship ceases to exist. Column and beam structures can be considered line elements, and walls and floors can be considered surface elements. During this period, Eisenman had a clear tendency to deny functionalism in his formal manipulation of lines, surfaces, and bodies.

To summarize, the inspiration and application of semiotics and linguistics in architecture focus on the expansion of meaning, information exchange with the public, the mix and match of decoration and style, association and metaphor effects, and the multiple feelings of architecture.

2.8.2.2 BUILDING TYPOLOGY

Architectural typology generally studies the independence of form, emphasizing the rational grasp of architectural form and the autonomy of form.

Conducting classification studies on buildings is an ancient method. Architectural forms, building layouts, structural systems, etc., can all be classified. The focus on typology in architecture is mainly reflected in the following aspects:

Selection of building types

Further treatment of types

Treatment of the relationship between building types and cities

The combination of the types of original buildings and historical buildings leads to the concept of the prototype. The original architectural prototypes mostly use the natural environment as the background for the construction, the primitive hut mentioned by M. A. Laugier in his book "On Architecture." In sorting out the types of historic buildings, they are mainly classified based on architectural appearance and floor plan characteristics, such as J. N. Durand's composition system.

After the Industrial Revolution, some new building types emerged to meet the needs of the times and society and adapt to the new socialized mass production. These studies of type are related to architectural design; in particular, architectural form is closely associated with typologies and is closer to the architectural design practice level(S. Li, Foliente, Seo, Rismanchi, & Aye, 2021).

After the 1960s, Urban Architecture by Aldo Rossi. The classification of urban buildings begins. Please point out the so-called urban architecture, which includes the mutual metaphor of city and architecture, personality, place, history, memory, and design; these terms are used to discuss urban architecture and its types. Aldo Rossi criticized naive functionalism, saying that the functions of urban buildings change over time and that the value of a building is not always reflected in its function.

Aldo Rossi's typology is the study of urban and architectural element types. I wanted to isolate those elements that endure. It emphasizes that the city comprises areas with different social and formal characteristics from other periods.

Aldo Rossi's emphasis on type highlights the critical role of specific areas and primary elements in the urban fabric, emphasizing understanding their permanence in terms of history and collective memory. Discussed economics, land expropriation, land ownership, etc., and understood the driving forces of urban change from the perspective of city scale and other aspects. Politics has also been added as a selective factor. He always insisted on a certain autonomy for urban structures, specific areas, and specific building types; beyond city function, economy, size, and even history continues to exist, the city can be explained by its architecture itself.

2.8.2.3 ARCHITECTURAL PHENOMENOLOGY

Architectural phenomenology emphasizes the integrity of architecture, environment, and city, emphasizes the overall atmosphere of the place, and emphasizes multiple sensory perceptions and experiences of architecture. The focus on environment, atmosphere, and artistic conception involves the referent. Architectural phenomenology also extends attention to the profound philosophical proposition of human existence. This part is more theoretical and abstract.

The word phenomenology comes from Greek, a philosophy that studies appearances, appearances, or phenomena. The German philosopher Husserl is known as the father of phenomenology. Advocating a phenomenological reduction is to return to the things themselves and eliminate the prejudices of philosophy, science, and culture, observe and feel things as they are, and use intuition to discover the essence directly from phenomena. In other words, essence is also a phenomenon; it's more general and purer(Chan, 2012).

Heidegger was a colleague of Husserl and a student. He restored Husserl's phenomenology, pointed to the existence itself, and established existential phenomenology. In some of his later works, Heidegger explored the relationship between human existence and architecture, environment, and the world.

Merleau-Ponty is a representative figure of French phenomenology. He agrees with Husserl's phenomenological reduction; his "Phenomenology of Perception" emphasizes the observation, cognition, and description of the world, emphasizing that people should return to phenomena of the perceived life world. Perception is the most basic level of knowledge, ranked above culture and science. It can be said that his phenomenology is, first of all, a phenomenology of perceiving the world.

Norberg-Schulz published a series of theoretical works in architectural theory in the 1980s. Spirit of Place - Toward a Phenomenology of Architecture is a work that reflects Schulz's thoughts. In the Genius Loci, the meaning of place is not just location and location; instead, it is determined by the essence, form, texture, color of matter, etc., and a specific object constitutes a whole. The sum of these things determines the characteristics of the environment. The admiration for the spirit of place follows what phenomenology calls returning to the things themselves. It opposes abstraction and rational mental constructs similar to philosophy and science. Every situation has its unique atmosphere and character.

And space is not a space that is homogeneous in all directions in geometry. Space is a system of places; the relationships between inside and outside, expansion and enclosure, describe multiple qualities in a specific space.

Architecture is an embodied character, simultaneously human and natural, and its buildings materially express these properties.

Schulz advocates the spirit of the place; its core is to give appropriate characteristics to various specific things. The lack of characteristics and personality will lead to poverty. When dealing with the relationship between different things in the natural and artificial environments, pay attention to the distinctive continuity of the landscape and the characteristic concentration, direction, rhythm, etc., of settlement buildings or cities.

American architect Steven Holl elaborated on the phenomenological ideas used in his designs in a collection of his work published in 1989.

Hall believes that Architecture can create a sense of interweaving time and space. By interweaving form, space, and light architecture, architecture can sublimate the experience of daily life. In this sense, architecture transcends geometry; it is the organic connection between concept and form.

In terms of vision, there are perspective spaces under different perspectives; there is color, light and shadow, water and mirrors; in terms of hearing, there are sound characteristics of indoor and outdoor spaces, or the feeling of space created by sound, in terms of touch, materials, and detailing provide important tactile areas for the architectural experience. In addition, the temporality of architectural experience also attracted Hall's attention.

Architectural phenomenology draws on Heidegger's existentialism, reminding designers that they should pay attention to the characteristics of the environment and architecture. Architectural phenomenology emphasizes that architectural design should combine and connect multiple human perceptions and experiences to get the place system and gain a sense of human existence in the environment. Only such architecture can inspire and transform people's daily existence. To see and experience phenomena in architecture will make people the subjects of perception.

In addition to the theories on form and formal interpretation developed from philosophy, linguistics, literature, and other disciplines, several propositions and theories on architectural form have also been directly created and summarized from the field of design practice.

2.8.2.4 FUNCTIONALISM AND RATIONALISM

The function of a building is a design factor closely related to its form(Castro, 2009). In the early 20th Century, Louis Sullivan came up with the statement that form follows function. According to functionalism and rationalism, the architectural form should clearly show the purpose of the building.

Functionalism and rationalism, the difference between the concepts involved two is not very obvious; in summary, we pay attention to the use function of the building, focus on the economy, pay attention to materials and structure, pay attention to space and three-dimensional volume, and oppose simple plagiarism and follow historical styles, Reject decoration. Functionalism and rationalism emphasize function, materials, economy, and other related factors that have restrictions and constraints on architectural form, a form of correlational research and theory.

2.8.2.5 FORMALISM AND DE STIJL

The theory of architectural formalism is about the independence of architectural form(Stenning & Gurr, 1997). In the manifesto-like book Toward a New Architecture, terms closely related to forms, such as volume, surface, plane, baseline, and order, constitute essential clues.

In the theory of art and architecture, three types of sports are more recognized: De Stijl and European Formalism, Russian formalism, popular from 1916 to 1930, and the genre of American Formalism developed in the 1950s.

2.8.2.6 STRUCTURALISM

Structure is also a factor closely related to architectural form(Dixit & Stefańska, 2023). Structuralism's discussion of architectural form mainly includes that form emerges as a logical consequence of structure, that structure provides architects with ideas for creating new forms, and that structural technology can also be an aesthetic expression.

In the constructivist movement that began in the Soviet Union in the 1920s, on the one hand, structural engineering and structural mechanics are emphasized; on the other hand, structure is also used to describe a formal feature, and not all are the results of force analysis.

2.8.2.7 POSTMODERNISM

Arnold Towne used the term postmodern in 1938 to describe the growing value of diversity.

A summary of postmodernism's propositions on the architectural form include that complexity and contradiction are necessary, architectural forms need to be rich in meaning, modern styles can be mixed with historical styles, and diversity can be measured in terms of multivalency of meaning. Charles Jenks said an architect should master several styles and symbolic codes, as well as variations on these styles and symbolic codes, to suit the particular culture for which he is designing(Daneshvari, 1998).

Concepts and theories from functionalism to postmodernism have social, technological, and cultural backgrounds. Large-scale residential standardized production, the emergence of modern engineering technology and new materials, the development of the modern manufacturing industry, the development of contemporary art, social and cultural changes in the modernization process, the influence of traditional culture, regional culture historical research, etc. These concepts and theories have an essential impact on postmodernism.

Over the years, form follows function, and form follows structure, which has become the mainstream guiding ideology in modern architectural design practice, while other trends of thought and concepts are declining day by day, either as a necessary supplement outside the mainstream. The support of modern technological development for construction is mainly reflected in the high efficiency of batch-standardized production—and structural economic rationality. Contemporary architecture poses specific questions and challenges to these mainstream principles.

2.9. CONCLUSION OF LITERATURE REVIEW

The field of contemporary Chinese architectural design is changing with each passing day; the development of architecture has diversified needs, and Design requirements have ushered in a series of changes. Cultural inheritance and integration have become critical design elements, and improving sustainability and environmental protection awareness is an inevitable trend in contemporary Chinese architectural design. Innovation and the application of modern technology are other requirements for architectural design; humanity and social functionality are also vital considerations; at the same time, they maintain multiple levels of economic efficiency and controllability. Therefore, Chinese architects should respect tradition while innovating, expressing respect for China's rich history and culture through clever design to achieve the organic integration of tradition and modernity and create architectural works with contemporary characteristics and social responsibility. Experimental research on Lotus bionic parametric architectural design forms a new way of designing and learning.

This chapter, through a review of relevant literature, summarizes the Lotus bionic parametric architectural design as an emerging design concept, the importance of design in contemporary Chinese architecture, application areas, and the results achieved. The lotus is an elegant plant in nature. Introducing bionic features into architectural design, taking them from nature, using them with nature, and enhancing the aesthetic value of the building can also achieve more efficient energy use and environmental adaptability. Lotus bionic parametric design is not just a design technique; it is also a strong support for the concept of sustainable development. The literature review shows that this design concept has successful practical cases in cultural architecture and other fields and plans for the city, public space design, and other aspects that show unique advantages. By introducing advanced computer parametric design technology, architects more accurately simulate the morphological characteristics of the lotus, improve design efficiency, can be used flexibly in different scenarios, bring more possibilities to architecture, realize the organic integration of architecture and environment, and improve the overall quality of urban space.

Finally, through an in-depth literature review, lotus bionic parametric design plays a vital role in contemporary Chinese architecture; it brings new design ideas and technical means. The purpose is for Chinese contemporary architectural designers and college graduates majoring in architectural design to provide study reference and help and look forward to seeing more balanced innovation in the future, Cultural inheritance, sustainability, etc., the emergence of innovative architectural works based on bionic parametric design.

CHAPTER 3

RESEARCH METHODOLOGY

A mixed research approach was adopted in the research on plant bionic parametric architectural design, including a literature survey method, comparative analysis, combining qualitative analysis methods with quantitative analysis methods, case study, design practice, expert consultation method, etc. The purpose is to allow Chinese architectural designers to understand Chinese traditional pattern culture better, to have a flexible application of modern scientific and technological techniques, and to have an interdisciplinary approach, which is inspiring and positive in promoting. Researchers use exploratory methods, conduct research according to the logical sequence of architectural design, and gradually complete the research process of contemporary Chinese bionic lotus parametric architecture.

In the process of research methods, a holistic approach to traditional Chinese lotus patterns, parametric design technology, in-depth study and research of architectural design theoretical knowledge.

First, literature review study, master aesthetic theory, to the essence of beauty, understanding of aesthetic experience and artistic expression, form information symbols. Through sociology, one understands the social environment, cultural differences, understanding of target audience, and social context. Theories of architecture and urban planning help to understand the organization of space and design principles for urban environments and environmental places; creating architectural works in urban and built environments is essential.

Secondly, a study of traditional lotus patterns creates a lotus database. Understanding the lotus is an integral part of traditional Chinese culture and is widely used in Buddhist art, literature, construction, and other fields. Different periods have different cultural backgrounds. It is a significant symbol in traditional Buddhist art; as the materialized image of Buddhist teachings, it is substantial. In ancient society, the lotus pattern became a clan totem, an auspicious symbol of fertility. It has a beautiful meaning in people's pursuit of reproduction. In Chinese folk culture, the lotus symbolizes peace, harmony, unity, union, etc. The lotus symbolizes the cause of peace and a harmonious world's nobleness. Come out of the mud but not infected by the sludge; the lotus represents purity, integrity, holiness, and wealth. Lotus is often one of the themes of ancient Chinese poets' songs and paintings.

Again, for architectural design and production expressions, in-depth learning and application of parametric design. Parametric design is a commonly used form of the computer-aided design method; the main principle is to flexibly turn essential factors into a specific function module in the design by changing a particular factor of its module to change the result of the function variable, thereby obtaining a variety of different design solutions, improving the work efficiency of architectural designers. It provides an intuitive visual interface through parametric design tools, allowing architectural designers to see design changes in real-time. Increased interactivity of design helps designers better understand and adjust designs. At the same time, parametric design tools, modules, and elements can be reused to promote standardization, maintain consistency in design, and improve design maintainability.

At last, through understanding the literature, research methods, research tool settings, and a conceptual framework for exploratory formative research methods.

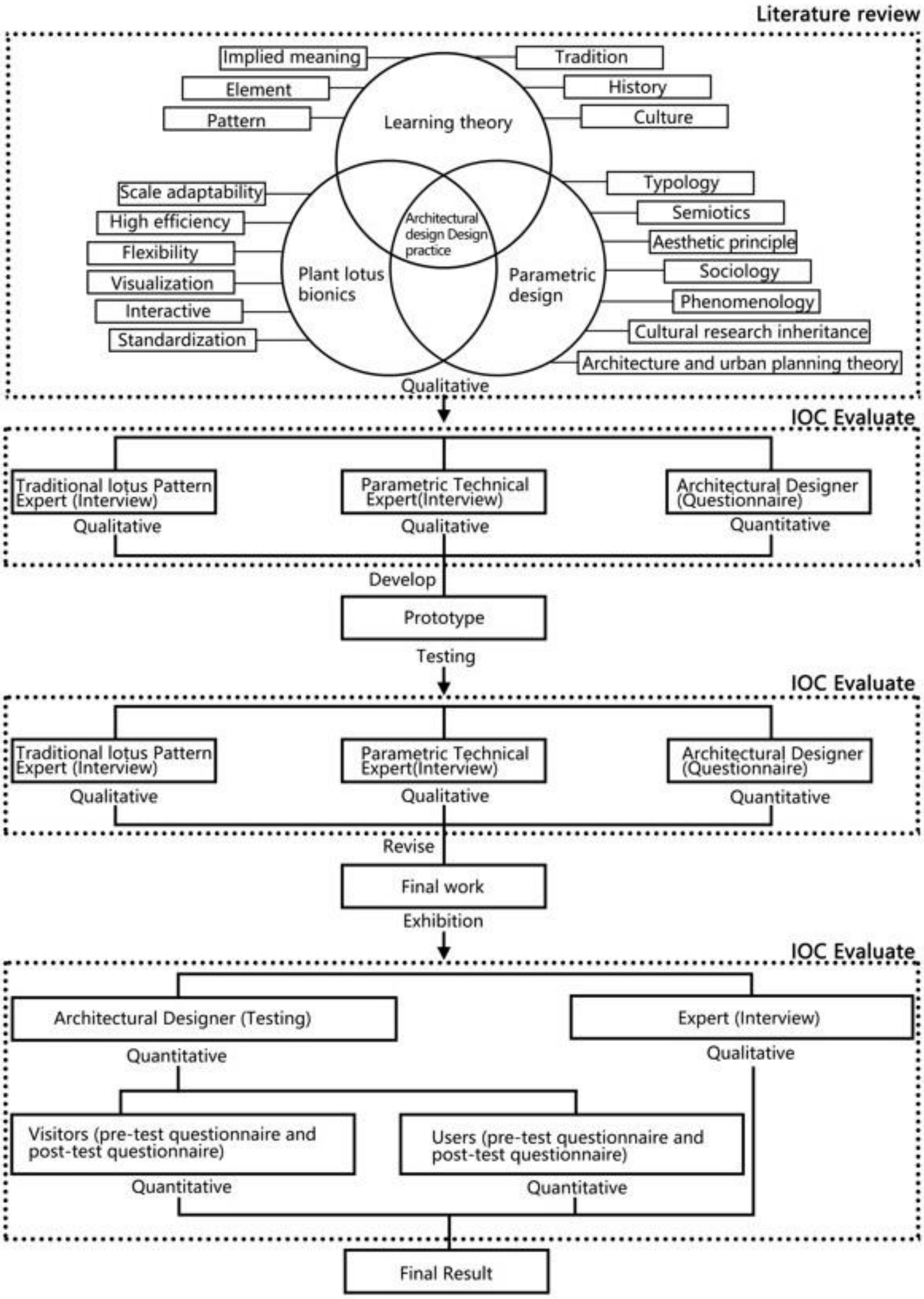


Figure 89 *Research methods mind map*

Note. Researchers draw their own, 2024

The research methods and research tools include the following four stages.

PHASE 1

The first stage is quantitative research, which involves making research tools and designing an Index of Item Objective Congruence (IOC). Determine research target groups, collect large amounts of quantitative data, perform statistical analysis of data, and determine the final valid data results. The data collection work was carried out in two phases: data collection in China and data collection in Thailand. In China, 11 professors and experts were invited to conduct research and discuss research tools. Six professors and experts were invited to Thailand to conduct research and discuss research tools and in-depth discussions on traditional Chinese lotus patterns and parametric technology, respectively, to get valuable information. Through 560 questionnaires representing representative target groups, the final data were tallied and applied to the second stage research questions.

PHASE 2

The second stage is qualitative research, through literature review, case study, field observation, in-depth interviews, and other methods used to explore and verify theories. Research focuses on integrating bionics with parametric design methods. Deeply understand the origin and foundation of bionic parametric architectural design, optimizing architectural form and structure, etc., and compare the differences and advantages of bionic parametric design and traditional design methods in form and structure. Explore the impact of bionic parametric design on building energy efficiency, the potential for reducing energy consumption, and improving building performance. Field visits use direct observation to obtain valid and reliable data. Analyze actual bionic parametric building cases, including success and failure cases. In-depth interviews are vital in interdisciplinary research; the researchers used face-to-face and remote interviews, various techniques and strategies such as open-ended and structured interviews, explore research design, sample selection, critical issues in interview guide development, and data analysis. Analyze the interview content and summarize experts' recommendations. Therefore, the in-depth interview method is a solid theoretical foundation for the research. Through qualitative research, it is concluded that the lotus bionic parametric architectural design in contemporary China is of research value. This hypothesis lays the foundation for the design experiments in the third phase.

PHASE 3

The third stage is to design experiments; based on the results of the first and second phases, the researchers conduct design experiments on the Lotus bionic parametric building. At the same time, the concepts and methods of promoting lotus bionic parametric architectural design in art design education should be researched. The design experiment is divided into four parts, and four workshops are held simultaneously. The first part is to study the generation of traditional Chinese lotus patterns. The second part is a learning study on generating parametric modeling algorithms. The third part is a study on the architectural generation of the bionic plant lotus. The fourth part is the simulation production and evaluation of the Lotus architectural model based on 3D printing technology. Combining the above four modules, conduct test research and analysis. The research results and identified issues from the first workshop were used as research hypotheses and will be tested and evaluated by the second workshop. The third seminar was the second round of experimental research based on the first and second seminars. The holding of the Lotus Bionic Parametric Architectural Design Experimental Workshop provides substantial support for implementing the fourth phase of design practice.

Throughout the research project, the design experiment in the third stage and the innovative design practice research in the fourth stage are carried out simultaneously. These two stages promote each other, interdependent and mutual support; together, the research hypotheses for lotus bionic parametric architectural design were tested.

PHASE4

The fourth stage is design practice, mainly applying research results in design. The researchers passed the first stage, the second stage, the third stage, and the fourth stage of design practice research. In the fourth stage, the researchers conducted three practical studies on the design and production of lotus bionic parametric buildings. The third stage of design experimental research is interspersed with the fourth stage of design practice research. Below is a conceptual diagram of the research methodology.

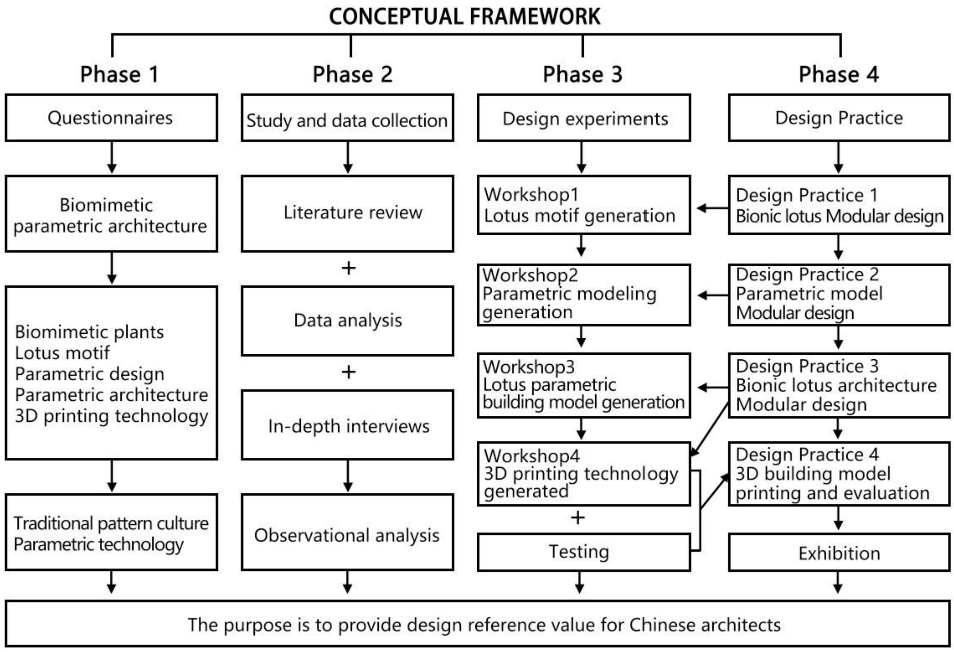


Figure 90 *Conceptual framework diagram of research methods*

Note. Researchers draw their own, 2024

The first design practice study is a case study on the modular design of bionic lotus patterns. According to Chinese historical dynasties, we will review the lotus patterns that have historical references and can be queried; there are thirteen lotus patterns from different periods, creating a lotus pattern database. Researchers base on lotus' uses and meanings, combined with the creative reality of lotus art, divide it into solemn themes, symbolic themes, support themes, metamorphosis themes, and other types. Based on the comparative analysis of lotus-themed patterns, researchers, based on linear drafts, took the shape of a lotus flower as the object to sort out and refine the styling genes of the lotus. Thus, the most basic lotus pattern in a linear draft was extracted. The second design practice research is on the modular design of parametric models. Adjusting parameters allows designers to generate various parametric bionic lotus pattern designs quickly and to produce diversified design solutions to meet different needs. Parametric modeling significantly shortens design time, reduces the designer's workload, and enhances the speed and efficiency of design. The third design practice study is the design of the bionic lotus architectural model. Based on the bionic lotus as architectural parametric modeling, carrying out parametric modeling of the bionic lotus can improve modeling efficiency and model accuracy. The fourth design practice study is 3D architectural model printing and evaluation. 3D printing technology has the advantage of highly integrating factors such as building structure, building form, and building materials; it is a brand-new design logic and construction model; it embodies a new architectural ecological relationship under the future digital design and construction model; it represents the direction of future construction digital development. This is also the focus of this applied research.

3.1 RESEARCH METHODS AND STRATEGIES

3.1.1 LITERATURE SURVEY METHOD

Through extensive research on decorative patterns at home and abroad in the field of contemporary Chinese bionic parametric architectural design, Chinese traditional decorative patterns, documents related to regional architectural decorative patterns, demonstrate the correctness of classification of ornamental patterns and other relevant literature, carry out targeted, targeted, systematic data collection and organization, understand the historical records of Chinese architecture, the origin of many building types, can be more objective, gain a more comprehensive understanding of the current research status and research trends related to parametric design of bionic buildings at home and abroad, establish an initial understanding of the problem, lay a solid theoretical foundation for subsequent research.

3.1.2 COMPARATIVE ANALYSIS METHOD

Parametric technology provides robust analysis and practical tools for bionic architectural design. This study takes the architectural discipline as its origin and the comprehensive economics, management, and scientific operations research method. It also quantifies theoretical principles into mathematical theoretical indicators and numerical images. Relying on the parametric design process, from the design perspective, technology platform, and algorithm properties, analyze and introduce different parametric bionic design paths at levels such as morphogenesis and support opinions with quantitative analysis.

3.1.3 MULTIDISCIPLINARY RESEARCH METHODS

During the research process of this paper, combining the characteristic research issues on the application of traditional architectural lotus decorative patterns with relevant disciplinary theories, according to pattern science and semiotics, the theoretical basis for aesthetics has been formed, further application of history, anthropology, typology, art, analyze decorative patterns with theories related to composition. Regarding complexity science, topological geometry, the intersection of digital construction, and many other disciplines, including natural sciences and humanities, engineering and technical research, and artistic and aesthetic discussions are involved. Using multidisciplinary knowledge methods, interpreting the decorative patterns on regional architectural carriers can more accurately and efficiently obtain analytical data and form a complete knowledge framework. This kind of interdisciplinary research gives the results a broader theoretical foundation and value.

3.1.4 COMBINATION OF QUALITATIVE ANALYSIS METHOD AND QUANTITATIVE ANALYSIS METHOD RESEARCH

Qualitative research is a research technique that analyzes the essence of things; the research and analysis of lotus decoratipatternnly qualitative research, introducing analytical methods that combine qualitative and quantitative methods, studying lotus decorative patterns can more objectively analyze the application characteristics of lotus decorative patterns. This study adopts this research method in collecting and organizing based on comprehensive analysis, comprehensively researching parametric bionic architecture, conducting segmental research, reducing perceptual errors in analysis steps, improving the accuracy of research results, realizing the whole process from quantitative to qualitative, comprehensive research, ensure the reference value of research results to design practice.

3.1.5 DESIGN PRACTICE

The application of parametric bionic architectural design methods in actual projects will be discussed through project cases in project engineering design practice. Although the original intention of the construction method did not originate from the concept of bionics, looking back at the design logic of the project, we can see that it coincides with the parametric bionic form design method. Therefore, lotus bionic parametric architectural design practice is an innovative design process that combines bionics principles and parametric design methods. By observing and analyzing the shape of the plant lotus, researchers, movement patterns, and ecosystem interactions take elements from it. Injected into architectural design, buildings are no longer just static structures but dynamic systems that can interact and adapt to the environment. Design practices make architectural design more eco-friendly, prompting researchers to seek solutions for symbiosis with nature constantly.

3.1.6 EXPERT CONSULTATION METHOD

Expert consultation is an effective research method for architectural design research methodology, through in-depth consultation with experts with extensive experience and expertise for in-depth insights and guidance. The architectural design field is a complex industry; there are many types of jobs in the industry, and the projects involved are complex. Expert consultation is key in solving complex design problems and acquiring expertise. Researchers must carefully select experts who fit the research field and situation and ensure that their experience and knowledge provide a valuable perspective on the research question. Keep detailed records of the consultation process, including words and opinions from experts, and the focus of communication; researchers can build an in-depth data foundation. Through deep, face-to-face communication and interaction with experts, researchers can gain insights into the latest trends, technological innovations, information on practical experience, etc. This not only helps solve complex problems in research but also provides researchers with practical perspectives and experiences. Analyzing this data will help researchers understand how experts think and the decision-making process and guide subsequent research work.

3.2 SAMPLE SELECTION CRITERIA

3.2.1 QUANTITATIVE RESEARCH BASED ON CHINESE ARCHITECTURAL DESIGNERS AND UNIVERSITY GRADUATES ENGAGED IN DESIGN MAJORS

Investigate the current status and cognition of bionic parametric architectural design in contemporary China and provide data support for future research on modern Chinese lotus bionic parametric architectural design. The researchers conducted a questionnaire survey in Jiangsu Province, China, in July 2023. This study adopted a questionnaire survey method for different regions, genders, and ages; a sample survey was conducted among architectural designers with academic qualifications and university graduates engaged in design majors. Among the 560 questionnaires, there are 407 valid questionnaires. The questionnaire survey results included 267 male and 140 female designers, ranging from 20 to 60 years old. In this sample, 17% have a college degree, 74% have undergraduate degrees, and 9% have a graduate degree or above. 89% of the target group suggested that bionic parametric architectural design suits urban construction. 9% of the target population suggested that bionic parametric buildings be placed in rural China. 2% of the target population suggested bionic parametric architectural design as another unique art. The participants' careers were architectural designers, college graduates engaged in design, construction engineers, town planners, research scholars, and the general public interested in innovative architecture.

3.2.2 EXPERTS

Experts in this study can be divided into two groups.

The first group is a professor at the China University of Design, an architectural design research expert, and an abbot of a Chinese temple.

In-depth interview with a professor at Nanjing Forestry University in China, dean of the Rural Revitalization Creative Design Institute of Nanjing Forestry University, and architectural design doctoral supervisor Wang Ruixia.

(1) In-depth interview with a professor from Changzhou University in China, dean of the School of Art and Design, Changzhou University, master instructor, Huang Haibo.

(2) In-depth interviews with professors from Changzhou Institute of Technology, China, the dean of the School of Art and Design of Changzhou Institute of Technology, and master instructor Peng Wei.

(3) In-depth interviews with professors from Changzhou Institute of Technology, China, the vice dean of the School of Art and Design of Changzhou Institute of Technology, and master instructor Yu Jie.

(4) In-depth interview with a professor from Changzhou Engineering Vocational and Technical College in China, the dean of Changzhou Engineering Vocational and Technical College, and architectural design doctoral supervisor Li Xiongwei.

(5) In-depth interview with a professor from the School of Art and Design, Changzhou Institute of Technology, China, Master Instructor, Qi Jinsong.

(6) In-depth interview with Changzhou Buddhist Association of China, hosted by Pumen Zen Temple in Changzhou, Hyde.

(7) In-depth interview with the Buddhist College in Beijing, China, hosted by Huayan Temple in Beijing, Dowling.

Second Group, a professor at Thailand Design University, is an architectural design research expert.

(1) Dr. Pat Wong Pradit, Faculty of Architecture, Arts and Design Naresuan University

(2) Dr. Thanick Muankhamwang School of Architecture and Fine Art Payao University

(3) Dr. Suriyun Chans Wang College of Architecture Sun and Rajbhat University

(4) Asst. Prof. Chantanee Chiranthanut, Ph.D. Faculty of Architecture, Khon Kean University

3.2.3 FIELD INVESTIGATION

(1) Visit the Sichuan Museum, a special exhibition on the lotus image in Chinese

culture, and see the lotus in bloom.

(2) Visit the Changzhou Museum's traditional Chinese patterns exhibition.

(3) Visit the Suzhou Folk Culture Museum exhibition.

(4) Visit Changzhou Tian Ning, Qing Liang, and Pumen Zen Temple.

(5) Visit the Yundong Library in Haikou, Hainan Province, China.

(6) Investigate the Changzhou Innovation Design Institute in China.

(7) Investigate the Jiangsu Rural Revitalization Research Institute in China.

(8) Visit Phra Pathom Chedi.

(9) Visit Ayuthaya-Suphanburi

(10) Visit Chiyapoom-Mahasarakham.

3.2.4 REPRESENTATIVE GROUP

The representative group of this study can be divided into three groups.

The first group, Changzhou University College of Art and Design, visual communication design central, traditional Chinese Buddhist lotus pattern design workshop. Place, Changzhou, Jiangsu, China. Team members: 5 undergraduate students and five graduate students.

The second group, Changzhou Institute of Technology School of Art and Design, Environmental Art Design Major, parametric modeling design workshop. Place, Changzhou, Jiangsu, China. Team members: 11 undergraduate students.

The third group, Changzhou Technician College, Jiangsu Province, is an architectural design major with a lotus bionic parametric architectural design workshop. Place, Changzhou, Jiangsu, China. Team members: 16 undergraduate students.

3.3 DATA COLLECTION METHODS

(1) Literature review is the beginning of research; it is a comprehensive review and analysis of existing knowledge in the current research field. Literature information needs to be obtained through various data collection methods to understand the pic of biomining in the literature on parametric architectural design in contemporary China. Researchers search libraries, find relevant books, journals, and academic papers, and get traditional paper documents. Search online with academic databases, online journals, and professional databases are also essential resources, as are access to many of the latest research papers in subject areas, review articles and other academic research results. Collect these documents for later analysis and form a conceptual framework.

(2) Through a questionnaire survey, print the designed questionnaire on paper and distribute it to target respondents; they can fill in their answers on a paper questionnaire. Collect their questionnaire data and analyze it using percentage analysis.

(3) Case site inspection, observe behavior in a specific environment through observation, and get data from it. Take photos, videos, and other visual observation records, combined with the questionnaire survey, provide multi-dimensional case field data collection.

(4) The expert group's data collection was conducted in four phases. The first batch of experts conducted face-to-face, in-depth interviews; researchers faced experts directly, asked questions, and recorded answers. Face-to-face interviews can help explain issues, provide more detailed explanations, and follow up immediately when needed. In the second batch of in-depth interviews with experts, the researcher conducts interviews and records the answers, photographs, recordings, and more. The third batch of telephone survey experts communicate, ask questions, and record their answers. The fourth batch passed with high efficiency and convenient email, social media, or website links sent to experts, online surveys, and data collection provided by experts.

(5) Collect data from a representative group; after the first traditional Chinese Buddhist lotus pattern design workshop, the researchers held an exhibition of their works and interviewed visitors to discuss opinions on designing experimental research projects. After the second parametric modeling design workshop, in-depth interviews will be conducted, the parametric modeling design method will be explored to bring efficient verification to designers, and their answers will be recorded on behalf of the group. Researchers take photos and descriptive observations of representative groups and analyze and summarize the data. After the third Lotus bionic parametric architectural design workshop, conduct project exhibitions and interviews, investigating the effectiveness of summary harvesting. The researcher took photos and videos to record the answers.

3.4 RESEARCH TOOLS

3.4.1 SIX PARTS OF THE RESEARCH TOOL

(1) Index of Item Objective Congruence (IOC) For Questionnaire Consideration, Evaluation, Suggestions.

(2) Index of Item Objective Congruence (IOC) Expert Interview Consideration, Evaluation, Suggestions.

(3) Index of Item Objective Congruence (IOC) Pre-Test Questions Consideration, Evaluation, Suggestions.

(4) Index of Item Objective Congruence (IOC) User Observation Form (For Researcher) Consideration, Evaluation, Suggestions.

(5) Index of Item Objective Congruence (IOC) Post-Test Questions Consideration, Evaluation, Suggestions.

(6) Index of Item Objective Congruence (IOC) Evaluation Form Consideration, Evaluation, Suggestions.

3.4.2 THE FOUR PARTS OF THE QUESTIONNAIRE

(1) The design and inheritance of traditional Chinese lotus decorative patterns.

(2) Optimized design solutions for parametric design tools and algorithms.

(3) Design of Lotus bionic parametric building model.

(4) Production and evaluation of parametric architectural models based on 3D printing technology.

3.4.3 EXPERT INTERVIEW FORM

The expert interview form included two topics.

One is to study the re-creation and inheritance of traditional Chinese lotus patterns and the significance of lotus bionic design.

Two is that the parametric architectural design method improves architectural designers' efficiency and accuracy. Questions are adapted based on experts' expertise on each topic.

3.4.4 REPRESENTATIVE GROUP QUESTIONNAIRE

(1) Workshop Questionnaire

Select two groups of students with similar backgrounds. One group of students had yet to participate in the bionic parametric architectural design workshop, and another group participated. Collect questionnaires and comparative data, and analyze the difference between pre-test and post-test.

(2) Exhibition Questionnaire

Select two groups of visitors. One group of visitors had never visited a model exhibition, and another participated. Collect two sets of questionnaires for comparison, and analyze the difference between pre-test and post-test.

3.4.5 EXHIBITION OF 3D PRINTED ARCHITECTURAL MODELS

Taking the conclusion of the bionic parametric architectural design method as a design guide for the exhibition of the contemporary Chinese Lotus bionic parametric architectural model, the exhibition will be held on March 17, 2024, in the Craftsman Hall, Floor 1, Building 6, Changzhou Technician College, Jiangsu Province, China.

3.5 DATA ANALYSIS

(1) Questionnaire survey, collect data for analysis. The researcher adopted a quantitative research method. Data are presented in bar charts and pie charts, summarizing the data analysis results in descriptive language.

(2) Expert interviews and target group evaluation forms adopt qualitative research methods. Based on interviews with experts, the researchers concluded that collecting and analyzing this data laid the foundation for later design experimental research.

(3) the researchers conducted several comparative analyses of the workshop phases in designing experiments. Through comparison, we can more intuitively understand the differences between the groups, thus obtaining the influence of design experiment factors on design results. Comparative analysis of data from experimental groups that participated in the workshop and those that did not participate in the seminar

verify the causal relationship between changes in the design experiment. Comparative data analysis between visitors and visitors who did not visit the model exhibition helps identify best design practices and the most effective design methods. This is useful for optimizing experimental design, improving experimental efficiency, and achieving better architectural design solutions is crucial. Comparative analysis takes the form of comparison tables and descriptive conclusions.

(4) Case studies, field observation, expert interviews, representative group statistics, and other data analysis results develop an appropriate design approach.

3.6 CONCLUSION OF RESEARCH METHODS

This study adopted a mixed research approach, combined with a literature survey, comparative analysis method, qualitative analysis methods, quantitative analysis methods, and other research methods, organically combining different research methods, thus comprehensively advancing the research on plant bionic parametric architectural design at the theoretical and practical levels.

This research can be divided into four phases. The first stage is quantitative research, which fully understands the research topic. The second stage is a qualitative research design using the results of the first stage of the study. The purpose of qualitative research is the critical factor in providing optimal solutions for quantitative results. Apply the first-stage and second-stage results to the third-stage design experimental research and explore how the traditional Chinese lotus flower pattern and parametric design methods can be combined into architecture. After, the results of the third stage are applied to the generation of the fourth-order bionic lotus parametric architectural model. Conclusions from the overall results answered the research questions and tested the research hypotheses. The result will be a discussion and presentation of findings, other relevant analyses, and suggestions for further research and development. Finally, it aims to deeply explore the optimal solution of plant bionic parametric architectural design in contemporary Chinese architecture.

CHAPTER 4

RESEARCH PROCESS AND RESULTS

This chapter mainly introduces the research process and research results. In the wave of contemporary Chinese architectural design, integrating traditional Chinese cultural symbols and modern technological means has become a new research topic for designers. The lotus is a symbol in Chinese traditional culture, with its graceful beauty and fresh and elegant form, triggering strong interest in its bionic parametric design in the architectural field. This design concept pursues giving new life to traditional cultural symbols in the context of modern Chinese architecture through the exquisite combination of parametric modeling and bionics principles, making buildings more than just rigid concrete and steel structures, and has become a traditional Chinese culture model of harmonious symbiosis between modern science and technology and nature.

The lotus flower has profound significance in Chinese culture; it is regarded as pure, symbolizing holiness and auspiciousness. However, contemporary architecture does not simply embed traditional symbols into designs; it is through the science and technology of parametric modeling that these symbols are given new visual forms and spatial languages. As an advanced digital design method, parametric modeling allows designers to explore complex forms and structures, thus giving the ancient totem of the lotus a new vitality in modern architecture.

This article aims to deeply explore the process and principles of contemporary Chinese lotus bionic parametric architectural design, analyze the role of parametric modeling and bionics in design, and demonstrate its practical application in modern architecture through specific cases. Through this new and creative design paradigm, we will explore how, at the intersection of tradition and modernity, culture and technology, create an architectural form with more depth and connotation, adding a touch of cultural color to China's urban modernization construction.

Combine the research summary of Chapters 2 and 3. The data comes from 560 questionnaires. Interviews with 18 experts and scholars. Field investigation at Sichuan Museum in China, Yundong Library, Haikou, Hainan Province, China, and other places. The design experimental results of the traditional Chinese Buddhist lotus pattern design workshop, parametric modeling design workshop design experimental results, and architectural design project practice results. After completing the qualitative research and forming hypotheses in the first part of the survey analysis, conduct the second part of expert interviews and field investigations. The researcher will determine the research keywords and representative groups used in the third part of the design experimental study; the researchers explored how to co-design the traditional Chinese Buddhist lotus cultural symbol and modern parametric design technology into the field of contemporary Chinese architectural design education, improve the designer's work efficiency. The fourth part includes the research practice of bionic plant lotus, parametric design, 3D printing technology and architectural collaborative design projects. Provide design reference materials for Chinese contemporary architectural designers and architectural design students. The research process and results include the following five parts.

First, through a questionnaire survey, in-depth interviews, and the evaluation results of field investigation, an innovative design based on the lotus pattern bionic architectural shape.

Second, via questionnaires, in-depth interviews, and the evaluation results of field investigation, using parametric technology to develop a lotus bionic model.

Third, contemporary Chinese bionic parametric architectural design, production, and evaluation combined with 3D printing technology.

Fourth, through the design experiments and practical research results of art and architectural design education workshops, I realized Lotus bionic parametric building digital technology collaborative design innovation and precise construction.

Fifth, the results will be summarized by integrating the above research results, focusing on the Lotus bionic parametric collaborative design of contemporary Chinese architecture.

4.1 INNOVATIVE DESIGN OF BIONIC ARCHITECTURAL SHAPE BASED ON LOTUS PATTERN

4.1.1 SURVEY RESULTS OF LOTUS PATTERN BIONIC ARCHITECTURAL DESIGN

In the rapid development of contemporary Chinese architectural design, researchers gradually focus on the rich traditional culture, trying to incorporate unique cultural symbols into the architecture to integrate tradition and modernity. In the process of this exploration, the lotus, this ancient and mysterious totem, gradually entered the design vision of architects. In traditional Chinese culture, the lotus has been endowed with profound cultural connotations, regarded as pure, auspicious, and a symbol of holiness; its shape and the language symbols of flowers have always inspired architects.

4.1.1.1 SURVEY RESULTS OF LOTUS PATTERN

This questionnaire survey widely covered participants of different ages, occupations, and regions to fully understand the public's views and expectations on the lotus pattern bionic architectural design. By collecting and analyzing survey data, researchers can gain a deeper understanding of the public's views and better meet people's perceptions and needs of the built environment. The results of this study will provide valuable reference for architectural design and help researchers better understand and meet society's expectations. Through this survey, we will contribute to the development and innovation in architectural design, making the built environment more beautiful and adaptable to people's living needs.

4.1.1.2 EXPERT INTERVIEWS ON LOTUS PATTERNS

July 16, 2023, at Huayan Temple in Xicheng District, Beijing, during an interview with Master Daolin from Wuyi Jingshe, telling the true meaning of the reason why the lotus pattern is encouraged in traditional Buddhism. In Buddhism, the lotus flower represents purity and purity, Qinglian in troubled times, and represents cause and effect. When the flowers bloom, seed lotus seeds are also generated at the same time; the lotus blooms in June, representing coolness in the heat; being born in sludge is an evil law and a symbol, being longer than clear water is a symbol of good deeds, blooming in the air means separation from the two dharmas of good and evil, represents neither good nor evil. Lotus shapes are used in architectural bionics, back to basics, back to nature.

Figure 91 *Interview with Master Daolin*
Note. Photographed by researcher, 2022

4.1.2 DESIGN BACKGROUND

The choice of Lotus is not just for decoration but also lies in its unique cultural connotation. As an important symbol in Buddhist culture, the Lotus carries spiritual sustenance that transcends the world and represents the purification and sublimation of the soul. In traditional Chinese paintings, sculptures, and literary works, lotus flowers often appear, providing a steady stream of inspiration for artistic creation. Therefore, Lotus is introduced into architectural design, which respects traditional culture and gives architecture a more profound cultural connotation.

The critical position of the Lotus in Chinese culture is reflected in its symbolic meaning, growth environment, and unique physiological structure. Lotus flowers usually grow in muddy and unstained waters, and the harsh growing environment makes them challenging, a symbol of tenacity. Its blooming petals, the dignity of the lotus pods, and the lightness of the stem make the Lotus show a coordinated and moving beauty. This natural beauty triggered the architectural designer's fascination with the lotus shape, trying to restore this harmonious natural beauty through architecture.

In the rapid development of contemporary architecture and urbanization, preserving and promoting traditional culture has become a critical mission. However, the inheritance of conventional culture does not mean simple copying and copying; it means giving it new life through modern design. Against this background, the Lotus bionic parametric architectural design combined traditional culture with modern technology, aiming to create an architectural form with profound cultural heritage and modernity.

Integrating lotus designs into buildings is not only a tribute to traditional culture but also injects a cultural atmosphere into the urban landscape. The use of this cultural symbol means that the building is no longer a cold urban structure; instead, it is a carrier that carries historical memories and cultural emotions. At the same time, this also provides a resonant space for residents, making the building part of the city rather than a simple existence.

Overall, behind the Lotus bionic parametric architectural design is a profound understanding of Chinese traditional culture and a unique exploration of the development of contemporary architecture. By incorporating the aesthetic and cultural connotations of the Lotus into the design, researchers are trying to bring a new architectural language to the city and make the building more than just a functional existence; it is an organic combination of cultural heritage and contemporary innovation.

4.1.3 RESEARCH RESULTS OF LOTUS BIONIC INNOVATIVE DESIGN OF ART AND DESIGN EDUCATION WORKSHOP

The first art and design education workshop, Lotus Bionic Innovation Design, was held at the College of Art and Design, Changzhou University, Jiangsu, China; participants in the seminar were undergraduate and postgraduate students majoring in visual communication design. During the workshop, the researchers analyzed the research methods of the entire lotus bionic innovative design, planned the research technology route, classified forms of lotus patterns, and innovated a new lotus bionic design pattern. After the first traditional Chinese Buddhist lotus pattern design workshop, researchers held an exhibition of their works and interviewed visitors to discuss opinions on designing experimental research projects.

4.1.3.1 RESEARCH ON LOTUS PATTERN METHOD

The research methods for the lotus pattern are the literature survey, fieldwork, and comparative research methods. Use the passage of time to study and analyze the continuous evolution and development of Chinese lotus patterns throughout the ages, and it has been interpreted and applied differently in different historical periods. Field visits and documentary research methods were used to explore these lotus patterns' origin, evolution, and application. Gather information on the lotus pattern used in architectural decoration. Records use formal analysis and changes in content analysis. The pattern information data were grouped and compared through qualitative analysis of the collected data. Researchers visited historical museums across China, temples, palaces, ancient ruins, and other places to understand the patterns used in traditional Buddhist lotus designs at different times. Interviews were conducted with local chroniclers and cultural heritage research institutes to obtain information. Browse many publications, journals, books, and websites. Through different literature survey methods, Chinese lotus patterns throughout the ages can be studied in depth from multiple angles. These studies can not only understand the vital position and profound historical and cultural heritage of the lotus pattern in Chinese traditional culture, but you can also be a researcher, manufacturer, and user experience to provide reference and inspiration.

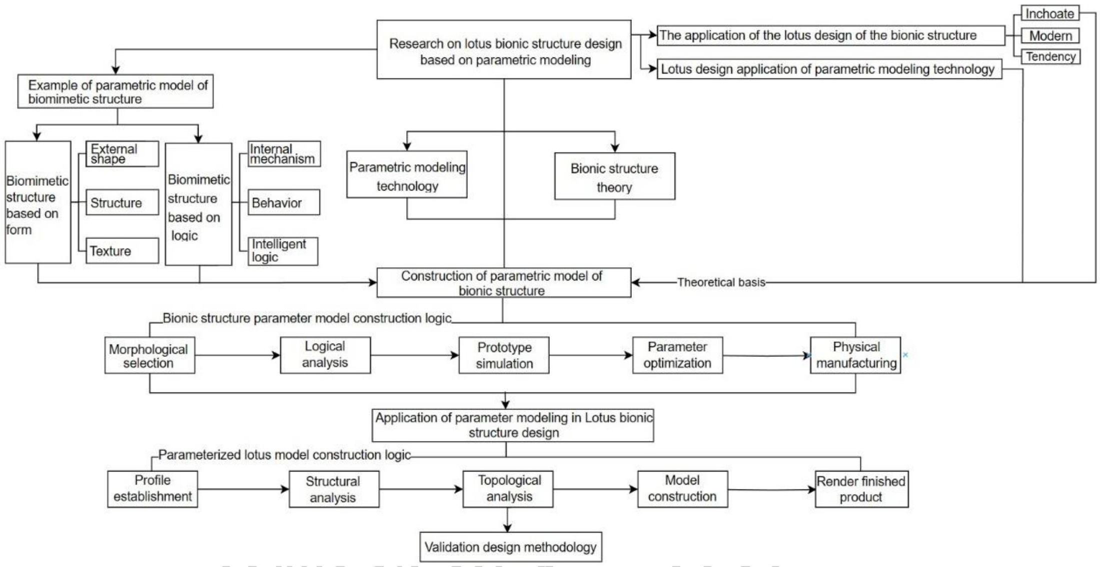


Figure 92 *Lotus bionic structure design framework diagram based on parametric modeling*
Note. Researchers draw their own, 2023

4.1.3.2 RESEARCH TECHNICAL ROUTE

In terms of historical and cultural research on the lotus pattern, to understand the symbolic meaning and use of traditional Chinese Buddhist lotus patterns in culture and religion in different periods, conduct analytical research. Regarding pattern type analysis, for types of lotus patterns, shape, color, and features such as combination methods, learn about the similarities and differences of lotus patterns in different cultures. In inheritance and evolution research, the popularity of lotus patterns in various historical periods, inheritance methods, the evolution process through Chinese paintings, and Chinese folk customs are studied. The lotus components of Chinese architecture are examined. In terms of aesthetic value analysis, through the form of lotus pattern, composition, analysis color matching, and expression techniques. In terms of application development, from design and art, from a cultural perspective, discuss the application and development of lotus patterns in modern society and its influence and inspiration on contemporary culture and art.

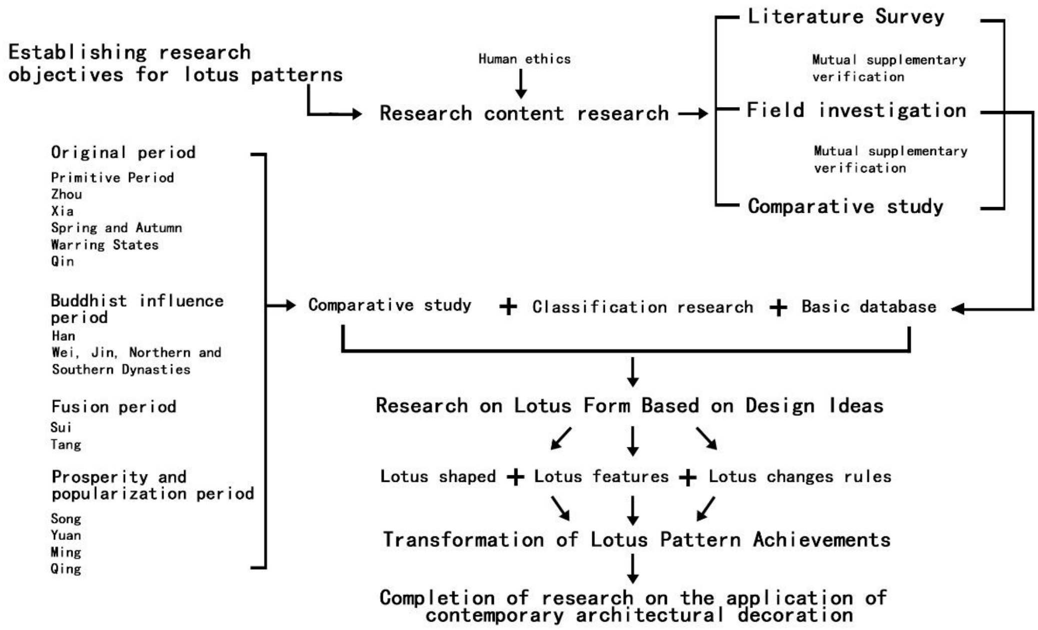


Figure 93 *Technology roadmap*
Note. Researchers draw their own, 2023

4.1.3.3 ANALYSIS OF LOTUS PATTERN FORM

Based on the analysis of the characteristics of the lotus pattern in different periods, the interpretation of Dunhuang, a complete collection of Chinese Dunhuang Murals, Chinese Grottoes, On the image of Lotus in the murals of Silk Road Grottoes, the series of books Lotus patterns in Dunhuang Murals provide a systematic interpretation. Through a large amount of data collection, sorting, and analysis, we completed the morphological research on the lotus patterns of thirteen representative dynasties; a large number of lotuses of different shapes are presented and interpreted by category; it also explains the drawing styles and artistic styles of each period, the basic appearance of the entire lotus art emerges clearly. Through data analysis and a large amount of data collection, most of these documents are distinguished and studied according to the different positions of the lotus pattern, such as the tiles in Buddhist temple buildings, the Lotus in the cave caisson, and the backlit Lotus, types such as lotus seats in temple architecture. This classification method is convenient; many basic information is divided like this, but there are also areas for improvement. If researchers only focus on the most prominent lotus flower, the scattered lotuses are ignored, but these lotus flowers also have rich forms. Therefore, the study of lotus art loses its integrity.

Researchers searched and reviewed a large amount of data, and recording and analysis were done; it is feasible to discover that the different meanings of the lotus pattern in Buddhism are divided into various themes. Researchers based on the purpose and meaning of lotus in Buddhism, combined with the creative reality of Lotus Art, divide it into solemn themes, symbolic themes, support themes, metamorphosis themes, and other types. The definition of each theme is based on the description of the lotus in the scriptures.

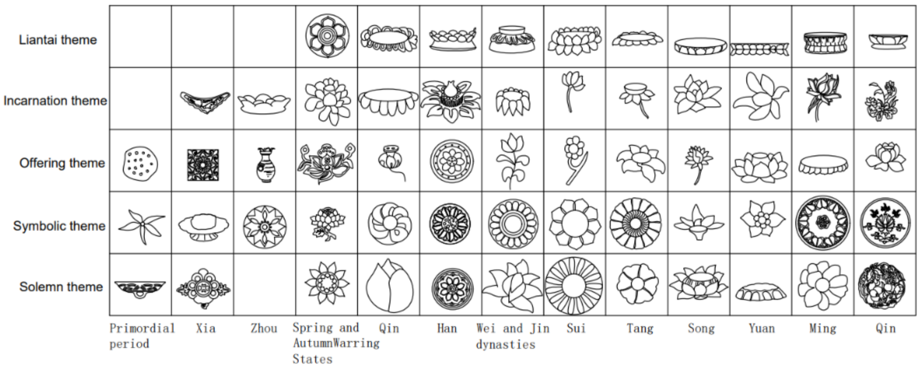


Figure 94 *Lotus pattern shape diagram*
Note. Researchers draw their own, 2023

The first type is a solemn theme.

In the Infinite Life Sutra, various kinds of precious lotus flowers emitting light are described everywhere, majestic in the Buddhist world. In Buddhist terminology, it is called solemnity, the solemn theme. The lotus pattern overall shows an evolutionary trend from non-realistic to realistic.

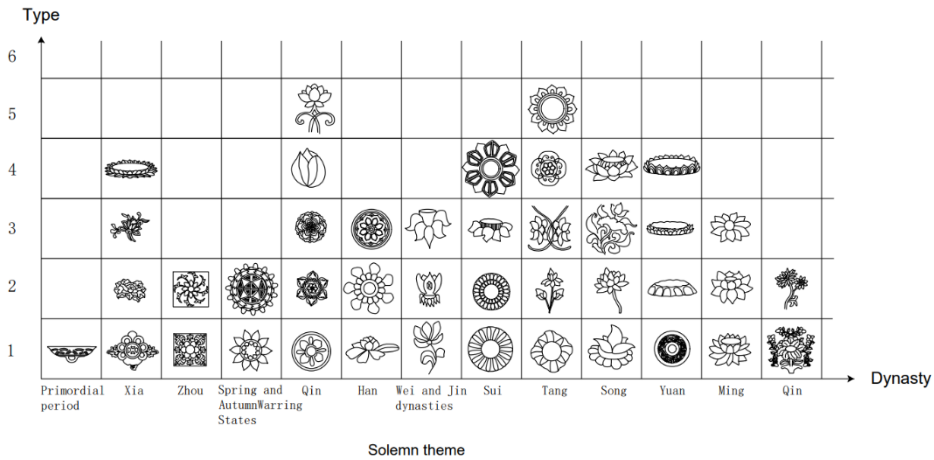


Figure 95 *Solemn theme lotus pattern shape diagram*
Note. Researchers draw their own, 2023

The second type is a symbolic theme.

In temple buildings, the large lotus pattern in the center of the caisson symbolizes the infinite Buddhist spiritual world, and the lot and pattern that appears on the backlight of the Buddha statue symbolize light. The lotus pattern that represents the theme is the most unified in its overall form, the perfect interpretation of form from simple to complex, especially the complicated and gorgeous lotus flowers, the most distinctive.

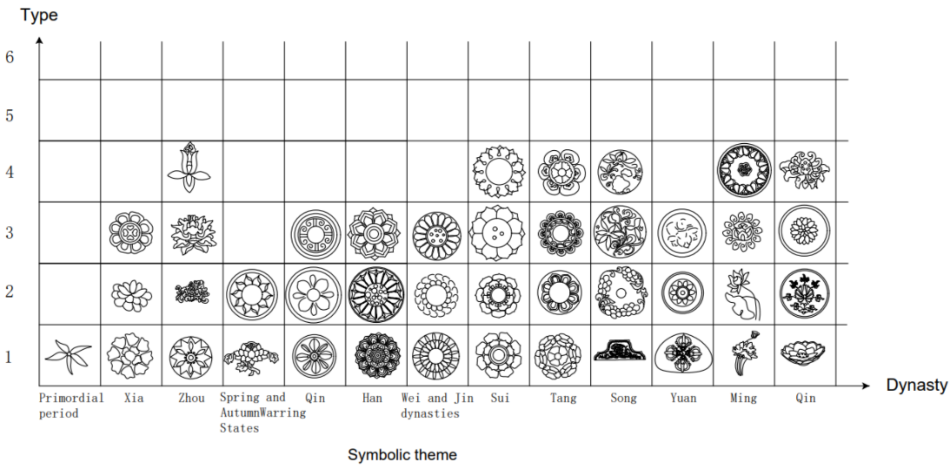


Figure 96 *Symbolic theme lotus pattern shape diagram*
Note. Researchers draw their own, 2023

The third type is offering a theme.

The Mahayana Jātaka Mind-Earth Contemplation Sutra writes about the scene of offering lotus flowers to the Buddha; it fully describes the use of lotus flowers to support the Buddha. With the offering theme, the lotus presents overall independence in basic plant form, very similar to the solemn lotus, a relatively apparent morphological evolution process from non-realistic to realistic.

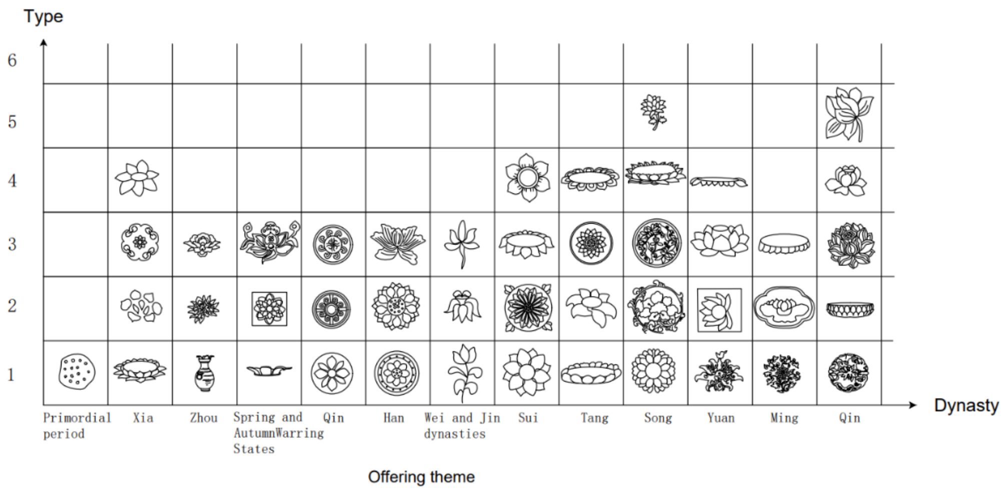


Figure 97 *Offering themed lotus pattern morphology diagram*
Note. Researchers draw their own, 2023

The fourth type is a metaplastic theme.

In the Avalokitesvara Sutra, Buddhism believes believers need to be reborn in reincarnation to be reborn in the Buddha's land of bliss. The uniqueness of the lotus's overall shape with the metamorphosis theme could be more precise; you can often see similar forms to other themes, and there is no noticeable consistency feature, which seems more confusing.

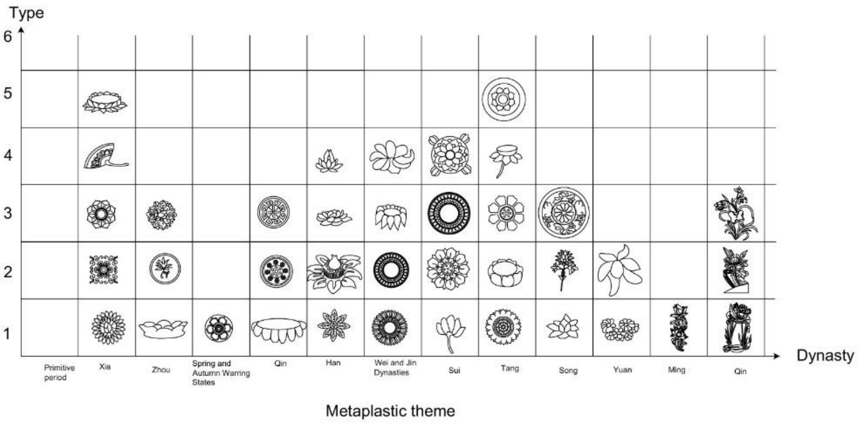


Figure 98 *Metamorphosis-themed lotus pattern morphology diagram*
Note. Researchers draw their own, 2023

The fifth type is the Lotus theme.
Lotus stands are ubiquitous in Buddhist architecture, and the shape of the lotus platform is also vibrant. The lotus platform has a straightforward functionality, uses lotus pods with exaggerated proportions to meet this functional requirement, and plays a foil role; the core part consists of two parts, a la otus pod, and lotus petals; it has the most significant and most stable characteristics. The seat of Buddhist Bodhisattvas is the sacred flower of Buddhism; it has a sacred meaning. Therefore, there are also temple-related buildings, such as the Lotus Temple.

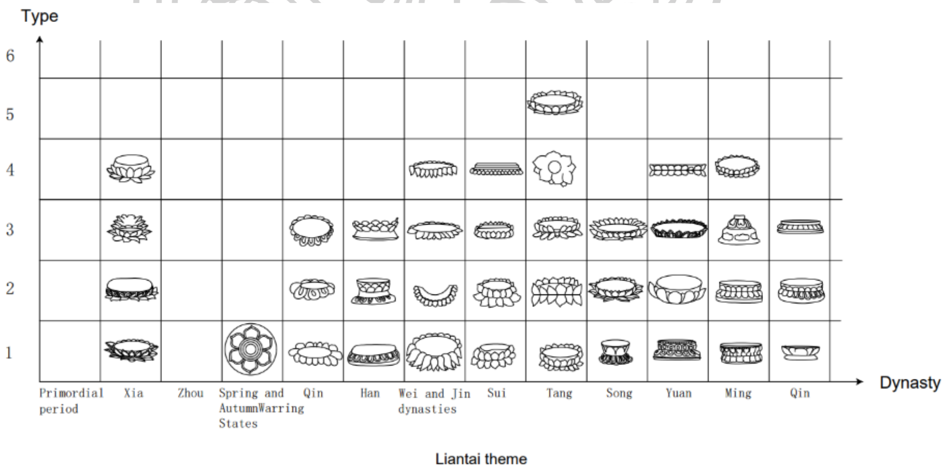


Figure 99 *Lotus theme lotus pattern shape diagram*
Note. Researchers draw their own, 2023

4.1.3.4 INNOVATIVE DESIGN BASED ON LOTUS ARCHITECTURAL SHAPE

Lotus pattern structure analysis gene extraction application. According to the comparative analysis of lotus-themed patterns, the overall characteristics of the lotus flower have been presented, based on line drawing, taking the shape of a lotus flower as the object, to sort out and refine the styling genes of the Lotus, to extract the most basic form types, presented in diagrams in the form of line drawings.

The components of the lotus pattern include petals, stamens, Lotus, etc. The shapes of the elements include petal shape, the shape of the stamen, the shape of lotus pods, etc. In the structural form of flowers, single-layer lotus petals spread horizontally around the lotus pod in an annular shape, and multi-layered lotus petals spread downwardly in an annular shape around the lotus pod.

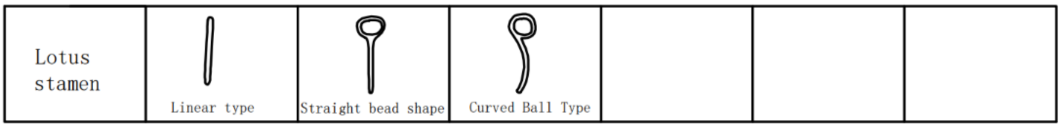


Figure 100 *Lotus stamen gene extraction map*
Note. Researchers draw their own, 2023

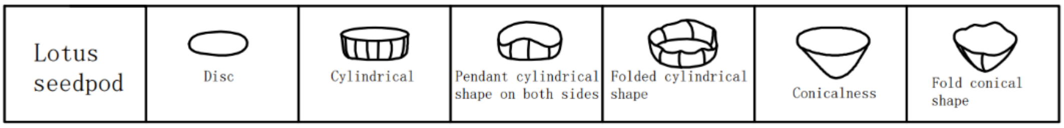


Figure 101 *Lotus gene extraction map*
Note. Researchers draw their own, 2023

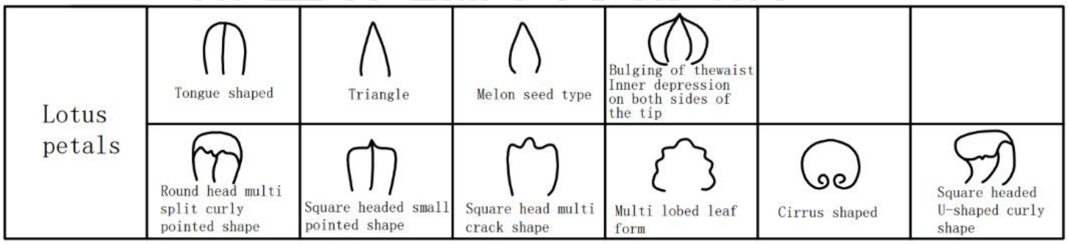


Figure 102 *Lotus petal gene extraction map*
Note. Researchers draw their own, 2023

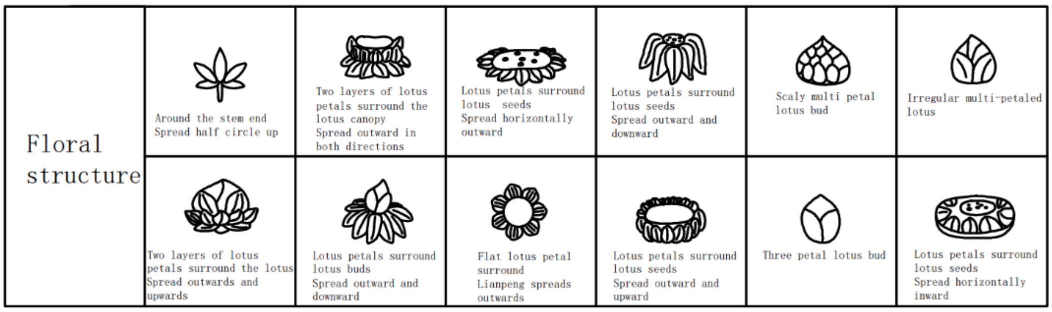


Figure 103 *Flower pattern structure gene extraction diagram*
Note. Researchers draw their own, 2023

Through a comprehensive analysis of the line drawing of the lotus shape, the evolution of the lotus shape shows the morphological characteristics of the lotus more clearly, abstracting the essential elements of the lotus shape; this makes it easier to apply the complex lotus shape in traditional Buddhism to later designs in some form.

The flow chart presented below is the process of analysis and recombination based on the lotus structure.

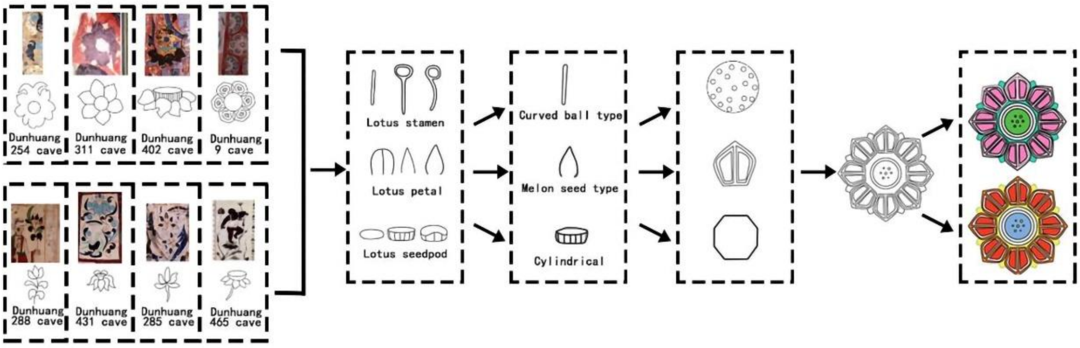


Figure 104 *Lotus pattern structure analysis gene extraction flow chart*
Note. Researchers draw their own, 2023

4.1.4 SUMMARY OF LOTUS BIONIC INNOVATION DESIGN RESEARCH WORKSHOP

Lotus bionics as the research object; through observation, it can be found that the entire leaf is composed of 8 protruding petals, a central vein organizes each valve, it can be divided into eight smaller branches, and the spaces between these branches are divided into smaller groups, each group has its pattern. Then, the above-observed physical structure is used to create a geometric diagram of the blade using geometric methods. A digital model is built on this basis, based on this diagram and analysis of the geometric characteristics of the blades. And explore the feasibility of irregularly shaped structures in actual projects. This research examines biological structures as prototypes, illustrates biological tissue structure, writes a numerical parameter model of the structure and form, and uses it as a design approach for nonlinear bulk structural systems.

Lotus morphology is not only diverse but has specific common characteristics and attributes. The first workshop aimed to study the intersection of developmental biology and architecture and try to use digital technology to combine lotus morphology with form generation in architectural design to expand the scope of architectural design.

4.2 USE PARAMETRIC TECHNOLOGY TO DEVELOP LOTUS BIONIC MODEL

Basic concepts of parametric modeling technology, and the advantages of this technology, application status, and development prospects, based on an overview of existing bionic structural theories, according to the properties of bionic objects, are divided into morphological bionic structures and form-finding bionic structures. Based on the above two parts, the advantages of applying parametric modeling technology to bionic structural design practice, and proposed the general process of parametric modeling of bionic structures based on Rhino3D software and its Grasshopper visual programming platform, it provides a theoretical basis for subsequent design practice.

4.2.1 IN-DEPTH INTERVIEWS WITH PARAMETRIC DESIGN EXPERTS

Exclusive interview with the School of Art and Design, Nanjing Forestry University, China, director of the Rural Revitalization Creative Design Institute, professor at Nanjing Forestry University, PhD Tutor, Wang Ruixia. She provided valuable suggestions on parametric design.

Figure 105 *Picture of invited expert Professor Wang Ruixia*
Note. Photographed by researcher, 2023

Professor Wang Ruixia said, currently, in the field of parametric technology in China, I think it should be top-notch. Compared with the application of parametric technology in architecture, nowadays, more and more people are designing building structures and building skins; very complex integration technology makes the building structure and skin cool, that is, of course, a method, technically it also has its challenges, but I feel that architecture is not just a simple structure and skin, this parametric technology is integrated into all technical design and installation technical control, these all show that it is still relatively superior, is a natural building, rather than one way. Parametric technology has no temperature but can achieve the highest degree of humanization. People's requirements can be reflected in the space of parametric buildings, even in the form of the building. Using new parametric techniques is a new tool; this tool allows the spirit of construction to be expressed to the highest degree. When using parametric technology to generate the overall shape, we may need to use the word design and replace it with generate; the entire shape is generated by software technology. Parametric software programs themselves contain algorithms, and algorithms refer to relationships. This relationship is a geometric relationship; that is to say, this shape is constructed from the most basic geometric relationships. The parametric architectural form is the object of computer graphics research, and building shapes are in the computer. This building is also being built. The fundamental relations of construction are algorithmic; this shape is constructed through algorithmic relationships, and using computers to create virtual shapes, the generated logical relationship can be extracted and used to deepen the relationship between architectural construction.

4.2.2 PARAMETRIC DESIGN BACKGROUND

Parametric design is an innovative method based on digital technology; it plays a vital role in today's engineering and design fields. The rise of digital technology provides new possibilities for design, the rapid improvement of computing power, and the continuous development of algorithms lays the foundation for parametric design. In this context, the parametric design introduces parameters, variables, and algorithms, giving your design greater flexibility and innovation. Parametric modeling is based on a series of parameters that can be adjusted; these parameters affect the form of the building, size, proportions, etc. These parameters can be numbers, curves, or other design elements; by setting these parameters in the design software, architectural designers can observe changes in building form in real-time. This process not only speeds up the iterative design process but also provides a more intuitive design experience.

The parametric thinking divergence process is a vital link in parametric design. The designer first needs to define a series of parameters, including buildings, materials, variables, fractal geometry, curved shapes, etc. These parameters are connected to the geometry and properties of the architectural elements through algorithms and scripts. When one or more parameters are modified, the entire parametric building will change accordingly, allowing designers to observe their designs' effects quickly.

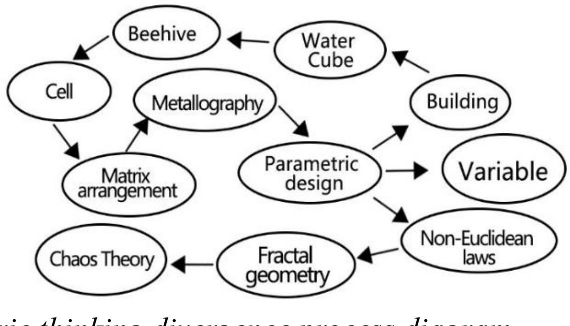


Figure 106 *Parametric thinking divergence process diagram*
Note. Researchers draw their own, 2023

4.2.3 RESEARCH RESULTS OF PARAMETRIC MODELING DESIGN OF ART AND DESIGN EDUCATION WORKSHOP

The second parametric modeling design workshop for art and design education was held at the Department of Environmental Art and Design, College of Art and

Design, Changzhou Institute of Technology, Jiangsu, China; the team members of the parametric modeling design workshop included 11 undergraduate students. Parametric modeling workshop experimental design, focusing on the computer digital generation of traditional lotus patterns and extracting graphic style elements, carries out parametric modeling design research. After the second parametric modeling design workshop, in-depth interviews will be conducted, the parametric modeling design method will be explored to bring efficient verification to designers, and the representative group's answers will be recorded. Researchers take photos and descriptive observations of representative groups and analyze and summarize data.

The second art and design education parametric modeling design workshop used the petals of the lotus as the basic shape, which is one of the most basic and essential components that form the lotus parametric architecture. A parametric structural prototype was obtained in the research process, and data experiments were conducted on two lotus flowers and their changing forms. One is round; one is pointed type. The two sets of geometries for trigonometric experiments on one or more sin functions are relatively simple: draw a circle with point c as the center, the algorithm for distance c to m is 1-r, $\alpha = 2\pi/6$, the length m of the perpendicular line to the tangent line of the circle is $(1-r)\sin\alpha/2$, the equation is $r=\sin\alpha/2/(1+\sin\alpha/2)$. The vertical angles a and b combine to form a module group, rotate and copy the arc endpoint n times, and the petals of the lotus pattern are formed. Symmetrical displacement along a straight line through the midpoint m, the cusp points (a, m) and (b, m) can be obtained, combined with the center point C of the circle, form a graphic group, the amount of displacement determines the sharpness.

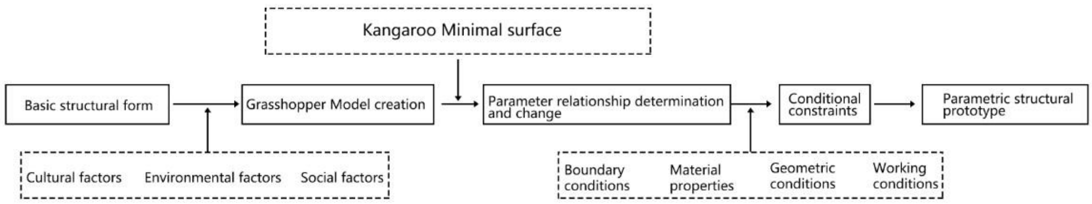


Figure 107 *Diagram of how to obtain a parametric structure prototype*
Note. Researchers draw their own, 2023

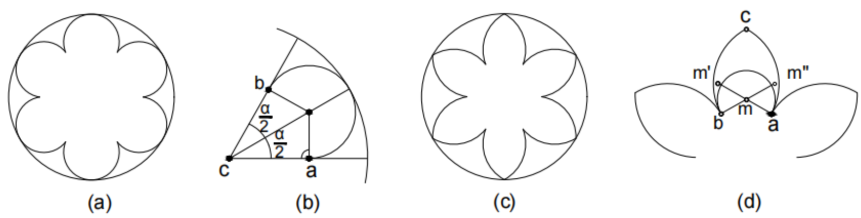


Figure 108 *Lotus pattern basic shape algorithm structure*
Note. Researchers draw their own, 2023

In the primary method of designing the organizational form of a lotus pattern in the early stage, a certain logic is required: a triangle formed by straight lines and arcs, square, round, lotus pattern created from polygonal and other shapes, composed of a symmetrical point and a curved line, they wrap around points on geometric figures, represented with stylized graphics, then transform it into a lotus shape and overlap it, generate different kinds of geometric rosette patterns.

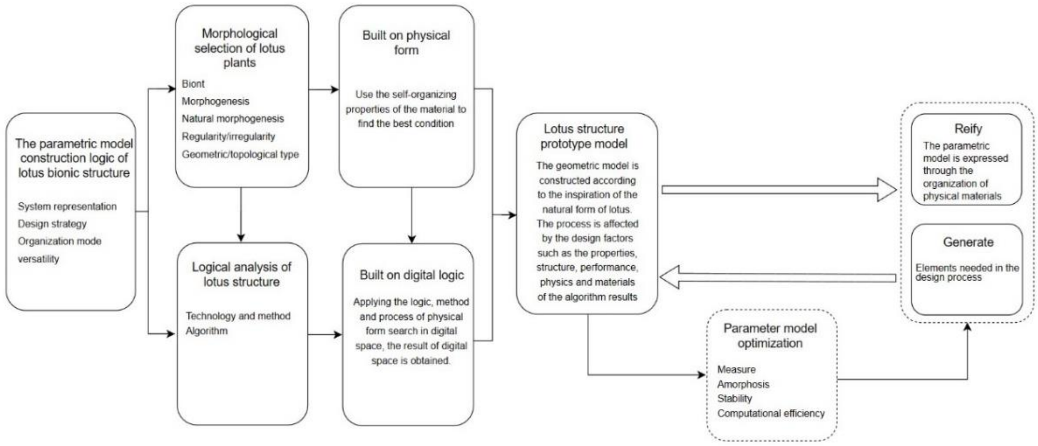


Figure 109 *Parametric modeling logic diagram of lotus structure bionics*
Note. Researchers draw their own, 2023

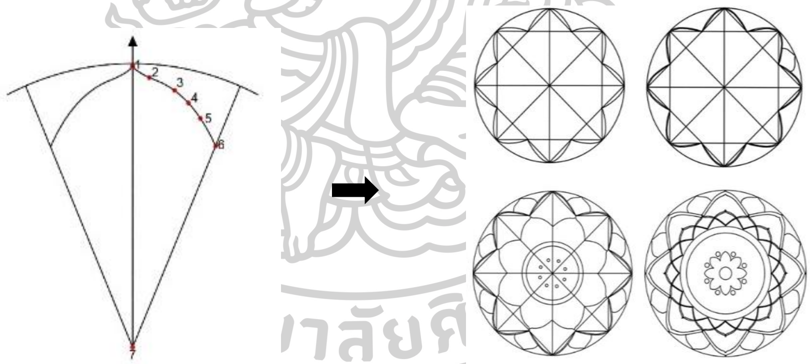


Figure 110 *Parameters to generate lotus pattern*
Note. Researchers draw their own, 2023

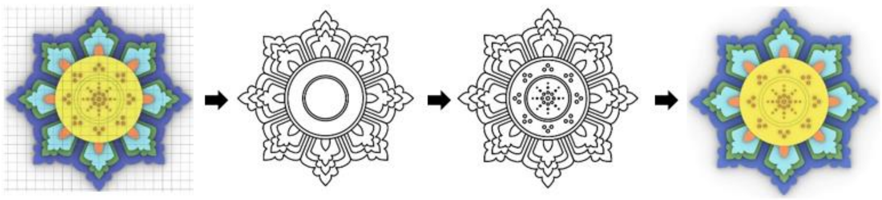


Figure 111 *Generation of Lotus Pattern with Reference Grid Specification*
Note. Researchers draw their own, 2023

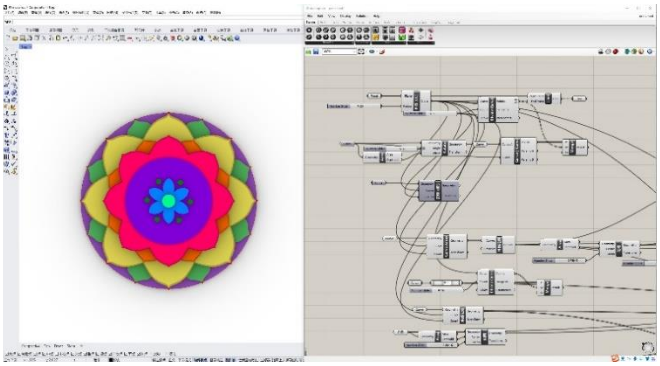


Figure 112 *Generation of interactive lotus pattern*
Note. Researchers draw their own, 2023

This is the framework diagram of the parametric modeling and generation method of the lotus pattern. According to the geometric characteristics of the lotus shape, a model of the parametric pattern was constructed, which can better quantify the geometry of the lotus-shaped pattern and explore the design space of the lotus pattern. We use a hierarchical structure of concentric circles and progress the lotus pattern from outside to inside to generate the final inner lotus pattern; parameter values are determined from a reference interval grid. A comparison of experimental results shows that this method can effectively develop a layered lotus pattern. Using computer platforms such as parametric Grasshopper and other modeling tools, by setting the parameters and color of the lotus pattern and arranging them in different rings, flexibly generate stylized lotus patterns with any shape and color.The petals of the lotus pattern can contain 4, 8, 10, or 16 other petal patterns, from the outer ring to the inner core. This experiment uses eight petal patterns as an example to describe the parametric modeling and generation of lotus patterns. The model is divided into two parts: bones and decorative shapes. The main body of the skeleton is the entire petal structure and petal outline; the center part has a decorative shape. Combining these two parts forms the structure of skeletal patterns and decorative shapes.

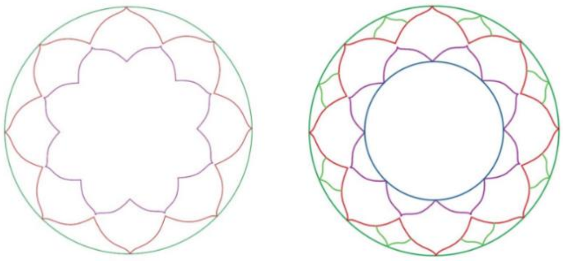


Figure 113 *Lotus pattern skeleton and decorative shapes*
Note. Researchers draw their own, 2023

Experimenting with 8 lotus petal patterns, the petals are confined to one-eighth of a unit circle, the shape of the petals is symmetrical around the central axis, and the specified 7 control points can be used as the original set of control points, then use these points to model the other half of the petal. The positions of these seven control points are expressed in polar coordinates. We use a three-dimensional array to store the radius ri, angle θi, and relative angle $\triangle i = |\theta re\ f - \theta i|$, where i = 1,2,..,7, and θref are the angular coordinates of the reference control point taken from the given control point. In this experimental case, the 7th point is used as the reference point.

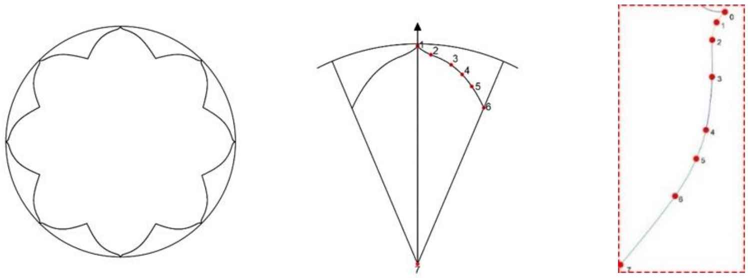


Figure 114 *Construction of an eight-petal skeleton pattern*
Note. Researchers draw their own, 2023

For n p > 8 petals, we can modify the relative angle $\triangle I$ and set it on the original control point. The shape of the petals is narrower than the shape of the original control points. A pattern of n petals can be generated similarly with new control points. It can be a skeletal pattern with 8, 12, 16, etc. petals.

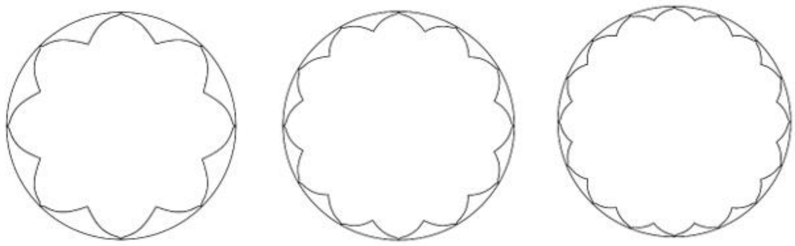


Figure 115 *Skeleton pattern of different numbers of petals*
Note. Researchers draw their own, 2023

Figure 116 *Decorative shapes of different numbers of petals*
Note. Researchers draw their own, 2023

The following steps can be taken to build different pattern models in the lotus pattern, as well as parametric modeling and generation. The first step is to specify np as the number of petals in the pattern, then divide the unit circle into n points p. Generate skeletal patterns for external and internal patterns in lotus petals and add decorative shapes to get a full lotus petal pattern. Perform grouping to obtain unit one, and generate the petal lotus pattern for the rest of the unit circle by rotating the petal pattern of unit one by 2 π/n p about the center of the circle. This allows you to generate lotus patterns with different petals. Because the lotus pattern is limited to a unit circle, therefore, the entire control point can be controlled coordinately by expanding or reducing the radius r, to get the limited lotus pattern inside the circle.

Figure 117 *Lotus pattern with different numbers of petals*
Note. Researchers draw their own, 2023

After the above experiments and data analysis, corresponding patterns can be added to each link with the lotus pattern model to generate a lotus pattern with hierarchical concentric circles. The parametric modeling and generation tool Grasshopper computing platform provides data visualization, graphs using functions and data, algorithm implementation, user interface display, etc. An efficient interface for Lotus graphics visualization enables interaction with computing devices.

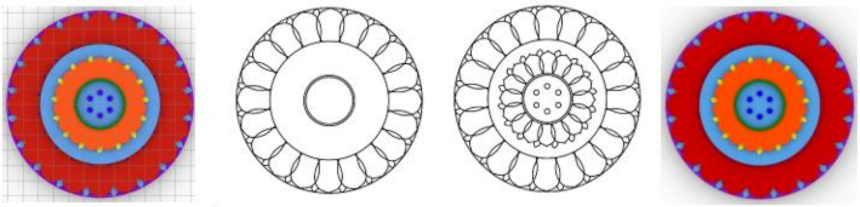


Figure 118 *Computer-aided parametric modeling and generation of lotus patterns*
Note. Researchers draw their own, 2023

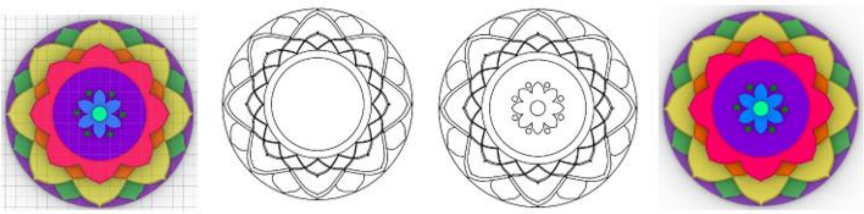


Figure 119 *Computer-aided parametric modeling and generation of lotus patterns*
Note. Researchers draw their own, 2023

4.2.4 SUMMARY OF THE WORKSHOP ON DEVELOPING LOTUS BIONIC MODEL USING PARAMETRIC TECHNOLOGY

The second parametric modeling workshop experimental design consists of basic geometric patterns, round shapes in traditional lotus patterns, arcs, copying in a straight line, crossing, and combination operations such as pruning, forming a complex geometric form of lotus pattern. Improve work efficiency and model accuracy, the process of realizing these lotus patterns, use mathematical models or modeling languages to analyze the shape characteristics of the lotus pattern, construct rules or stylized layouts for parametric coding, a lotus pattern entity with a specific design style is formed through aesthetic conventions and spatial constraints, generate a new visual art form of lotus pattern with a particular style. Through programmatic methods, modularize the lotus pattern, generate modeling language to combine to form a natural lotus configuration, automatically simulate specific art styles, parametric modeling, and generation using deep neural network technology. Then, through different combinations of specific parameterized features, re-rendering produces a specific lotus decorative pattern with diversity.

4.3 CONTEMPORARY CHINESE BIONIC PARAMETRIC ARCHITECTURAL DESIGN PRODUCTION, N, AND EVALUATION COMBINED WITH 3D PRINTING TECHNOLOGY

As China's economy and people's living standards continue to improve, labor costs are also increasing year by year. To adapt to the development of China's construction industry, 3D printing technology is gradually emerging as an innovative technology. At the same time, it is an essential manifestation of the development of the digital sector of architectural graphics. It is widely used in the construction, agriculture, auto, locomotive, aviation, medical insurance, food processing industries, etc. As a new technology, digital software can be integrated with processing equipment to achieve personalized customization and mass production of objects. 3D printing technology has mold-free molding, features such as material saving and customization, and shows great potential in improving construction productivity and safety. The unique potential of 3D concrete printing is that it can create complex geometric structures and has economic and environmental benefits. It is the intelligent construction of China's current construction industry, the development trend of green construction.

4.3.13D PRINTING PROCESS

The complete process of 3D architectural printing mainly includes the following five steps.

(1) 3D model generation: there are many ways to model now. Generally, professional modeling software or a 3D scanner is used; some may be point cloud data

obtained by scanning, NURBS surface information generated by modeling, etc. However, the data obtained may not be in a file format that the 3D printer can recognize; therefore, no matter which 3D modeling software is used, the 3D model generated needs to be converted into a file format that can be read by 3D printers such as stl or obj.

(2) Support structure generation: the support structure can be generated after the slice layering; you can do this before layering the slices. A simple and effective support structure can improve the probability of successful 3D model printing and reduce the waste of expensive printing materials.

(3) Slice hierarchical calculation, slice layering is to layer complex three-dimensional models to obtain simple two-dimensional outlines, facilitating subsequent data processing.

(4) For print path planning, the polygonal outline obtained by slicing layering needs to be filled internally; after filling, the layer forms an actual thin physical layer, printed layer by layer, until printing is completed. Therefore, planning a specific printing path and performing reasonable optimization is necessary to get faster and better printing results.

(5) Post-processing: post-processing of 3D printing refers to processing the surface and unique details of the printed solid model; this aims to improve the accuracy of the model surface.

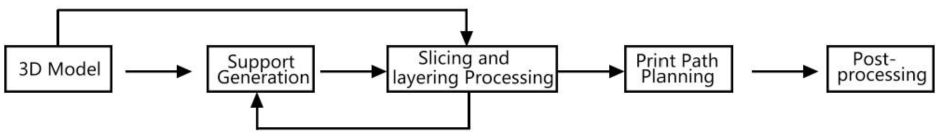


Figure 120 *3D printing process*
Note. Researchers draw their own, 2023

4.3.2 3D PRINTING PATH PLANNING

3D printing path planning refers to, when performing 3D printing, determining the movement path of the print head to construct the object accurately. This is an essential and critical step in the early preparation of digital models and directly affects print quality and efficiency. During the 3D printing process, the 3D printed components need to be modeled and converted into a language that 3D printing can recognize. The print head needs to move according to a particular trajectory, and appropriate path planning must be designed to avoid poor flow or drying out of the material. Then, stack or spray materials layer by layer until the final object is constructed. The path planning algorithm is used to find the optimal moving path, make the movement distance of the print head as short as possible, and find a path with the shortest moving distance to improve printing speed and efficiency. While avoiding collisions, ensure the print head does not collide with the object itself or other parts during movement. Avoid the problem of excessive transition speed and appropriate movement speed, control the moving speed of the print head to print stably during high-speed movement, and slow down when detail is needed to ensure quality.

3D printing path planning requires slicing software to convert the 3D model into a language code that the 3D printing device can recognize. Software matching 3D printing includes 3Dsmax, Maya, Rhino, ZBrush, Fusion 360, Solidworks, UG, Blender, ProE, AutoCAD, Creo, SketchUp, etc., and each modeling software has different features. Different industry fields will have differences in model processing details and function selection; users can choose appropriate modeling software according to their fields. The export formats suitable for slicing software include STL format, AMF format, OBJ format, 3MF format, etc. The advantages of the STL format are that it is easy to read and write, it will make 3D printing easier in the process of reading and writing, STL files have nothing to do with modeling methods, do not rely on any three-dimensional modeling method, regardless of the model structure built using some 3D modeling software, its surface geometry can be discretized into triangular faces and exported to STL format. The STL format also has the characteristic of a smaller storage volume. The advantage of the OBJ format is that it is very convenient for data exchange; almost all software on the market supports the OBJ format. The advantage of AFM is that the AFM format can record color information, material information, internal structure of objects, etc. The advantage of AFM is that it is more precise than the STL format. 3MF format combines the benefits of AFM format and STL format; in addition to geometric information, 3MF, internal information, colors, materials, textures, and other features can also be maintained. After converting the format file, it must be put into the slicing software for 3D printing code processing, providing a recognizable printing language to the 3D printer. Commonly used open-source slicing software includes Cura, PrusaSlicer, Slic3r, Repetier-Host, MatterControl, etc. Most of these software are designed based on FDM 3D printers.

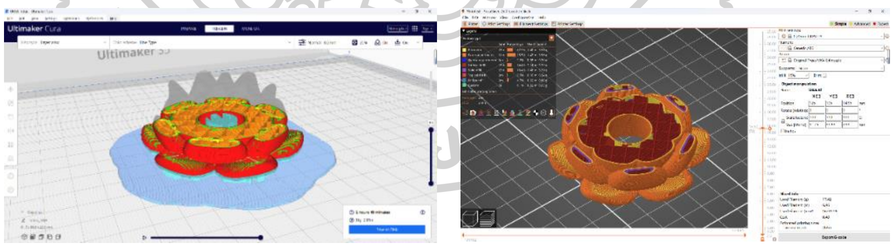


Figure 121 *Cura slicing software preview/ PrusaSlicer slicing software preview*
Note. Researchers draw their own, 2023

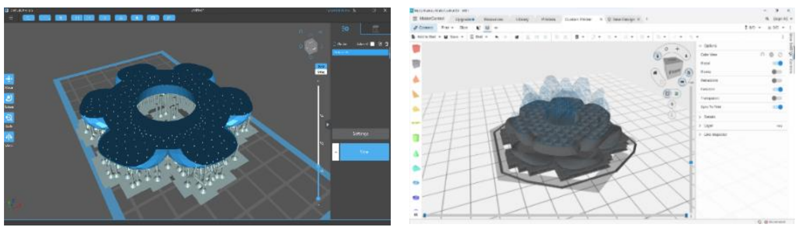


Figure 122 *ChiTuBox slicing software preview/ MatterHackers slicing software preview*
Note. Researchers draw their own, 2023

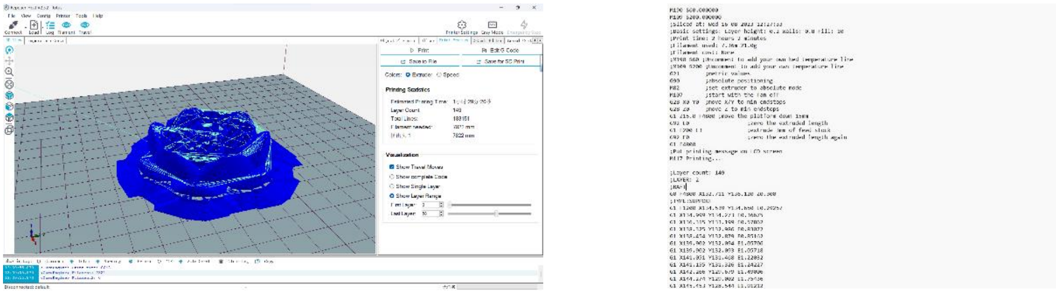


Figure 123 *Repetier-Host slicing software preview/ Slicing code preview*
Note. Researchers draw their own, 2023

There is no open-source slicing software specifically for concrete 3D printing; conventional slicing software processes relatively tiny amounts of data and highly accurate models. How to more accurately convert complex structural models of building components into language codes that can be recognized by printers in the future, concrete 3D printing slicing software is a critical problem that needs to be solved.

4.3.3 RHEOLOGICAL PROPERTIES OF 3D PRINTED CONCRETE

The success or failure of 3D-printed concrete depends on its rheological properties. The rheological performance requirements of 3D printed concrete differ from those of ordinary concrete in achieving the required physical properties of printed concrete components. Rheology is the flow characteristics and performance of concrete during the printing process; 3d printing concrete materials must have some printable properties; it directly affects the accuracy of printing results and the stability of the structure. Good rheological properties ensure the normal flow of concrete in the printing equipment; the diameter of the aggregate particles in the newly mixed concrete slurry shall not exceed one-tenth of the nozzle, preventing clogging during pumping and extrusion. At the same time, it can fill the gaps on the printing path and ensure structural coherence and uniformity. The process of 3D printing is layer by layer; the underlying material needs to bear its gravity for subsequent printed lines; proper plasticity enables concrete to adapt to various component shapes and complex geometric requirements, which allows more diverse and refined print designs. The stability of concrete is also one of the keys to rheological properties. Stability is the ability of concrete to maintain its shape after printing; the shorter the accumulation time interval between layers, the better the interface bonding performance to avoid collapse or loss of structural stability. There is sufficient adhesion between layers when building challenging vertical and cantilevered structures; good stability is essential. The setting time of concrete also needs to be considered for its rheological properties. Generally, the initial setting time of 3D printed concrete materials is between 10 and 45 minutes, and the final setting time is 20~60min; it can be adapted to most printing jobs. Reasonable control of coagulation time can improve printing efficiency, but too fast a solidification rate can cause clogging or structural imbalance. Therefore, the balance between solidification time and printing fluidity must be considered during the proportioning and material selection process.

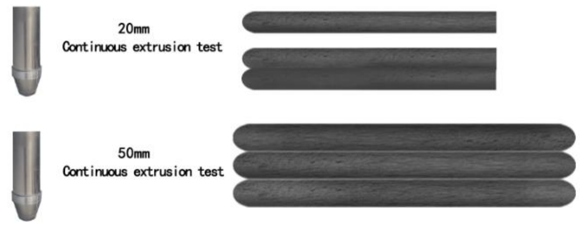


Figure 124 *3D printing line test experiment diagram*
Note. Researchers draw their own, 2023

The rheological properties of 3D printed concrete are crucial elements to ensure printing quality and structural performance; its optimization requires careful consideration of liquidity, can be pumped, extrudability, constructability, plasticity, and indicators such as stability and clotting time to meet specific printing needs and achieve accurate, stable printing results.

4.3.4 3D PRINTING CONCRETE MATERIALS

Research on 3D-printed concrete materials has promoted technological innovation in the construction industry, improved construction efficiency, reduced environmental impact, and achieved a rational use of resources. Further exploration and research in this field will bring more possibilities to the construction industry and promote the construction field to move towards a more innovative, sustainable, and flexible future. Selection and mix design of critical raw materials required for 3D printing concrete materials is to satisfy the pumpability, extrudability, and buildability. LE studied reinforced aggregate concrete, made of CEM525 cement, fly ash, composed of silicate ash and other materials, for print density, strength, systematic testing of porosity, and drying shrinkage; experiments show that density is 2.350Kg/M3, the compressive strength is as high as 91-102MPa, the tensile strength is 13-16 MPa, the porosity is 1.0%, drying and curing shrinkage is 3-4 times that of curing at 100% relative humidity. Ogura designed a high-strength PE fiber ECC material; the volume content of PE fiber is 0.3%-1.5%, and research shows that printed ECC is higher than cast-in-place ECC. Fan Shijian and others combined phosphate cement with rapid hardening, characterized by high adhesion; research shows that the setting time of the material is 1-10 minutes, the compressive strength reaches 40 MPa in 1 hour, and meets structural load requirements. 3D-printed concrete materials highlight the need for improvements to traditional building construction methods. Traditional concrete construction requires a lot of labor and formwork support, resulting in long construction times and high costs, and it limits the realization of buildings with complex geometries. Many studies have been conducted on raw material selection and mix ratio optimization for 3D concrete printing by dispensing concrete directly from the printing nozzle or extrusion port, layer upon layer, realizing the rapid construction of buildings and automated and customizable printing. This technology provides architectural designers greater design freedom and the ability to create unique architectural forms and complex structures. Curved walls, free shapes, and personalized designs are possible, promoting innovative development in the construction industry. Research on 3D-printed concrete materials has also significantly improved the efficiency of building construction. Compared with traditional manual construction methods, 3D printing can dramatically reduce workforce and waste time and resources.

Also, research on 3D-printed concrete materials focuses on environmental impacts. The production process of concrete produces a large amount of carbon dioxide emissions, with the help of 3D printing technology, which can reduce material waste, energy consumption, and pollution, enabling sustainable building construction. This is crucial for environmentally sustainable development and positively impacts the construction industry's sustainability.

The ingredients of 3D printing concrete materials mainly include cement, aggregate, filler, additive, fiber materials, and admixtures. Cement is the primary cementing material in concrete, such as ordinary Portland cement, sulfate cement, etc., and it forms a gel-like substance through a chemical reaction with water and plays the role of bonding and hardening. Commonly used cement types include Ordinary Portland Cement (OPC) and other specialty types of cement. Aggregate is the granular concrete filler, including fine aggregate and coarse aggregate. Fine aggregate is called sand or mortar; it is a filler in concrete used to fill the gaps between cement gels. Commonly used fine aggregates include quartz sand, stone slag powder, etc. Coarse aggregate is used to increase the strength and stability of concrete; common coarse aggregates include gravel, pebbles, gravel, etc. Additives are chemicals added to concrete and used to adjust the fluidity of concrete, delay or accelerate setting time, improve concrete properties, etc. Common additives include water-reducing agents, delay agents, accelerators, bubble agents, thickeners, etc.

In some cases, fiber materials, such as steel fiber, polymer fibers, etc., can be added to increase the crack resistance and toughness of concrete. Admixture is a material that partially replaces cement, such as fly ash, slag powder, etc., that can improve the performance of concrete and reduce environmental impact. The specific composition of 3D-printed concrete materials can be adjusted and optimized for different projects and applications. Customized design can meet specific building needs and performance requirements and further promote the innovation and application of 3D printing concrete technology in construction. The concrete mix ratio Cement refers to ordinary Portland cement that meets the IS12269 standard 10% - 15%, Fly ash refers to fly ash F-ASTMC618 type 25% - 30%, Quartz powder, Quartz sand 1/2 quartzite sand with two different particle sizes, the particle size is smaller, polypropylene fiber 30%-40%, Length 12 mm, Diameter is 40um. Add 0.3% nanoparticles clay NC to concrete, 10% silicate ash SF, and 0.1% viscosity modifier VMA as a percentage of cementitious material mass, which can increase its stability and robustness. Formulating a 3D printing concrete mix ratio is dynamic; continuous experimentation and optimization are required. To develop the best mix ratio that suits the project needs.

Table 7 *Concrete mix proportion diagram*

Material	Quantity(kg/m³)		
	Mix SF	Mix NC	Mix VMA
Cement	573.6	663.0	663.0
Fly ash	164.0	165.7	165.7
Quartz powder	491.7	497.2	497.2
Quartz sand 1	368.7	372.9	372.9
Quartz sand 2	368.7	372.9	372.9
Water	262.2	265.2	265.2
Polypropylene fiber	1.8	1.8	1.8
Superplasticizer	1.39(0.17%)	1.08(0.13%)	1.49(0.18%)
Superplasticizer	Silica fume	Nanoclay	VMA
Additive dosage	81.9(10%)	2.47(0.3%)	2.47(0.3%)

Note. Researchers draw their own, 2023

4.3.5 3D PRINTING EXPERIMENTAL ANALYSIS

3D printing uses a multi-window format, and layers and paths are used to display visual effects; it helps researchers to make local adjustments to the STL three-dimensional model to be printed; many unique STL 3D models require layering or adding supports at appropriate locations and improves the probability of successful 3D model printing, it can also save printing materials during the 3D printing process, thereby saving the cost of 3D printing.

Table 8 *Hierarchical algorithm execution time*

Model name	Triangular dough number	Slic3r processing time (s)	KISSlicer processing time (s)	Current algorithm processing time (s)
Door	950	2.29	3.76	2.01
Window	5204	4.12	5.89	3.24
Stairs	43690	6.98	8.06	7.56
Roof	69664	10.41	9.56	8.37
Wall	100368	30.72	31.288	26.14

Note. Researchers draw their own, 2023

4.3.6 3D PRINTING EVALUATION ANALYSIS

Evaluation analysis is a crucial step in the design production and process of the parametric lotus building based on 3D printing technology. At this stage, we will discuss the structural stability of lotus buildings and the building exterior, conduct detailed data evaluation and analysis on economics and sustainability, etc., to ensure the quality and feasibility of its design and production.

(1) Structural stability evaluation analysis

In assessing the structural stability of the lotus building, we first used the finite element analysis method. Using finite element analysis tools, we simulated the structural response of the lotus building under various load conditions and promptly compiled relevant data. Then, we compared the results of the numerical analysis with the experimental data; the consistency between the two was very high. We measured the deformation of the structure under different loading conditions, including displacement and stress distribution under vertical and horizontal wind loads. We also conducted experiments on strain and temperature changes within individual parts of the structure and the overall system. With the help of this data set, we can evaluate the structural stability of Lotus buildings to ensure that the building maintains excellent structural integrity and a high level of safety under various load conditions.

Table 9 *Structural stability assessment results*

Structural stability index	Vertical load	Maximum displacement	Maximum stress	Horizontal wind load	Maximum displacement	Maximum stress
Numerical value	5KN	0.023mm	40MPa	2KN	0.018mm	30MPa

Note. Researchers draw their own, 2023

According to the above data, Lotus buildings' structural integrity and safety are guaranteed under conditions such as vertical and horizontal wind loads.

(2) Building appearance evaluation analysis

The exterior design of the Lotus Bionic Parametric Building is one of the critical elements of its unique charm. There are significant differences in form and spatial layout from other architectural styles. When evaluating a building's appearance, the researchers compiled the three-dimensional data of the architectural model and analyzed it in depth from a visual perspective. Researchers have studied the smoothness of lines in lotus architecture; data on the overall sense and visual effects were comprehensively measured, including building height and multiple parameters such as width and curvature. To present the unique shape of the lotus building more deeply, researchers conducted detailed modeling and rendering work on the building. Lighting simulation analysis was also performed to evaluate the appearance of the building under different lighting conditions. Image analysis techniques were used to study the interior structure of the building. After an in-depth discussion of this batch of data, it can be evaluated whether the exterior design of the lotus building meets public expectations and aesthetic and practical requirements. Lighting simulation results: on a sunny day, the building's appearance is bright and clear, and the unique curvilinear shape makes it a distinctive landmark building. On a cloudy day, the building's appearance is soft and natural, highly integrated with the surrounding environment. At night, the lighting effect of the building exterior is good, presenting beautiful visual effects.

Table 10 *Building appearance assessment results*

Building appearance Index	Building and height	Building width	Building curvature
Data	12m	15m	2m

Note. Researchers draw their own, 2023

From the above data, the exterior design of the Lotus building is in line with expectations and has reasonable aesthetic and functional requirements.

(3) Economic evaluation analysis

Researchers have mainly focused on construction costs and construction schedules in assessing the financial return on lotus construction. Various data related to 3D printing production were organized, including materials, labor, and equipment costs, and conducted an in-depth analysis of these data. In-depth data recording and detailed analysis of the Lotus Building's construction cycle were also performed. The number of components and required costs will also be estimated at each point in time. Through this data set, we can calculate the cost and time needed to manufacture a lotus building and then evaluate its implementation potential in economic terms.

Table 11 *Economic evaluation results*

Economic index	Material costs	Labor cost	Equipment cost	Construction Cycle
Data	10,000 yuan	15,000 yuan	8,000 yuan	30 days

Note. Researchers draw their own, 2023

From the above data, it can be seen that the production cost and production time of the lotus building are within the controllable range, and it has certain economic feasibility.

(4) Sustainability Assessment Analysis

Environmental friendliness and reusability were considered when assessing the sustainability of lotus buildings. For material recycling efficiency, data is collated on the energy efficiency of buildings and their impact on the environment during their life cycle, and an in-depth analysis of these data is conducted. The accountability and reconfigurability of Lotus buildings were analyzed to assess their performance in terms of sustainability. After an in-depth analysis of this batch of data, we evaluated the performance of Lotus buildings in terms of environmental friendliness and resource efficiency; this ensures that it can demonstrate outstanding performance on the road to sustainable development.

Table 12 *Sustainability assessment results*

Economic index	Material recycling rate	Building energy efficiency	Building life cycle environmental impact	Disassembly and reconfigurability

Data	70%	80%	Medium	Good

Note. Researchers draw their own, 2023

From the above data, lotus architecture has good environmental protection and sustainability performance and meets the requirements of sustainable development.

Overall, the evaluation and analysis of the parametric lotus architectural design using 3D printing technology covered multiple data collection and analysis steps to ensure that the design is structurally designed, appearance design, economic benefits, and sustainability can meet the predetermined design goals. Renewable building materials also have the feature of being able to be used multiple times. This set of data analyses provides precious reference information for researchers and architectural designers. It helps optimize design solutions more effectively to ensure Lotus bionic parametric architecture's high quality and practicality.

4.4 LOTUS BIONIC PARAMETRIC ARCHITECTURE DIGITAL TECHNOLOGY COLLABORATIVE DESIGN INNOVATION AND PRECISE CONSTRUCTION

Lotus bionic parametric architecture attempts to explore a new design method, interpreting our new understanding of contemporary architecture. Create innovative architectural value in many aspects. The topological creativity of the lotus eliminates the straight and orthogonal features in traditional architectural spaces and creates a harmonious relationship between buildings and urban public spaces. Based on the overall design concept and the robust control brought by digital technology, being fully involved in morphological geometry, building logic, and the material expression of aesthetic experience created a unique technical system and original aesthetic form. This is also a promotion of the poetic construction spirit in traditional architecture. The establishment of complex geometric systems has provided significant help for the high-precision design control of Lotus bionic parametric buildings; it not only gives the building a clear geometric order, but at the same time, he is also an auxiliary architect in the function, aesthetics, thinking comprehensively about complex issues such as structure, an effective way to integrate solutions.

4.4.1 DESIGN BACKGROUND

In the research process of contemporary Chinese bionic parametric architectural design, using China Knowledge Infrastructure Engineering Network search for relevant keywords, for example, bionic design, parametric design, architectural design, lotus pattern, etc. As the academic community's understanding of bionic parametric architecture increases, as well as the continuous deepening of architectural design exploration, researchers are more focused on specific aspects of bionics applications, and with the help of parametric design modeling, 3D printing technology and other means are explored and tried.

The Lotus Bionic Parametric Building adopts new technological means, such as parametric design and three-dimensional collaboration, to cope with the test of complex technology. For terrain analysis, functional features, structure, material, aesthetics, energy saving, sunshine, innovations in building systems such as ventilation, digital construction control, and other technical links, several technological innovations have been carried out based on the conditions of the construction industry and the project itself, lotus bionic parametric architecture provides a new paradigm for the development of digital architecture.

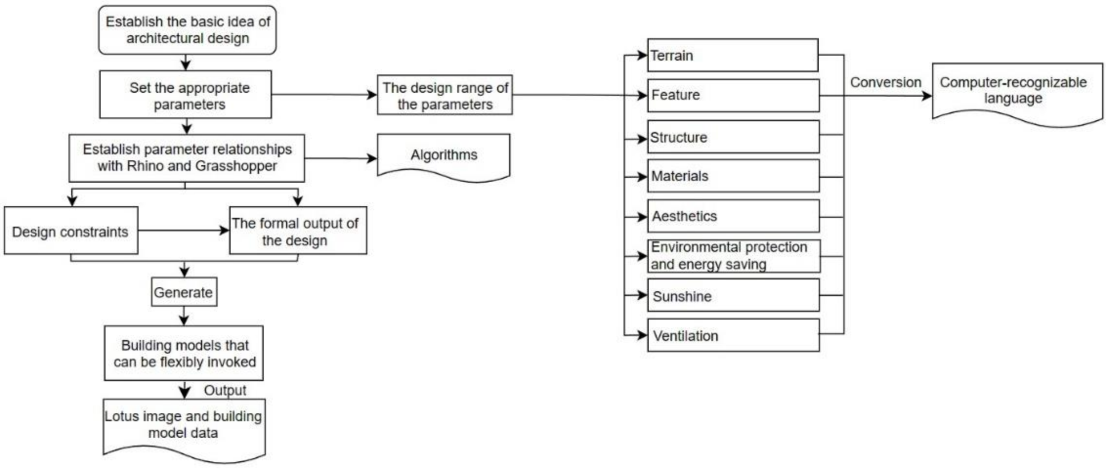


Figure 125 *Architectural collaborative design Process analysis chart*
Note. Researchers draw their own, 2024

4.4.2 RESEARCH RESULTS OF ART AND DESIGN EDUCATION LOTUS BIONIC PARAMETRIC ARCHITECTURAL COLLABORATIVE DESIGN WORKSHOP

The third Art and Design Education Lotus Bionic Parametric Architecture Collaborative Design Workshop Research was held at Changzhou Technician College, Jiangsu Province, China, and the team consisted of 16 undergraduate students. Through bionic parametric design methods, combined with the shape of a lotus, explore innovative architectural design. Through teamwork, combined with the profound conclusions of the first workshop on lotus bionic morphology, an in-depth study of the biological characteristics and structural morphology of lotus flowers explores the laws of nature. Based on the practical work efficiency and valuable experience of the second workshop, use parametric design tools to explore incorporating the natural beauty and structural features of the lotus into architectural design.

After the third Lotus bionic parametric architectural design workshop has ended, project exhibitions and interviews will be conducted, and the effectiveness of summary harvesting will be investigated. The researcher took photos and videos to record the answers.

4.4.2.1 ADDRESS ANALYSIS

The Lotus Bionic Parametric Building is located at the public training base of Changzhou Technician College in Jiangsu Province, China. On the south side are high-rise buildings constantly being updated; on the east and north sides are the irreproducible ecological landscapes of the adjacent forest park, surrounded by school roads from the west to the south. With the new round of development of the school's practical training base, the location of the Lotus Bionic Parametric Building shows superior location advantages. Only by allowing Lotus bionic parametric architecture to dialogue with the environment can architecture truly be rooted in urban development.

Figure 126 *Lotus bionic parametric building address map*
Note. Researchers draw their own, 2024

4.4.2.2 FUNCTIONAL FEATURES

Lotus bionic parametric architecture is used in the art design exhibition of the public training base of Changzhou Technician College in Jiangsu Province, China. Presenting a unique characteristic form in the public training base, provided to schools as culture, a communication platform for art, science, and technology. Lotus bionic parametric architecture can adapt to various exhibition activities and cultural performances and maximize the function of multi-functional space. Create an event space with an engaging, interactive display and experience design.

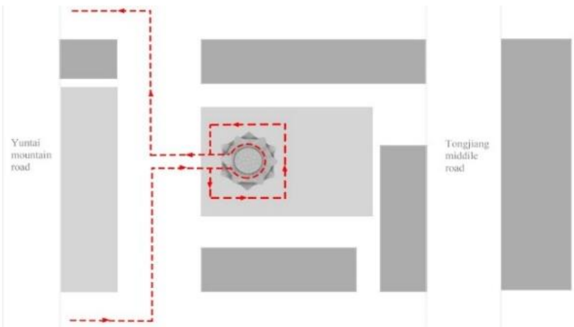


Figure 127 *Application renderings of Lotus bionic parametric building functional features*
Note. Researchers draw their own, 2024

The functional features of Lotus Bionic Parametric Building mainly provide ideal space for various art and design exhibitions and offer students and visitors a profound cultural experience. The streamlined appearance and flexible space planning layout of Lotus Bionic Parametric Building create a multi-level exhibition area and meet different types of project exhibitions. Lotus bionic parametric architecture also focuses on adaptability and coordination with the surrounding environment, using environmentally friendly and energy-saving materials combined with natural light to create a more comfortable exhibition atmosphere.

Lotus bionic parametric architecture incorporates elements of traditional culture, reflecting the charm of creative design in art decoration. This sustainable architectural design practice inspires architects to think, conveys the message of social civilization responsibility, and guides people to pay attention to environmental protection, folk customs, and social issues.

4.4.2.3 STRUCTURE

In essence, research on the Lotus bionic parametric building structure is the study of structural form; it is the focus of researchers' research. The study of structural forms promotes the integration of technology and art in architectural design, the artistic development of structure, and the progress of the two disciplines of architecture and structure.

Research on the Lotus bionic parametric building structure shows it is a complex system that intensely pursues the balance of nature. The lotus bionic structural form has good adaptability and stable living status; it presents the synergistic state of natural structural form and force. Through abstract cognitive understanding of lotus nature, nature is transformed into technological progress and development to better integrate into nature and the environment and unleash the more significant potential for creativity.

Researchers developed a gradient size lotus model for parametric design, spiral lotus model, abstract geometric lotus model, wavy lotus model, star-shaped lotus model, symmetric split lotus model, vector line drawing lotus model, three-dimensional lotus model, interspersed with staggered lotus models, a detailed experimental design study was conducted on the multi-level overlapping lotus model.

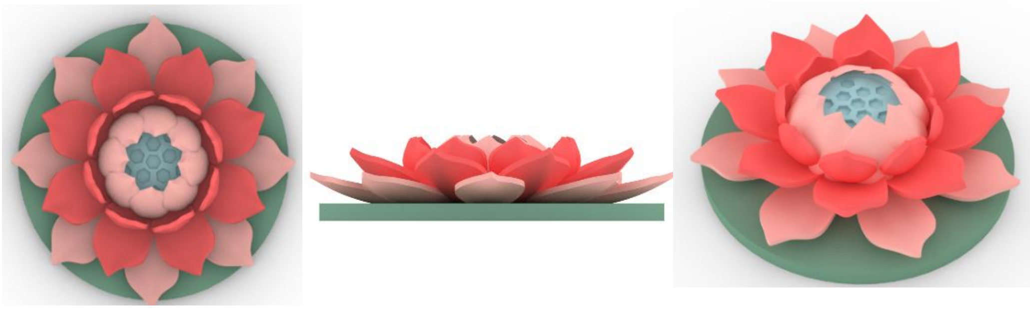


Figure 128 *Parametric design and development of gradient size lotus model*
Note. Researchers draw their own, 2024

In parametric design and development of gradient-size lotus models, researchers achieve subtle control over the shape of lotus flowers, creating a unique lotus shape with a gradient effect. It is both modern and full of artistic design effects. First, the number of lotus petals and their basic shape structure are determined, and a basis for subsequent parameter adjustment is provided. Adjust parameters at any time to achieve the ideal gradient size effect. The gradient size effect gives the lotus a smooth and dynamic appearance, creates a sense of layering between the petals, and increases the three-dimensional understanding of the overall lotus. This innovative design method enriches the expression of the lotus pattern while providing sufficient space for integrating art and technology.

Figure 129 *Parametric design and development of spiral lotus model*
Note. Researchers draw their own, 2024

Parametric design and development of spiral lotus model, by setting the rotation angle, make the petals wrap around the center point, with a certain angular velocity and angular acceleration, carry out spin motion to produce spiral direction growth, form a unique spiral shape. At the same time, by adjusting the helicity parameters, researchers can control the tightness of the lotus spiral, thereby changing the looseness or tightness of the overall structure.

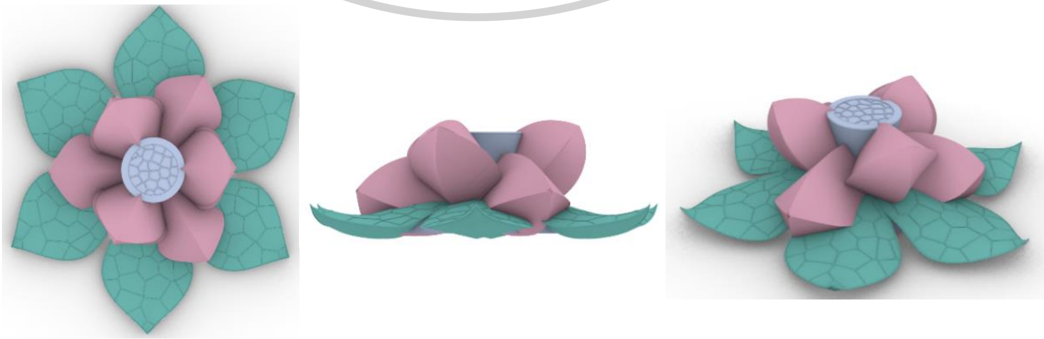


Figure 130 *Parametric design development of abstract geometric lotus model*
Note. Researchers draw their own, 2024

Parametric design and development of abstract geometric lotus models and parametric deformation give the lotus an abstract and dynamic form. Unconventional deformations of shape or structure, distorted, drag, stretch, and non-uniform deformation of graphics through rotation and other methods affect the entire structure. Researchers broke the rules; this design approach presents a modern and avant-garde feel; the lotus shape is full of unique creativity and a simple and contemporary design.

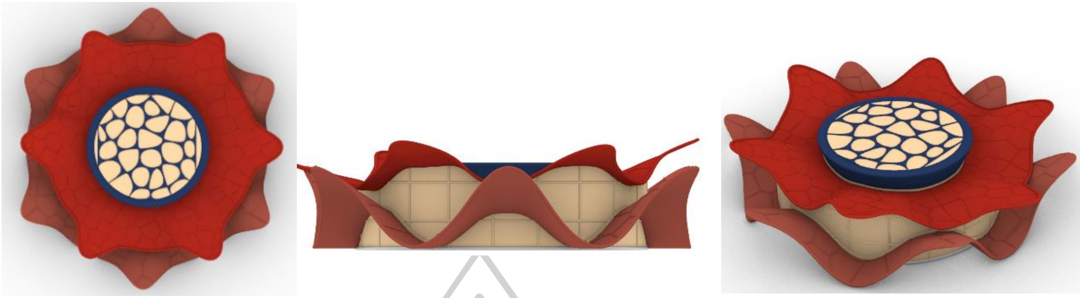


Figure 131 *Parametric design and development of wavy lotus model*
Note. Researchers draw their own, 2024

In the parametric design and development of the wavy lotus model, wave-like elements may carry specific meanings in culture, religion, artistic symbols, etc. Wavy is a pattern or structure that resembles water ripples or waves, with flow, continuous, and elegant features. By parameterizing the volatility and wavelength, adjust the amplitude, parameters such as frequency and phase, and get waves of different shapes and sizes. Researchers form a wavy lotus; the overall lotus bionic pattern presents a vivid and exciting dynamic. The wavy shape symbolizes change, flow, the cycle of life, and so on. This design method adds artistic abstraction, beauty, and flexibility to the shape.

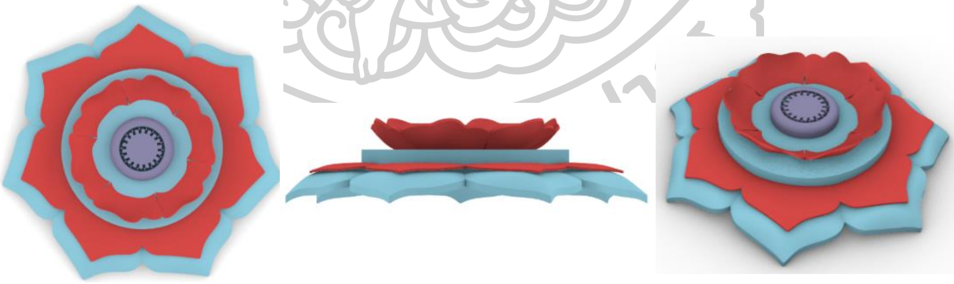


Figure 132 *Parametric design and development of star-shaped lotus model*
Note. Researchers draw their own, 2024

Parametric design and development of star-shaped lotus model: by adjusting the arrangement of petals, researchers create a star-shaped lotus form, creating a mysterious and breathtaking beauty of stars. In geometry, a star-like shape with prominent corners or branches, making it look like a star, forms a structure with a central point radiating outward. Star shapes convey symbolic meaning and represent light, uniqueness, inspiration, and more.

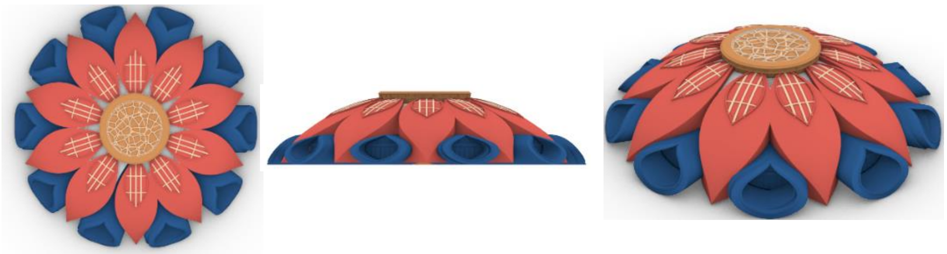


Figure 133 *Parametric design and development of symmetrical split lotus model*
Note. Researchers draw their own, 2024

In the parametric design and development of the symmetrical split lotus model, researchers adjust the symmetry and division of petals, realizing the petals from the center outward, and the layer-by-layer split creates a symmetrical and beautiful effect. A split shape appears around the center point. This design gives the lotus a layered and three-dimensional feel, showing rich morphological changes. Symmetrically Split Shapes: This shape attracts visual attention and brings a dynamic and exciting element.

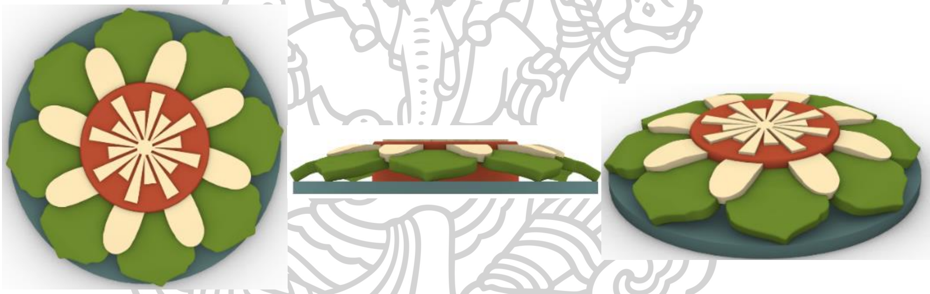


Figure 134 *Parametric design and development of vector line drawing lotus model*
Note. Researchers draw their own, 2024

Parametric design and development of vector line drawing lotus model: using parametric technology, researchers use shapes, paths, and curves to create a lotus model in a flat vector line drawing style. Defined by mathematical equations, edit the properties of shapes and lines, and adjust the curve's curvature to present a simple and modern design. This vector line drawing design method makes the overall effect artistic and fashionable.

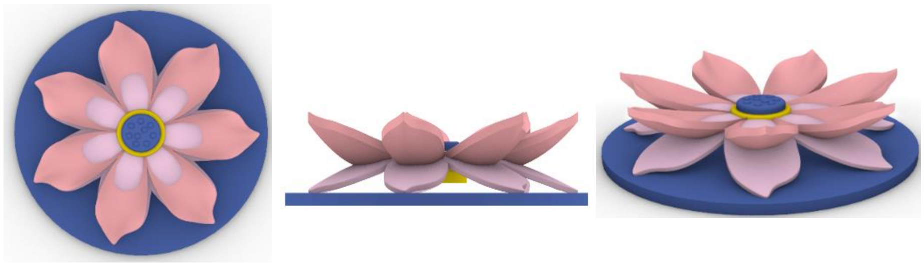


Figure 135 *Parametric design and development of a three-dimensional lotus model*
Note. Researchers draw their own, 2024

In the parametric design and development of the three-dimensional lotus model, the image of the lotus appears three-dimensional, with an effect of depth and layering. Researchers make petals, elements such as leaves visually present layering and a sense of depth and three-dimensionality. Adopt positive and negative shapes; floor plans tend to be flat; the facade makes the whole lotus no longer look flat, creates a lifelike three-dimensional effect, and presents a sense of reality.

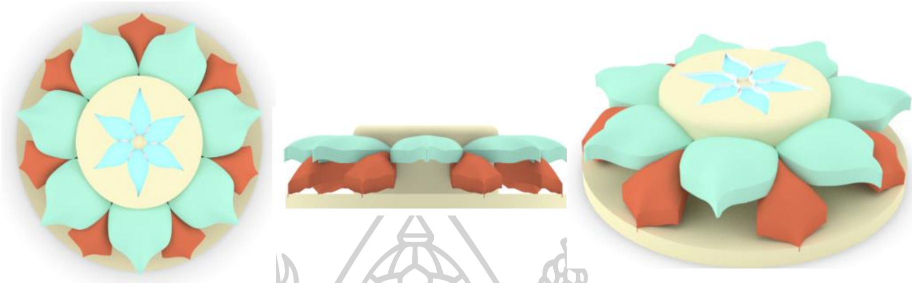


Figure 136 *Parametric design and development of interleaved lotus model*
Note. Researchers draw their own, 2024

Researchers interlaced and interspersed petals in the parametric design and development of the interspersed lotus model. Adjacent petals are not simply stacked one on top of the other; instead, they are intricately interwoven and arranged in a dislocated manner, creating an effect. The interspersed relationship makes the overall lotus model richer, has a three-dimensional feel, adds visual layering and depth, and adds complexity to the design.

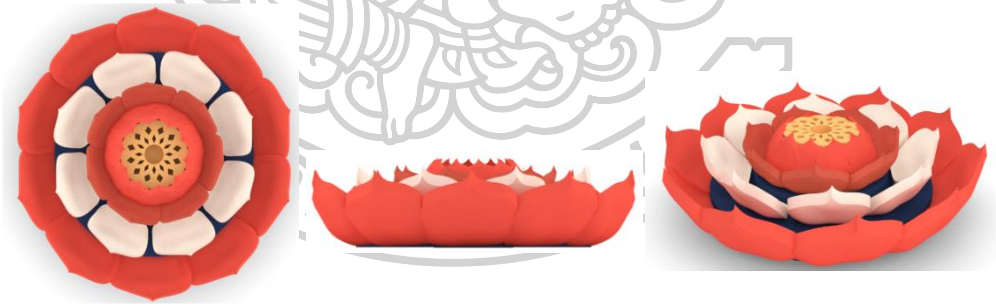


Figure 137 *Parametric design and development of multi-level overlapping lotus models*
Note. Researchers draw their own, 2024

Parametric design and development of multi-level overlapping lotus models create a plump and layered lotus flower. The multi-layered lotus model stacks petals or other structures layer by layer in a vertical direction, and a layered effect is formed. Each layer can exist visually independently; multiple layers overlap to create a sense of space, create visual depth, and add a sense of layering. This design makes the overall lotus three-dimensional, showing rich and vivid forms.

During the research process of lotus bionics, recognition and simplification of natural logic are critical, and the core lies in abstracting natural complexity into points, wire, dough slices, and a mathematical description language for bodies.

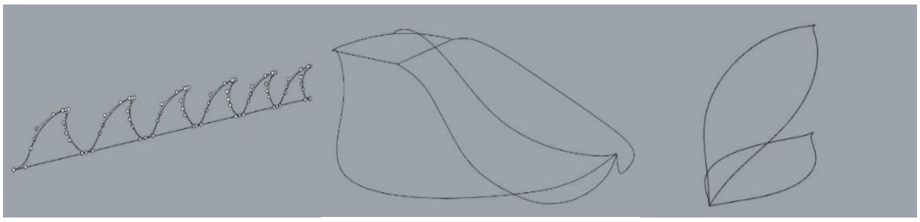


Figure 138 *Construct a lotus linear structure*
Note. Researchers draw their own, 2024

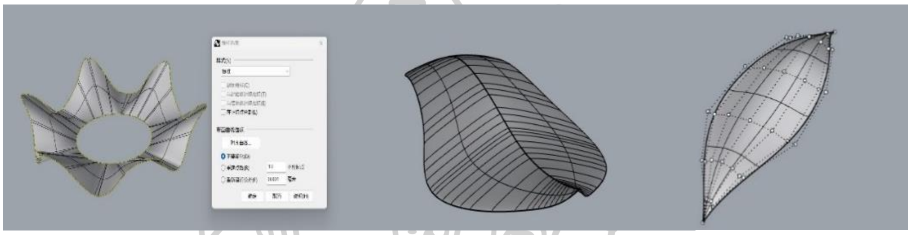


Figure 139 *Construct a lotus face structure form*
Note. Researchers draw their own, 2024

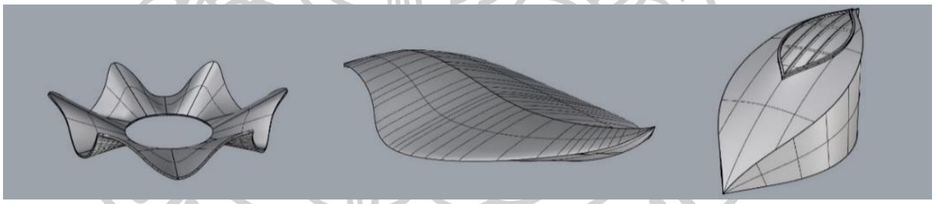


Figure 140 *Construct a lotus-like structure*
Note. Researchers draw their own, 2024

Parametric modeling Voronoi diagram plays a role in the structural design of the Lotus bionic building. By adjusting parameters, researchers can optimize the structure of Lotus Bionics to better adapt to the external environment; at the same time, the beauty of the building is taken into consideration. The structural design of this Voronoi diagram makes the building no longer just a functional existence; it has become an organism in harmony with nature.

The digital model of the Voronoi diagram algorithm program is generated by writing a Voronoi algorithm program. Put the Voronoi diagram algorithm program into the design software platform, such as RhinoScript, Maya built-in language, Visual Basic, 3DMaxScript, and other design software platforms. Achieved in combination with different algorithms and computer programming script languages, expand and generate a series of Lotus bionic parametric architectural design works. These design software platforms can generate algorithmic works of lotus bionic art forms with diverse, complex uncertainties.

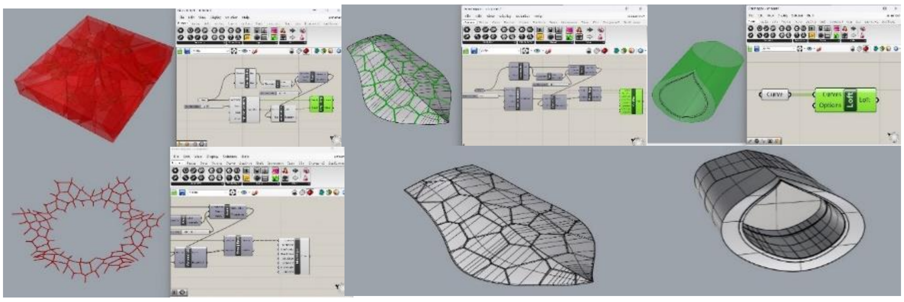


Figure 141 *Construct the structural form of the lotus Voronoi diagram*
Note. Researchers draw their own, 2024

In the Lotus bionic architectural design, some morphological characteristics of the lotus' basic form are applied to the bionic form; that is, while the bionic form meets the functional role, it gives it a specific visual beauty or symbolic meaning. The principle of lotus bionic design is to simulate the shape and structure of lotus flowers in nature, providing design inspiration and a basis for parametric modeling. The combination of parametric modeling and bionic design is the key to the success of Lotus bionic architectural design.

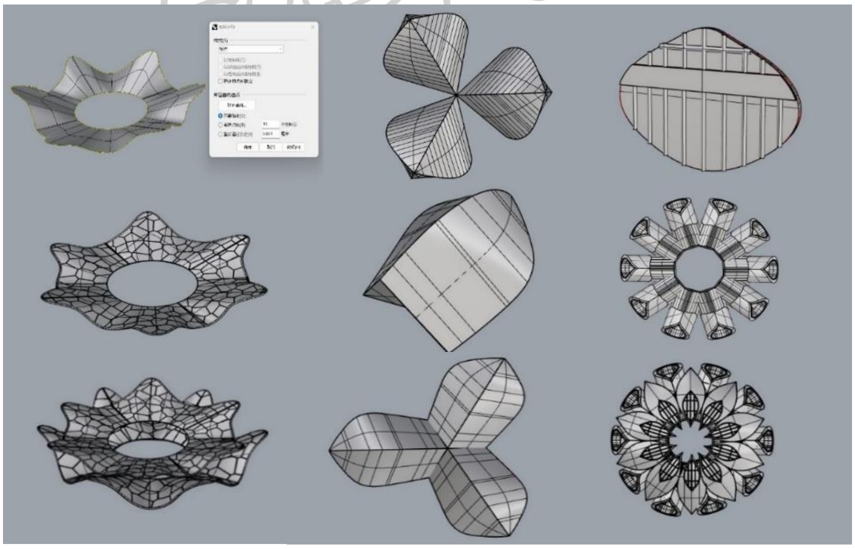


Figure 142 *Constructing the lotus bionic basic structure form*
Note. Researchers draw their own, 2024

The purpose of researchers applying bionic forms in lotus bionic parametric architectural design is to use the natural lotus shape, a well-known archetypal symbol, used in architectural form design, create humanized architecture, eliminate the barrier between people and buildings, constructing the bionic organic characteristic form of a lotus, make it easier for the public to understand and accept the message conveyed by the building, and get a sense of satisfaction and accomplishment from using it.

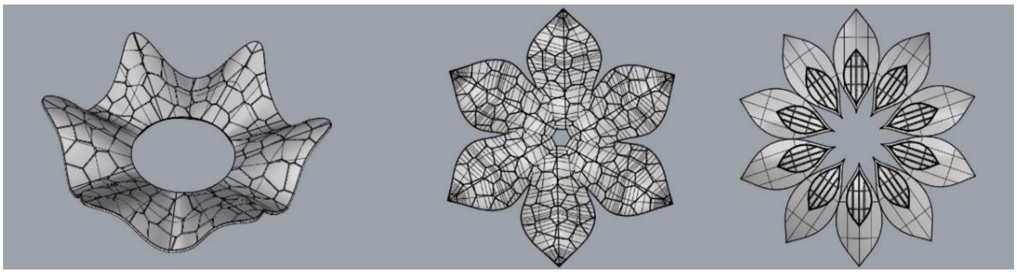


Figure 143 *Constructing the bionic organic characteristic form of lotus*
Note. Researchers draw their own, 2024

Parametric design is a method that integrates scientific rationality and artistic sensibility and allows researchers or architectural designers to tailor a design that conforms to the corresponding logical structure, making architectural design closer to the process of natural creation and constructing a geometric parametric structural form of a lotus. Therefore, parametric modeling design provides strong support for innovation in architectural forms. In traditional architectural design, designers are often limited because manually adjusting every design element is tedious and time-consuming. Parametric modeling uses mathematical and algorithmic operations and enables instant adjustment of many design parameters, allowing designers to explore different forms and structures more intuitively. This flexibility and efficiency provide a broader space for architectural form innovation so that architecture is no longer shackled by traditional thinking and can better adapt to the needs of contemporary society.

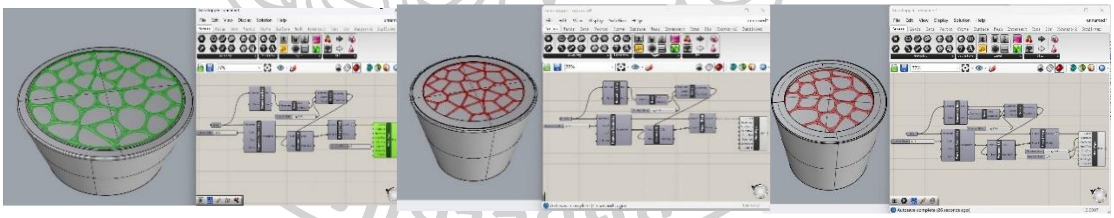


Figure 144 *Constructing the geometric parametric structural form of a lotus*
Note. Researchers draw their own, 2024

The lotus skin structure design left a deep impression. The development of modern computer graphics technology and the continuous rise of digital design involving mathematics in architectural design generation, geometry, physics, and complexity science has become a trend in architectural design. When researchers study epidermal characteristics, it is not difficult to find the Voronoi diagram graphic relationship, regardless of its surface characteristics or construction significance; all have a particular impact on the design, application, and construction of lotus bionic parametric buildings. In the geometric algorithm of the Voronoi diagram of the lotus epidermal structure, researchers generate digital models by writing Voronoi algorithm programs, using the Voronoi algorithm to generate lotus epidermal structure patterns, building structure, and space planning. This design method of skin structure form is pioneering architectural design and architectural schools for experimental purposes. As an exploration and innovation in architectural design, the Voronoi diagram has become one of the digital design methods for quickly finding shapes in epidermal structure and form design. With current computer technology, the Voronoi diagram can be used in architectural practice with building skin and construction layout and combined with applications in other systems such as building space configuration; this will be more conducive to promoting the development of architectural innovation.

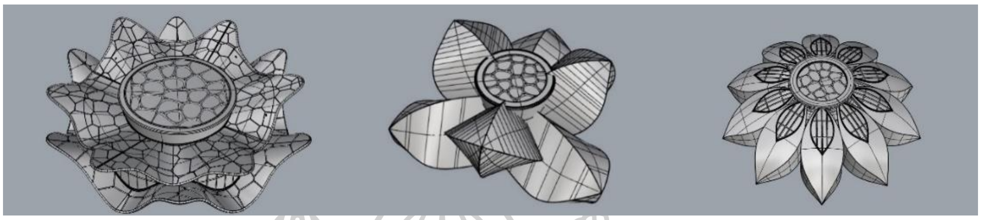


Figure 145 *Constructing the structure and form of the lotus epidermis*
Note. Researchers draw their own, 2024

It is constructing a lotus bionic parametric structural form resulting from applying nonlinear theory in architecture, negating the Euclidean geometric architectural form, and reflecting natural architectural forms. The structural form carries structural force through specific physical forms; it does not appear as a virtual force field; structural form is, therefore, a form of physical resistance. Therefore, structural form is not only about the function of building use; it also has the primary meaning of a structure. The birth of parametric architecture, breaking people's aesthetic standards for traditional architectural forms, gradually made this continuous flow; random, irregular, non-standard geometric shapes have become the mainstream architectural design.

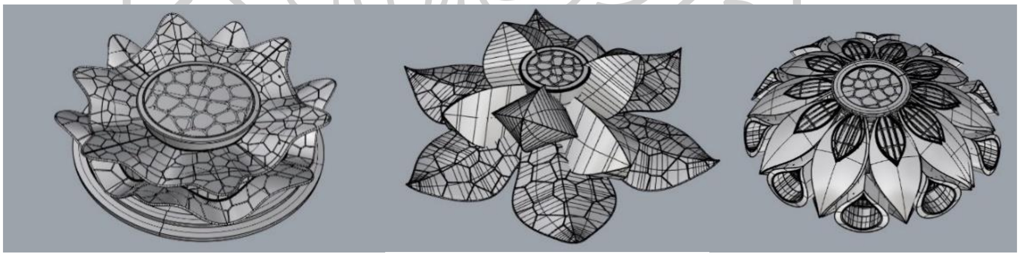


Figure 146 *Constructing a lotus bionic parametric structural form*
Note. Researchers draw their own, 2024

The application of parametric technology brings excellent flexibility to structural form design, makes architectural design easier to control, and accurately handles complex shapes. Parametric architectural design has changed traditional structural form design ideas and concepts, transforming structural form thinking from focusing on results to processes. The central core is to revolutionize the original top-down design method and process, make architectural design controllable from the bottom up, and develop technology-driven design.

4.4.2.4 MATERIALS

In lotus bionic parametric architecture, the surface covering of the form, the epidermis, and various creations have also appeared, some of them integrating ecology, sustainable technologies, and concepts. Regarding building materials and design, China encourages the adoption of renewable, recyclable building materials, reducing the loss of natural resources. Promoting green design concepts and the rational design of architectural forms, the application of green roofs, and other specific environmental design measures contribute to the sustainable development of buildings and improve the eco-friendliness of the entire industry. China has promulgated the GB/T 50878 green industrial building evaluation standard. They are starting by optimizing building materials, using new insulation materials, obtaining sound thermal insulation effects at lower costs, achieving energy savings, and producing environmental protection effects.

Solar energy is a green energy source with tremendous energy, is widely distributed, renewable, and has no pollution. It is currently one of the ideal alternative energy sources in various countries. Solar photovoltaic power generation uses the photovoltaic effect of solar cell semiconductor materials to convert the sun's radiant energy into electrical energy. In 2010, China's power generation capacity reached 10GW, and it is expected that in 2025, photovoltaic energy will account for 22% of the world's total energy. This shows photovoltaic energy is one of the most effective materials.

Solar photovoltaic power generation systems have three parts: a controller, solar panels, and an inverter. The solar controller controls the working status of the entire system and prevents overcharging or over-discharging of electrical storage equipment. Solar panels are the core part of the power generation system, but they are also the most expensive part. Solar panels can be connected in series or parallel as needed. Convert solar energy into electrical energy under sunlight, push the load to work, or send it to the power storage device for storage. Inverters are used in photovoltaic power generation systems; the output is generally 12V, 24V, and 48V DC. To get AC power, you need to use inverter equipment(Bushra, 2022).

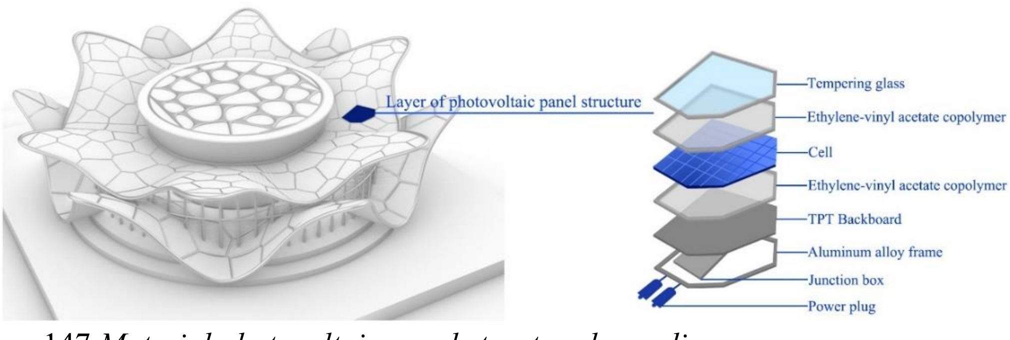


Figure 147 *Material photovoltaic panel structure layer diagram*
Note. Researchers draw their own, 2024

China updated and implemented 2019 a unified standard for energy-saving design of industrial buildings GB51245-2019; there are regulations on wall insulation materials and sunshade materials used in buildings. It is required that building design consider the concept of passive energy saving to the greatest extent, as this reduces active energy consumption.

Ethylene Tetm nuoro Ethylene's Chinese name is ethylene tetrafluoroethylene copolymer, commonly known as soft glass; it is a light and flexible, translucent and environmentally friendly film, fluorine-based plastic ETFE membrane material, suitable for building roofs and walls. Currently, the strongest fluoroplastic maintains excellent heat resistance of PTFE, chemical resistance, and electrical insulation properties; simultaneously, it is resistant to radiation, and the mechanical properties and processing properties have been greatly improved. ETFE membrane material, has light weight, good toughness, high tensile strength, muscular flexibility, strong weather resistance, and chemical resistance, has good fire safety, will not spontaneously ignite, has high visible light transmittance, has excellent self-cleaning function, dust is not readily adsorbed on its surface, good adaptability, can be processed into almost any size and shape, ETFE film can be pre-made into film airbags, assembled on site, inflatable, construction, easy maintenance, and other advantages.

Figure 148 *ETFE membrane material*
Note. Photographed by researcher, 2023

The light transmittance of ETFE film is excellent, the ability to reliably regulate environmental conditions within buildings through UV transparency, and layered to control sunlight conditions and low friction coefficient, prevents dust or dirt from adhering to its surface, this reduces maintenance requirements.

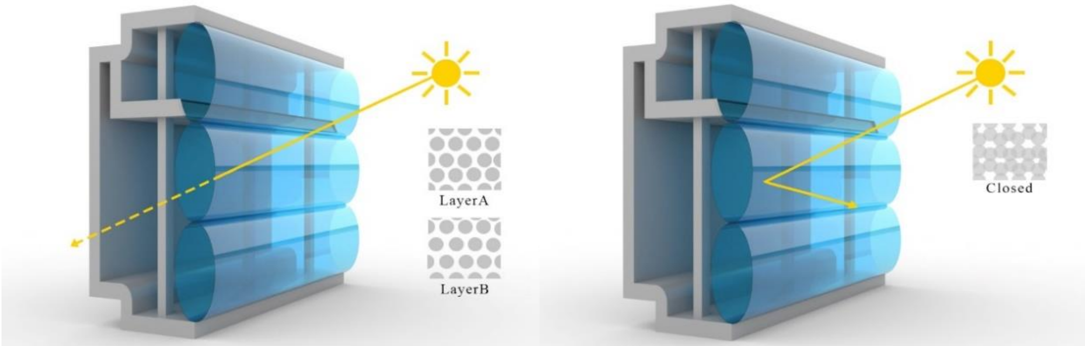


Figure 149 *ETFE film light absorption test simulation diagram*
Note. Researchers draw their own, 2024

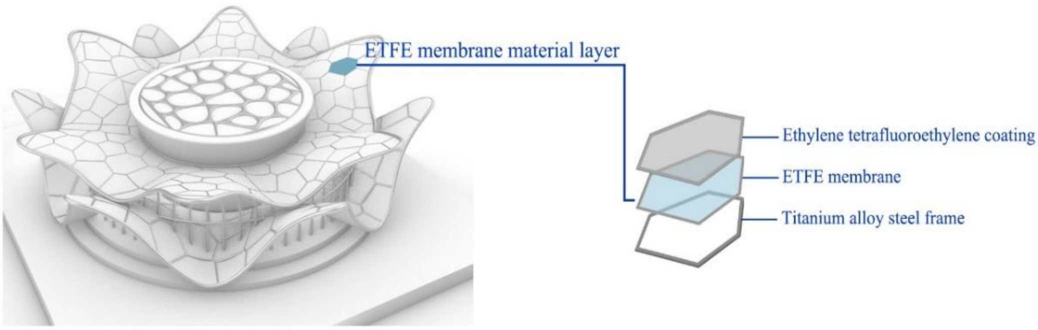


Figure 150 *Material ETFE membrane structure layer diagram*
Note. Researchers draw their own, 2024

4.4.2.5 ARCHITECTURAL AESTHETICS

Lotus bionic parametric architectural aesthetics, through the design of the lotus bionic structure, create something with elegance and a beautiful, eco-friendly particular building form. Cultural elements are incorporated into architectural design to reflect regional characteristics and cultural heritage. Architectural aesthetics blends art, project, cultural, and social factors and is a comprehensive system. Academician Ma Guoxin said that as a material and cultural product with a long history, architecture and the aesthetic significance of architecture, philosophers constantly ask about it. With the changes of the times and the development of science and technology, people's understanding of architectural beauty and aesthetic taste are also constantly developing and changing and keeping pace with the times. Tolbert Hamlin's on function and form in 20th-century architecture, volume 2, is written in the principle of formal beauty of architecture; the creation of beauty is the highest duty of an architect. In the final analysis, determining the significant value of a building is an aesthetic standard. The beauty of architectural aesthetics is mainly based on the independent form of the building and the synergistic relationship between form and aesthetics. Studying the objective, concrete, and tangible parts of architecture, elements of form, characteristics, and organizational structure are relatively rational. Experience and sensory perception constitute a relatively more subjective level. These two levels together constitute the principle of formal beauty, the basis of composition principles.

However, contemporary Chinese architecture has presented a complex phenomenon. Especially in the past 30 years, many architectural styles that are very different from conventional architectural forms have emerged. To a great extent, the so-called principle of formal beauty has been broken. The rationality of the existence of composition principles and effectiveness has been questioned. The logical connection between form and formal beauty is severed; even formal beauty has become problematic; beauty and unbeauty have lost their standards. The discussion of formal beauty is based on two levels of research: the principle of formal beauty is broken or questioned, and the two levels whose roots lie in form have changed in recent years.

But this does not mean, regarding formal elements, features, organization, and experience, the framework for thinking about sensory perception also no longer exists.

Simply put, the core of this framework, the so-called composition technique, is still an essential skill of architects. In an architectural work, the various elements still need to fit together in a certain way, form a composition, or composition. The aesthetic value of Lotu's bionic parametric architectural design stimulates the public's perception and understanding of beauty and improves the level of appreciation of architectural art. Architectural designers are reminded to create products that meet aesthetic standards, an architectural work of unique charm.

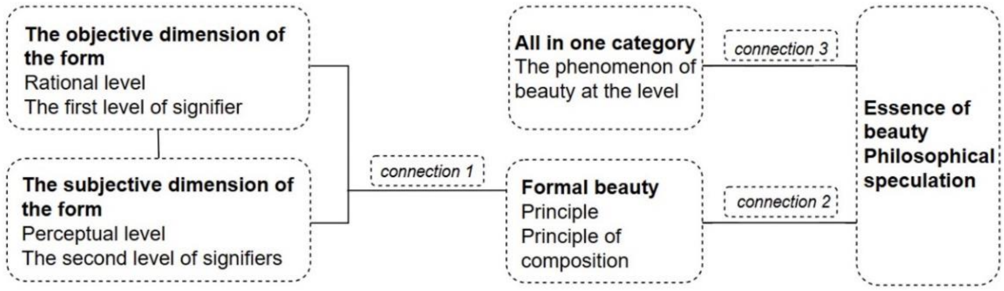


Figure 151 *Schematic diagram of architectural form aesthetic context*
Note. Researchers draw their own, 2024

4.4.2.6 ENVIRONMENTAL PROTECTION AND ENERGY SAVING

Faced with the climate crisis of global warming, China has been actively working hard to promote environmentally friendly and energy-saving buildings and adapt to the development of contemporary Chinese society. China has formulated stringent building energy consumption standards and green zero-carbon building standards. Construction standards mainly consist of national and local standards, and they reduce energy consumption by increasing the energy efficiency level of buildings.

China, in September 2021, a guide to identifying and evaluating zero-carbon buildings was developed under the leadership of Tianjin Low Carbon Development Research Center. The zero-carbon building standard uses energy-saving measures and renewable energy in the building itself, buildings whose annual carbon dioxide reduction from renewable energy sources is more significant than or equal to the building's total annual carbon dioxide emissions. In November 2022, zero-carbon building technical standards, led by the China Construction Research Institute, the preparation of national standards was officially launched.

Table 13 *Energy efficiency indicators*

Energy efficiency indicators for public buildings					
EneThe energyficiency rate of building	Severe cold region	Cold areas	Hot summer and cold	Mild Regions	Hot summer and warm winter

	body (%)	s	winter regions	regions
Energy efficiency indicators		≥30		≥20
	Annual cooling consumption for cooling supply [kwh/(㎡·a)]	≤3+1.5×WDH20+2.0×DDH28		
	Building airtightness (N50 air changes)	≤1.0	———————	

Note. Researchers draw their own, 2024

Table 14 *Indoor environmental parameters*

Indoor environmental parameters	Main indoor thermal and humidity environmental parameters of buildings		
	Parameter	Winter	Summer
	Temperature (℃)	≥20	≤26
	Relative humidity (%)	≥30	≤60
	Main indoor noise level requirements for buildings		
	Building type	Indicator requirements	
	Residential building	Daytime ≤40dB（A）, Night ≤30dB（A）	
	Public buildings	Complies with the provisions of the current national standard "Code for design of sound insulation in civil buildings" GB50118 for indoor allowable noise level one	
	Other types of buildings	Comply with the provisions of the current national standard "code for design of sound insulation in civil buildings" GB50118 for high indoor allowable noise levels	
	Main indoor air quality parameters of buildings		
	Indoor air quality parameters	Indicator requirements	
	PM2.5（ug/㎡）	≤50	
	Carbon dioxide concentration (ppm)	≤900	

Note. Researchers draw their own, 2024

Table 15 *Carbon emission accounting*

Carbon emission accounting	$C=\sum_i\left(E_{\substack{Purchasing\\electricity,\ i}}+E_{\substack{Purchase\\heat,\ i}}+E_{\substack{Purchase\\Cold,\ i}}+E_{\substack{Purchase\\gas,\ i}}\right)-\sum\left(E_{\substack{Green\\electricity,\ i}}\right)$

Note. Researchers draw their own, 2024

The Lotus zero-carbonara metric building is based on zero-carbon building technology standards and zero-zero-carbon evaluation; the Lotus bionic parametric architecture is subdivided into different dimensions. Maximize the use of solar, wind, and renewable energy sources such as geothermal energy. When necessary, take measures such as passive technical means, combined with China’s latest application technology GB51350-2019 near-zero energy consumption technical standard, further reduce building energy consumption. Integrating green display and experience makes this building a genuinely low-carbon city. Promote architectural designers to achieve zero-carbon buildings in the true sense, zero energy consumption, zero wastewater, and zero waste. Bionic parametric buildings can achieve zero carbon, feel, and be displayed.

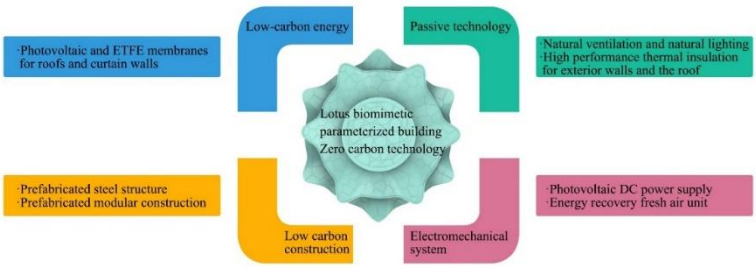


Figure 152 *Lotus bionic parametric building zero-carbon technology diagram*
Note. Researchers draw their own, 2024

4.4.2.7 INSOLATION, CLIMATE AND DRAINAGE

Lotus bionic parametric architectural sunshine, from the analysis of sun exposure time and solar radiation intensity, building solar radiation, south direction, southwest, is higher in the southeast. There are more significant fluctuations in autumn and winter. Analyzed from the comprehensive evaluation of regional sunshine and humidity, the amount of solar scattered radiation is large from March to June, and the amount of direct radiation is high from October to January.

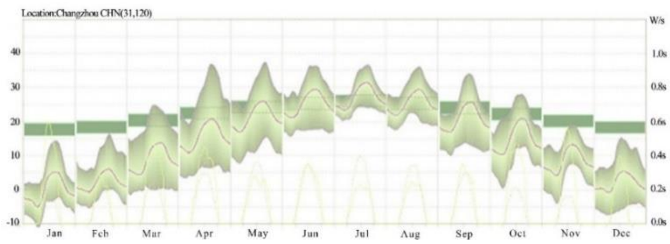


Figure 153 *Annual sunshine and humidity analysis chart of Changzhou, Jiangsu, China*
Note. Researchers draw their own, 2024

According to the sun's movement, adequate sunlight for a building must meet a series of essential parameters; the longer the sunshine time, the more energy is radiated. In a day, direct radiation from the sun is most substantial at noon; ultraviolet rays have the most potent sterilizing power. In the morning and evening, solar radiation is weak, and the intensity of sunlight cannot meet hygiene and other requirements. Solar elevation angleh_s, $sinh_s = sin\varphi^* sin\delta + cos\varphi^* cos\delta^* cos\Omega$ sun azimuthA_s, $cosA_S = \frac{sinhs * sin\varphi - sin\delta}{cosh_s * cos\varphi}$ sun azimuth angle, taking due south as 0°, the angle in the clockwise direction is positive, indicates the range in which the sun is located in the afternoon. The angle in the counterclockwise direction is negative, indicating the range in which the sun is located in the morning. For any given day, the positions of the sun in the morning and afternoon are symmetrical with respect to the position of the sun at noon, the values of the solar altitude angle and azimuth angle at the two moments are the same. But the sign of the azimuth angle is the opposite. At sunrise and sunset, solar elevation angle h_s=0°, substituted into equation (1-2) and equation (1-3) to get, $cos\Omega = -\tan\varphi * \tan\delta$, $cosAs = -\frac{sin\delta}{cos\varphi}$. From these two equations, we can get the time and solar azimuth angle corresponding to the sunrise and sunset moments.

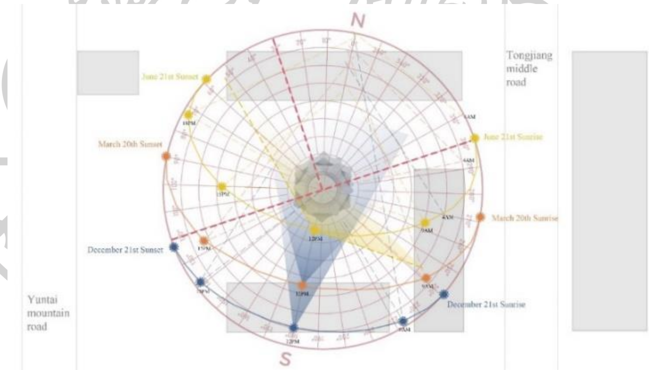


Figure 154 *Sunshine design drawing*
Note. Researchers draw their own, 2024

Figure 155 *Sunshine building interior and exterior analysis diagram*
Note. Researchers draw their own, 2024

Adapting to climatic conditions, one of the complex public buildings, the Lotus Bionic Parametric Building, is located in Changzhou, Jiangsu Province, on the eastern coast of China. The climate belongs to the temperate monsoon climate zone. Jiangsu is divided from China's architectural climate zones into a hot summer and warm winter area. Jiangsu's geographical location determines its regional climate conditions and characteristics. The climate has heavy rainfall, high temperature and humidity, strong sunshine, and other factors. In most areas of Jiangsu, solar radiation heat is intense in spring and summer, the sunshine hours are long, the temperature and humidity remain relatively stable throughout the year, the annual average temperature is 13 to 17°C, and the humidity is 80% to 90%. Therefore, it is under a humid and hot condition all year round; Changzhou has a temperate monsoon climate, January is the coldest month of the year, the average temperature is 8.5°C, July is the hottest month of the year, the average temperature is 24°C, summer is hot and rainy, winters are cold and snowy.

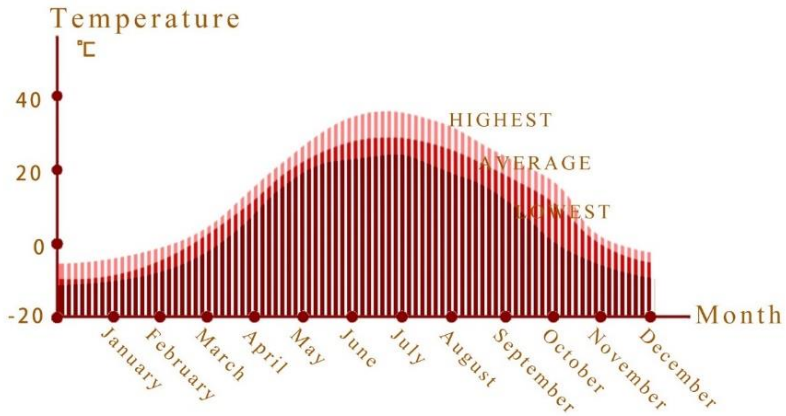


Figure 156 *Annual temperature data map of Changzhou, Jiangsu, China*
Note. Researchers draw their own, 2024

British architect Ralph Erskine said if there is no climate problem, humans no longer need buildings. To cope with different climatic conditions and provide suitable physical space and environment for human survival, this is the origin of architecture and the inner driving force for continuous development and change. Regional environments have different climate characteristics and regional cultures; people also have different needs and feelings about buildings and spaces. According to the climate zone where the Lotus bionic parametric building is located, adopting an active strategy is that solar radiation is abundant, can use solar photovoltaic power generation, organize rainwater collection, and can be combined with wetlands for water treatment. The passive strategy is that the best location is south or slightly west, strengthening the use of natural ventilation in passive strategies, especially the southeast wind in summer. Researchers advocate that Chinese architectural designers pay attention to regional climate design issues, inherit and carry forward the climate adaptability design thinking and methods of traditional Chinese buildings, make full use of natural environmental conditions, and create distinctive regional architectural features; not only is it beneficial to building energy conservation and emission reduction, it is also of great significance to China's path to sustainable development.

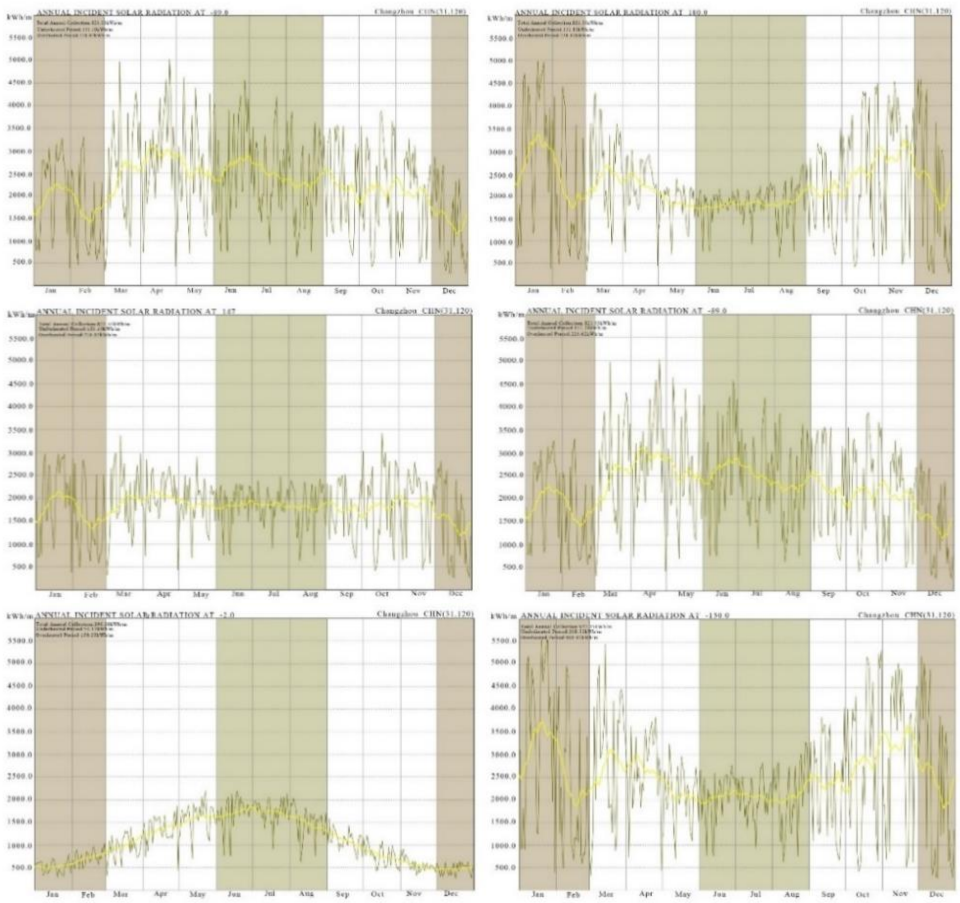


Figure 157 *Annual average climate data table for Changzhou, China*
Note. Researchers draw their own, 2024

Lotus bionic parametric building drainage has two main types: rainwater drainage and domestic sewage drainage.

The annual precipitation in Changzhou is about 1000 to 1200 mm. Lotus bionic parametric building rainwater drainage, the roof adopts a traditional gravity flow rainwater drainage system, and a rainwater reuse system is installed on the first floor. China's gravity flow rainwater systems generally use type 65 or 87 buckets; the structure is relatively simple and typically located directly in the gutter or lower part of the roof. When the system is working, rainwater on the roof is provided by a rainwater bucket; during the process of entering the drainage system, the water cross section shrinks to form a vortex, and the water flow carries air into the drainage system, making the entire system present a gas-liquid two-phase flow, the air takes up about 1/3 of the duct space. Establishing a rainwater reuse system on the roof utilizes large amounts of rainwater runoff; it can save water resources and reduce the burden on urban drainage facilities. Recycling rainwater as a resource will create an economy, social benefits, etc. The general process of rainwater reuse is as follows: rainwater from the sky and rainwater from the ground go to the rainwater outlet of the inspection well, then it flows into the waste water pool, through the rainwater filtration system or sedimentation tank, after arriving at the reservoir, through disinfection and other processing work, recycle. Precipitation runoff from the sky and precipitation runoff from the sky can be used with a bit of processing; if everyone in China participates in rainwater recycling, many water resources can be saved yearly. At present, the scale of urbanization in China has entered a stage of rapid development, which will inevitably lead to more land being turned into construction land; during this process, designing and building rainwater recycling as part of urban planning, rainwater, a vast wealth, can be used to its full potential.

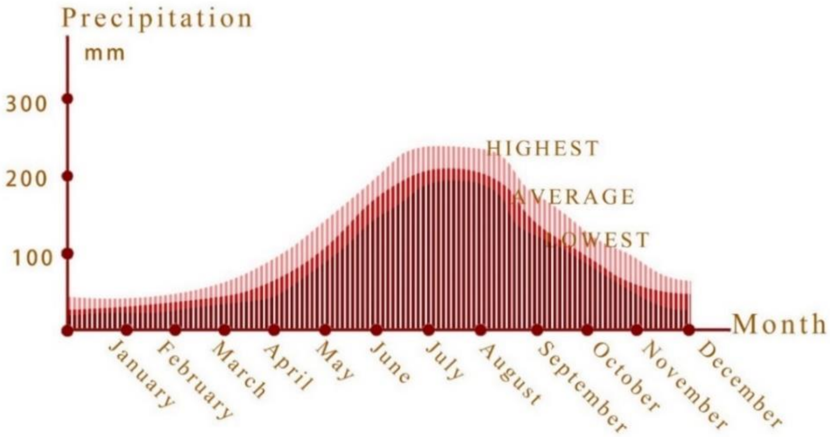


Figure 158 *Annual precipitation data map of Changzhou, Jiangsu, China*
Note. Researchers draw their own, 2024

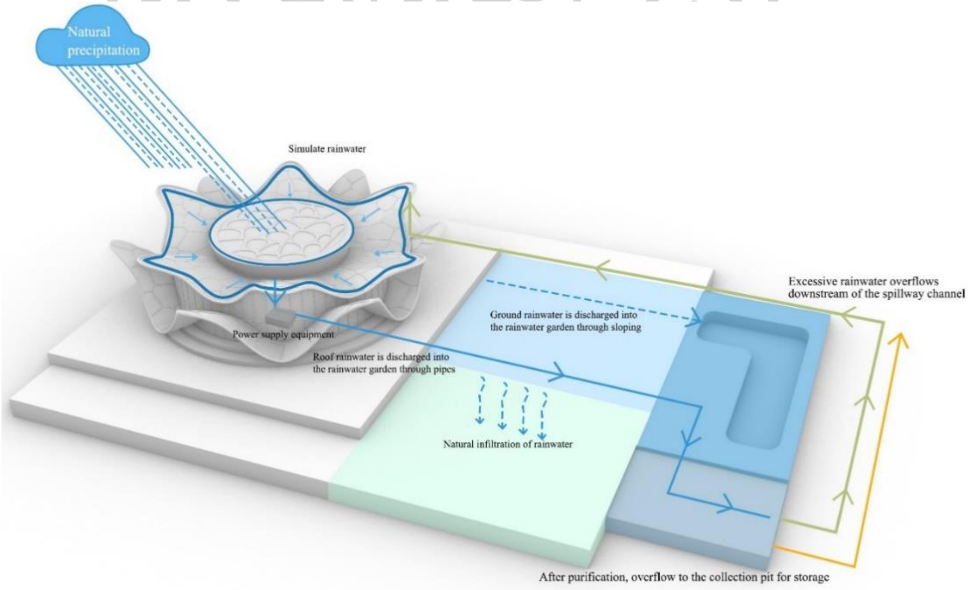


Figure 159 *Drainage design drawing*
Note. Researchers draw their own, 2024

Domestic sewage drainage: a vacuum drainage system removes domestic sewage from the bathroom. Currently, there are relatively few applications for vacuum drainage systems in China. Building indoor vacuum sanitary systems works based on the fundamental physical principle that air pressure differences can produce rapid airflow. The system comprises a vacuum pump station, vacuum piping, cleaning tools, sewage collection devices, etc. This technology saves 80% of water compared with traditional drainage methods. The vacuum control valve will open automatically when the sewage reaches a specific volume. The vacuum pump in the vacuum pump station maintains a negative pressure of 0.06MPa in the pipeline; the sewage will enter the vacuum tank in the vacuum pumping station through the vacuum pipeline at a speed of 4m/s. Vacuum drainage avoids the limitations of traditional gravity downward drainage. Therefore, the pipeline layout is arbitrary. The sewage is lifted through the pipeline and then enters the vacuum tank; after the sewage is stored in the vacuum tank to a certain water level, it automatically turns on, it is discharged directly from the drainage pipe system into the municipal pipe network, discharge to urban sewage treatment plant for centralized treatment.

4.4.2.8 VENTILATION, LIGHTNING PROTECTION, AND EARTHQUAKE RESISTANCE

Lotus bionic parametric building ventilation design helps achieve higher cooling and dehumidification effects at lower costs. Please use natural air, introduce natural air indoors, take away indoor heat, and drain it outdoors. Natural ventilation consumes no energy; using the relative balance principle of heat and wind pressure, sir density varies under different temperature conditions due to the effect of the earth's gravity; high-temperature air moves upward, and cold air moves downward. The climate in Jiangsu has typical hot and humid characteristics; the time required to cool down in summer accounts for more than 40% of the year. We need to solve the problems caused by high temperatures and high humidity. Therefore, buildings in this area should pay attention to creating natural ventilation. The cooling effect of natural ventilation depends on the temperature difference between the inside and outside of the building. When the temperature inside the building is higher than the ambient temperature outside, ventilation can cool down.

On the contrary, the effect is the opposite. Natural cooling ventilation is an economical method that can provide fresh air and calm and release heat stored in buildings; it can cost-effectively meet the air quality requirements of indoor personnel. From the moisture diagram and optimal orientation analysis, natural ventilation is a more suitable passive technology for this site when a building is ventilated. The orientation of the building should be south, and the wind inlet surface should face the dominant wind direction or have an inclination angle of not less than 45°. Outdoor air enters the room at its original temperature and mixes with indoor air during the flow process; it also conducts heat exchange with various indoor surfaces based on the temperature difference between the inside and outside of the building.

The traditional methods of utilizing natural ventilation are drafts or skylights, etc. To enhance the ventilation effect of the building, roof vent caps are commonly used. Make reasonable use of doors and windows, and set windows on the outer wall; the size of the window is related to the effect of natural ventilation, and the ventilation effect of opening windows on the windward side of the leading wind direction of the building is evident. Lotus bionic parametric building rational design and use of skylights, open the skylight at the ridge, place the heat source below the skylight and use sunken skylights, stagger the positions of skylights and recessed panels to shorten the ventilation distance, remove indoor heat as quickly as possible.

Natural ventilation may play a poor role; mechanical ventilation fans are often added for ventilation and cooling. The first thing to consider for building energy conservation is the energy consumption of air conditioning and fresh air, which account for the most significant proportion of building energy consumption. Natural ventilation can reduce the pressure on the building's air conditioning and fresh air systems. In that case, it can reduce building energy consumption and operating costs and provide better indoor ventilation.

Judging from the wind direction and frequency of the Lotus Bionic Parametric Building, east wind prevails throughout the year, with east wind prevailing in spring, southeast wind prevailing in summer, southwest wind prevailing in autumn, and northwest wind prevailing in winter.

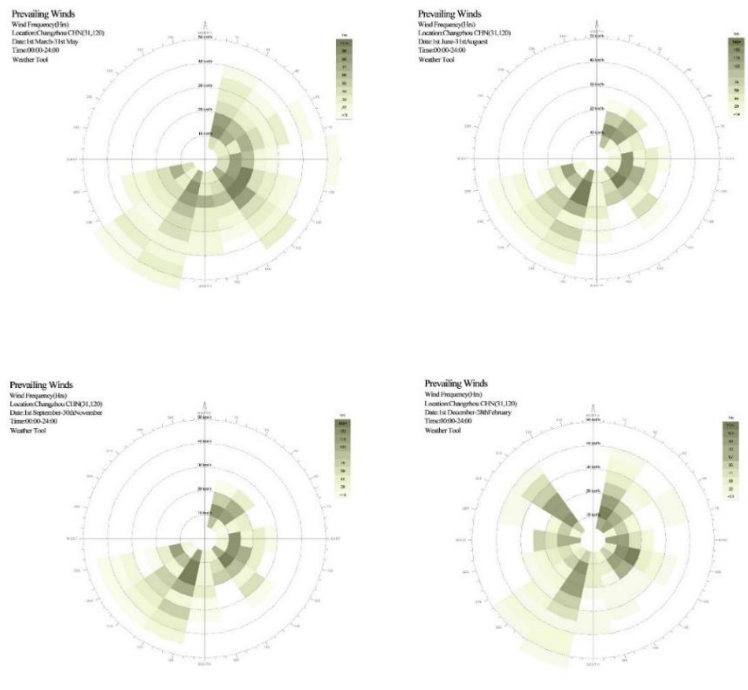


Figure 160 *Wind direction design drawing*
Note. Researchers draw their own, 2024

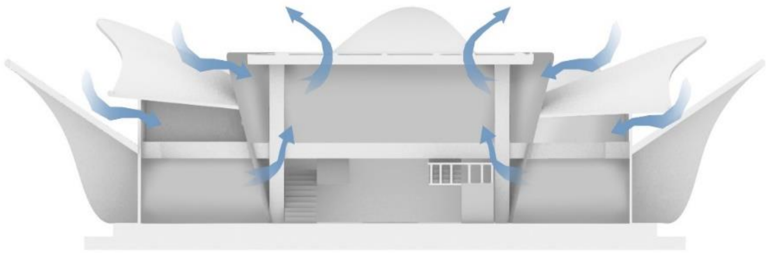


Figure 161 *Ventilation design drawing*
Note. Researchers draw their own, 2024

Lotus bionic parametric building lightning protection design adopts traditional lightning protection technology. The underground and foundation parts of the building are reinforced concrete structures, and the above-ground part is a steel grid. The steel bars in the steel structure and the reinforced concrete structure are connected by welding, forming a cubic cage. Each prefabricated Voronoi diagram modular steel component is inlaid or fixed on the roof, the steel members are broad and thick, and the steel grid is welded into one body and supports the entire roof. In thunderstorm weather, these steel members function as gutters, collecting and draining rainwater from the roof; at the same time, they also act as an air-termination device, introducing lightning current into the cage lightning protection net in time, protecting the entire building. This is also an ideal cage lightning protection net, relying entirely on the materials in the building's structure; there is no need to set up a separate lightning rod or take down a conductor or grounding body; there are no protruding lightning rods or lightning protection strips on the roof, it is both economical and beautiful, safe and reliable.

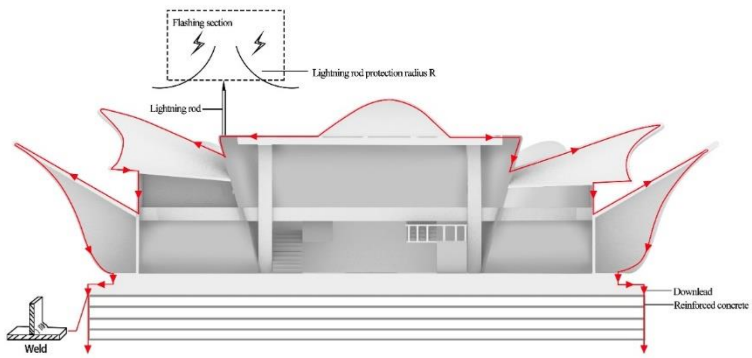


Figure 162 *Lightning protection design drawing*
Note. Researchers draw their own, 2024

Lotus bionic parametric building seismic design is a typical example of being soft on the outside but firm on the inside. Only photovoltaic panels and ETFE inflatable films similar to glass curtain walls can be seen from the outside; it seems that I can't help but be weak; what supports these membranes is a solid steel structure, and the inside is a reinforced concrete structure. The building's walls and ceilings are composed of a mesh of steel tubes connected by load-bearing nodes, which share the weight of the building evenly, making it strong enough to withstand Jiangsu's strongest earthquakes. The underground part of the building is a reinforced concrete superstructure; when pouring concrete, embedded steel blocks are installed at the position of each steel structure, and the steel columns are firmly welded to these embedded parts. Like that, the above-ground steel and underground reinforced concrete structures form a solid whole. It is precisely because of its superior structural form and good integrity that the architecture has a strong body; it has reached the earthquake intensity level 8 standard.

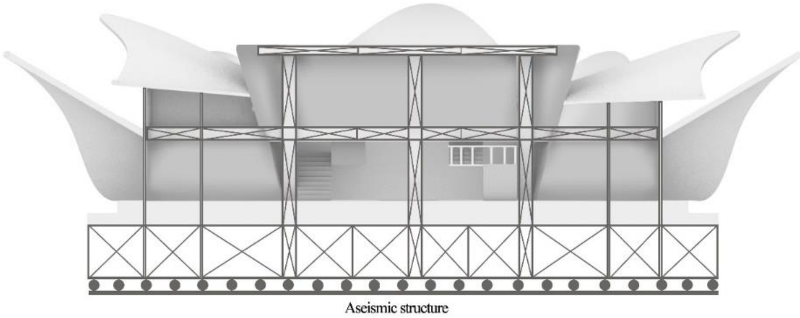


Figure 163 *Seismic structure design drawing*
Note. Researchers draw their own, 2024

4.4.3 SUMMARY OF LOTUS BIONIC PARAMETRIC ARCHITECTURAL COLLABORATIVE DESIGN WORKSHOP

Research on the Third Art and Dand design Education Lotus Bionic Parametric Architectural Collaborative Design Workshop, through design practice, understand the characteristics of the construction industry itself; compared with high-end manufacturing, it has always been in a relatively extensive state. With the arrival of the digital age, it is possible to change the weak points of the construction industry. Lotus bionic parametric building case provides solutions for high-quality construction through parametric technology. The building shell structure not only becomes a work of art with structural aesthetic expression but also an integral part of the skin curtain wall system, creating opportunities to overcome freeform surface issues in complex building skin designs. The complex body surface bridging was logically constructed through software programming; processing manufacturers use all-digital means to deepen their designs, processing, and installation, creating a system of all-digital skin construction. The skin texture is composed of smooth structural curves and rich texture; it shows the unique continuity, smoothness, simplicity, and unity of lotus bionic parametric architecture.

Through the design practice research of this Art and Design Education Lotus Bionic Parametric Architectural Collaborative Design Workshop, use digital information models to check every technical link of the project, deepen the design construction, coordinate the processing and manufacturing of construction products, let the designer, engineering construction party, construction product manufacturer, work on the same platform and the same standards. At the same time, a digital information database is established, collaboration in all aspects of the project through seamless data connection, and accurately transmits the design information to downstream processing and manufacturing enterprises, achieving high-quality architectural language and aesthetic form, making the final architectural work have a higher integrity, the control level has reached high-precision manufacturing, the lotus bionic parametric building can be said to have achieved several breakthroughs in construction technology, it has driven the digital upgrading of China's construction industry.

4.4.4 VERIFICATION AND EVALUATION OF LOTUS BIONIC PARAMETRIC BUILDING COLLABORATIVE DESIGN

To ensure the feasibility of the design practice research of the third Art and Design Education Lotus Bionic Parametric Architectural Collaborative Design Workshop, meet expected design standards, using questionnaire survey method and direct observation method, verify and evaluate the Lotus bionic parametric architectural 3D printing model at multiple levels.

The questionnaire survey method collects different groups of people to conduct a paper questionnaire survey and a face-to-face survey on Lotus Bionic Parametric Architecture.

Direct observation method, intuitive analysis of the overall impression of the lotus bionic parametric architectural 3D printing model. The observer visually perceives the appearance characteristics of the model, understands the emotions conveyed by architectural models, style, and design concepts, and develops a preliminary understanding of architectural design. It immediately reflects the observer's attitude towards lotus' bionic parametric architecture.

Part of the survey is shown in the table below.

Table 16 *Survey Content*

Interview topics
Sources of respondents' understanding of lotus biomimetic parameterized architectural culture
Respondents' first impression of lotus biomimetic parameterized architecture
The interviewee's representation of the appearance and shape of lotus biomimetic parameterized architecture
Respondent's perception of the materials and textures of Lotus bionic parametric architecture
The degree to which respondents like the color of lotus biomimetic parameterized architecture
Respondents' sources of acceptance of bionic art elements in lotus biomimetic parameterized architecture

Perception of respondents on the spatial layout design of lotus biomimetic parameterized architecture
Respondents expressed a sense of softness and stability in the parameterized structure and lines of lotus biomimetic parameterized architecture
Sensory experience of respondents on the environmental sound effects of lotus biomimetic parameterized architecture
The level and three-dimensional sense of the light and shadow effect of the lotus bionic parametric building
The level of understanding of lotus elements in lotus biomimetic parameterized architecture among respondents
Suggestions from respondents on the creative design of lotus biomimetic parameterized architecture
Respondents' understanding of lotus biomimetic parameterized 3D printed architecture
……

Note. Researchers draw their own, 2024

Through the above investigation and research, researchers learned about the current status of lotus bionic parametric architecture, different groups of people's expectations for bionic parametric architectural design, and the bionic elements in mind, possible carriers that can be effectively contacted in life. The investigation will be incomplete, but I hope it can bring specific reference value to the redesigned research of architectural designers.

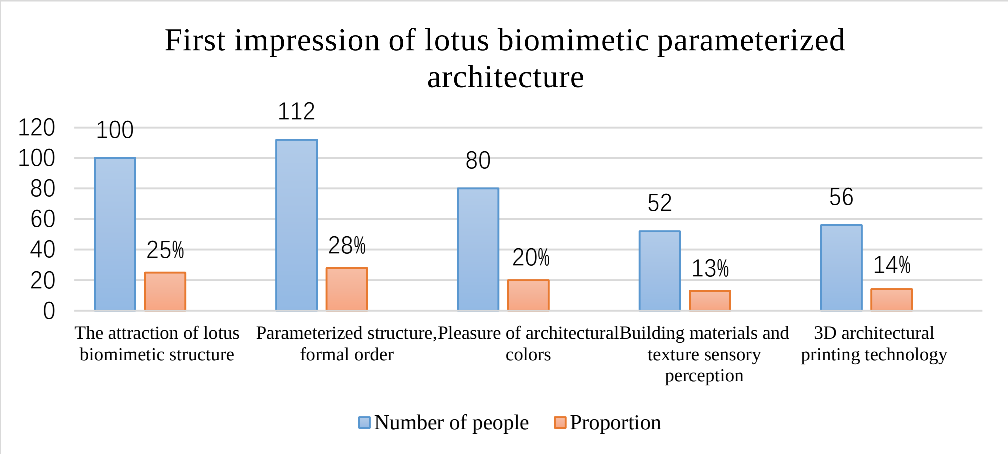
According to statistics from the survey results of the respondents, perform data analysis, first impression of Lotus Bionic Parametric Architecture.

Table 17 *First impression of lotus biomimetic parameterized architecture*

First impression of lotus biomimetic parameterized architecture	Number of people	Proportion
The attraction of lotus biomimetic structure	100	25%
parameterized structure formal order	112	28%
The pleasure of architectural colors	80	20%
Building materials and texture sensory perception	52	13%
3D architectural printing technology	56	14%

Note. Researchers draw their own, 2024

Table 18 *Column analysis chart of first impression of Lotus bionic parametric building*



Note. Researchers draw their own, 2024

Based on the above survey statistics, different interviewees have different emphasis on lotus bionic parametric architecture and the forms they are exposed to; these analyses provide a focus for the future redesign and application of bionic parametric buildings for contemporary Chinese architectural designers in bionic parametric architectural design, give a basis for learning and reference.

4.4.5 LOTUS BIONIC PARAMETRIC ARCHITECTURAL DESIGN EXHIBITION

Lotus bionic parametric architectural design exhibition, on March 27, 2024, held in the Craftsman Hall on the 1st floor of Building 6, Public Training Base of Changzhou Technician College, Jiangsu Province, China; the purpose is to collect feedback from visitors on the research results. At the same time, we aim to convey and promote the concept of bionic design to visitors through this exhibition, with emphasis on drawing on the power of nature, incorporating the wisdom of nature into architectural design, achieve harmonious coexistence between architecture and nature. The exhibition showcases examples of using lotus flowers as a source of natural inspiration, stimulating visitors' interest and understanding of bionic design. Through exhibitions, they encourage architectural designers and students to expand their innovative thinking in architecture, guide them in introducing the uniqueness and forward-looking nature of bionic design in architecture, and inspire them to think new about future architectural innovation.

The exhibition layout, in the form of posters for the research background, research methods, and research process, as a display of research results and other information, lets visitors understand the research on lotus bionic parametric architectural design. Promote interdisciplinary collaboration, break down discipline barriers, and prompt experts from different fields to discuss and study the feasibility of Lotus bionic parametric architectural design cases. We look forward to forming a more comprehensive and innovative design concept through exchanges and cooperation. Promote innovation and sustainable development in construction and inspire the public to think deeply about architectural aesthetics and natural inspiration.

Figure 164 *Architectural Model Design Exhibition*
Note. Photographed by the researcher, 2024

4.5 RESEARCH RESULTS OF LOTUS BIONIC PARAMETRIC ARCHITECTURAL DESIGN

4.5.1 RESULTS OF INNOVATIVE DESIGN EFFECTS OF LOTUS PATTERN

According to the first workshop at the College of Art and Design, Changzhou University, Department of Visual Communication Design, an innovative design workshop for ten people to recreate the lotus pattern was held for 146 college students in 3 classes, a questionnaire survey on Lotus Bionic Re-innovation Design of Architectural Design was conducted, there were 140 valid questionnaires in the end.

The questions asked are listed below.

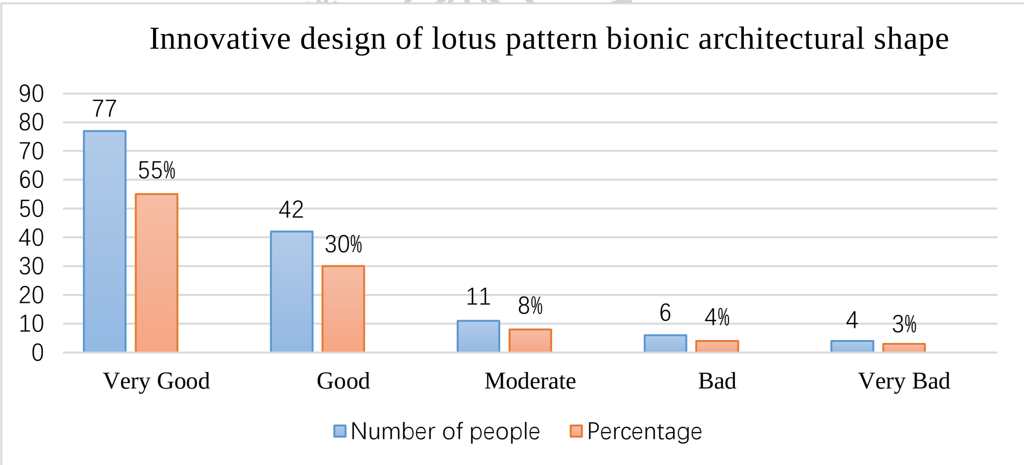
Table 19 *Innovative design Issues of lotus pattern biomimetic architectural shapes*

The innovative form and beauty of the lotus pattern
The number of lotus petals in a lotus pattern

Innovating the lotus pattern and matching colors to fit the main body of the building
The feasibility of lotus pattern in architectural design elements
Feasibility of extracting lotus pattern elements
The cultural information and symbolic significance of lotus pattern elements
Lotus pattern innovates the user's touch experience and emotional connection
The degree of differentiation in the application of lotus pattern elements in the evaluation of the construction market
……

Note. Researchers draw their own, 2024

Table 20 *Satisfaction analysis chart of the innovative design of lotus pattern bionic building shape*



Note. Researchers draw their own, 2024

The evaluation results of the innovative design of the lotus pattern bionic architectural shape are 55% of people think it is perfect, 30% of people think it is good, 8% of people think it is average, 4% of people think it is not good, 3% thought it was not good.

Through the questionnaire survey and evaluation of this 140-point lotus pattern re-innovation design, the results show that the lotus shape retains the traditional pattern structure characteristics and has overall formal beauty. The first lotus pattern re-innovation design workshop results show that the design experiment test result is successful.

4.5.2 PARAMETRIC DESIGN AND DEVELOPMENT AFFECT EVALUATION RESULTS

4.5.2.1 PARAMETRIC DESIGN AND DEVELOPMENT OF LOTUS BIONIC MODEL QUESTIONNAIRE EVALUATION RESULTS

At the School of Art and Design, Changzhou Institute of Technology, Department of Environmental Art and Design, the second workshop held a parametric modeling design workshop for 11 people. A questionnaire survey was conducted among 121 college students, and 116 valid questionnaires were recovered. The method of calculating the average of 116 rating results obtained the evaluation results of the parametric design.

Table 21 *Evaluation results of lotus bionic model developed using parametric technology*

Evaluating Indicator	Evaluation Content	Evaluation Score %	Satisfaction
Innovation	The novelty of parameterized design concept differs from traditional design	83%	Satisfied
	The parameterized design has originality in both form and structure	88%	Satisfied
	Has parameterized design attracted industry attention and response	77%	Satisfied
Flexibility	Flexibility of parameterized design	91%	Satisfied
	The impact of parameter adjustment on the final design result	84%	Satisfied
	Parameterized design determines the adjustability of the design	89%	Satisfied
Technical feasibility	The computational efficiency of parameterized algorithms	93%	Satisfied
	Parameterized algorithms can generate results in a reasonable amount of time	80%	Satisfied
	Comparison of development time between parametric design and traditional design	96%	Satisfied
	Parameterized design reduces waste of human and material resources	92%	Satisfied
Design effects	Visualization effect of parameterized design	80%	Satisfied
	The visual appeal of parameterized design	85%	Satisfied
	Does the parameterized design meet expectations	91%	Satisfied

Note. Researchers draw their own, 2024

In the second workshop, the evaluation results of the lotus bionic model developed using parametric technology are as follows: the highest satisfaction is in technical feasibility and comparison of development time between parametric design and traditional design; it illustrates the high efficiency of parametric design modeling and got recognition. The lowest level of satisfaction is innovativeness; parametric design has attracted attention and response within the industry, and the satisfaction level is 77%, explaining that parametric design needs to be promoted and developed as the road ahead remains arduous. Among the innovations of parametric technology, the parametric design form and structure are original and achieve 88% satisfaction, explaining the importance of form and structure. The flexibility of parametric design reaches 91%, explaining flexible design methods worthy of recognition and reorganization in line with the designer's design plan. The design effect meets the design expectations by 91%; the design effect meets the design expectations by 91%.

A satisfaction survey on developing a lotus bionic model using parametric technology explains the advantages of parametric design technology, and the feasibility of developing a lotus bionic model using parametric technology was verified. It shows that the design experiment of the second workshop was successful.

4.5.2.2 SUBJECTIVE EVALUATION RESULTS OF PARAMETRIC DESIGN AND DEVELOPMENT OF LOTUS BIONIC MODEL

The subjective evaluation comprises 110 people, including experts, architectural designers, and college students; a diverse range of perspectives is ensured—subjective feelings and opinions on the appearance of the lotus bionic model developed through parametric design. The subjective evaluation indicators are overall beauty and visual impact. Then, the scoring results are statistically organized, and the average of each indicator is the final evaluation result.

Table 22 *Subjective evaluation results of the appearance of the Lotus model developed with parametric technology*

Evaluating indicator	Evaluation content	Evaluation score %
Overall aesthetics	Developing a lotus model with parameterized technology for pleasant appearance aesthetics	86%
	Developing a lotus model with parameterized technology for overall aesthetic appearance	92%
	Developing lotus model with parameterized technology and exquisite appearance details processing	93%
	Developing a lotus model with parameterized technology and a distinctive appearance	84%
Visual impact	Parametric technology develops the visual impact of the appearance of the lotus model	94%
	The development of lotus models using parameterized technology leaves a deep impression on their appearance	85%
	Developing a lotus model with parameterized technology to coordinate natural features of appearance	87%
	Developing lotus model with parameterized technology, overall design with layered	85%

appearance

Note. Researchers draw their own, 2024

From the statistical table analysis, the visual impact of the Lotus bionic model developed through parametric design reaches 94%, which shows that the parametric design method can meet the visual requirements of bionic design. Secondly, the lotus model developed with parametric technology has an exquisite appearance detail processing of 93%; it shows that the parametric design method can control the accuracy of model calculation and reach the expected ideal value well. However, the lotus model developed with parametric technology has a distinctive appearance, accounting for 84%; maybe different researchers have different subjectivities because of other cultures and backgrounds, personal aesthetics, and personal taste; there is a big difference in preferences, there are differences in focus and focus, benevolence is in the eyes of the beholder, a wise man sees wisdom, understanding of form, thoughts on architectural power, control of color, etc. Produce different understandings of distinctive and characteristic appearances. Architectural designers need to understand and respect other perspectives to create more inclusive and diverse design work in design practice.

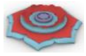
4.5.2.3 OBJECTIVE EVALUATION RESULTS OF PARAMETRIC DESIGN AND DEVELOPMENT OF LOTUS BIONIC MODEL

Through parametric design and development technology, objective evaluation of the lotus bionic model provides researchers with rich performance space and a design experiment to create a series of lotus bionic models. Researchers gave the lotus a softer, artistic shape, which makes the design and development more three-dimensional and delicate. By adjusting the curve of the petals, the length of the leaves, width, and curvature, parameterized number of stamens, density, and size, create a lotus bionic structure that gradually changes from the center to the edge, giving the entire model a layered look.

Based on the above ten kinds of lotus architectural design experimental models, through voting, each participant objectively selects three models and makes an objective evaluation. The architectural design models with the top three scores will proceed to the next step of detailed architectural design.

Table 23 *Lotus Architectural Design Experimental Model Objective Evaluation Voting Results*

Number	Type	Name	Quantity
1		Gradient size lotus	11
2		Spiral lotus	10
3		Abstract geometry lotus	30

4		Wavy lotus	35
5		Star shaped lotus flower	8
6		Symmetrically split lotus flower	31
7		Vector line drawing lotus	6
8		Three dimensional lotus flower	7
9		Interlaced lotus flowers	5
10		Overlapping lotus	7

Note. Researchers draw their own, 2024

4.5.3 LOTUS BIONIC PARAMETRIC BUILDING DISPLAY RESULTS

March 27, 2024, held in the Craftsman Hall on the 1st floor of Building 6, Public Training Base of Changzhou Technician College, Jiangsu Province, China. Lotus bionic parametric architecture exhibition. This exhibition invites university professors of art and design in China, architectural design designers, students, and so on. During the exhibition, they communicated with each other and learned their opinions on this Lotus bionic parametric architectural research work. During the exhibition, questions were raised and discussed with them.

(1) What do you think of the design works of the Lotus Bionic Parametric Building?

More than 85% of the visitors thought the research on Lotus bionic parametric architecture was interesting, and the design felt new and exciting. Incorporating the form and structural elements of the lotus plant in nature, innovation is applied to architectural design. At the same time, combined with parametric algorithm technology, this bionic fusion balanced innovation method and public acceptance are very high, and it is worthy of vigorous promotion in the future.

(2) Can you tell that parametric architecture is a bionic lotus pattern?

Most visitors answered this question; he expressed that he was inspired by the lotus bionic architectural design, which can be seen intuitively as a bionic lotus. However, a few visitors responded that they felt like plant bionics; after seeing the design process, you can imagine it is a lotus pattern. Because the back and forth of visitors' thinking will affect their judgment, the researcher's design thinking is different from his habits, and the process of biomimetic the lotus shape will also be different.

(3) Do you like this Lotus bionic parametric architecture?

Visitors preferred this bionic parametric building, a cross-professional integration, innovation, and technological breakthrough. The architectural style is abstract, and I love the simple and functional design. I was demonstrating the continuous progress and evolution in architectural design.

(4) How does lotus bionic parametric architecture inspire you?

Most visitors said they draw inspiration from nature, create unique architectural forms, and pursue a balance between artistry and practicality. Technology plays a vital role in architectural design, inspiring research and applying innovative technologies to improve buildings' ecological sustainability and performance. It inspires architects to explore and adjust their thinking about architecture flexibly.

Based on suggestions and feedback from visitors, the results and research methods of lotus bionic parametric architecture were unanimously recognized by visitors. At the same time, some tips for visitors were optimized and adjusted.

During the optimization and adjustment process, the researchers selected the top three design experimental building models with the highest scores. They conducted more in-depth analysis and optimization of building structures to ensure their stability and sustainability.

After the Lotus bionic parametric architectural design is completed, the project's construction is a complex and delicate process that requires close collaboration between architects and engineers, using advanced design tools and construction techniques, ultimately achieving the perfect integration of nature and technology after completing the concept design plan for the lotus bionic form, combined with parametric design. Obtain the best lotus shape that meets the design requirements. Simulate the analysis of building construction structure, airflow, lighting, and other aspects in the computer, and verify how the design performs under real-world conditions. They are reaching the detailed design stage, including structural details, material selection, construction methods, etc. Parametric models can be refined down to the size and connection of each component. Generate detailed construction documents, including drawings, materials list, budget cost, and construction instructions. These documents will guide the actual construction process. Then comes the construction preparation stage. Lotus bionic parametric buildings require many prefabricated components; these components must be manufactured in advance in the factory according to the design requirements and then transported to the construction site. The accuracy and quality of prefabricated components directly affect the final construction effect. Carry out on-site 3D concrete printing construction work; there are equipment and tools for foundation construction and installation of prefabricated components. The Lotus bionic parametric building covers an area of 100 square meters and is 8 meters high; during the construction phase, robotic arm 3D concrete printing equipment was selected according to the frame structure requirements of the architectural design, and the building was printed. The 3D printing process and the installation of prefabricated components are carried out simultaneously. This process requires precise measurement and positioning, ensuring accuracy for every element and 3D printing position. In the construction completion and acceptance stage, architectural details need to be completed, and the installation of external solar light templates and ETFE films conform to the functional design of the building. Ensure all design requirements and construction standards are met. After passing the acceptance, the building is officially put into use. The last step is to develop a detailed Lotus building maintenance plan, regularly inspect and maintain all parts of the building, and ensure its long-term safety and functionality.

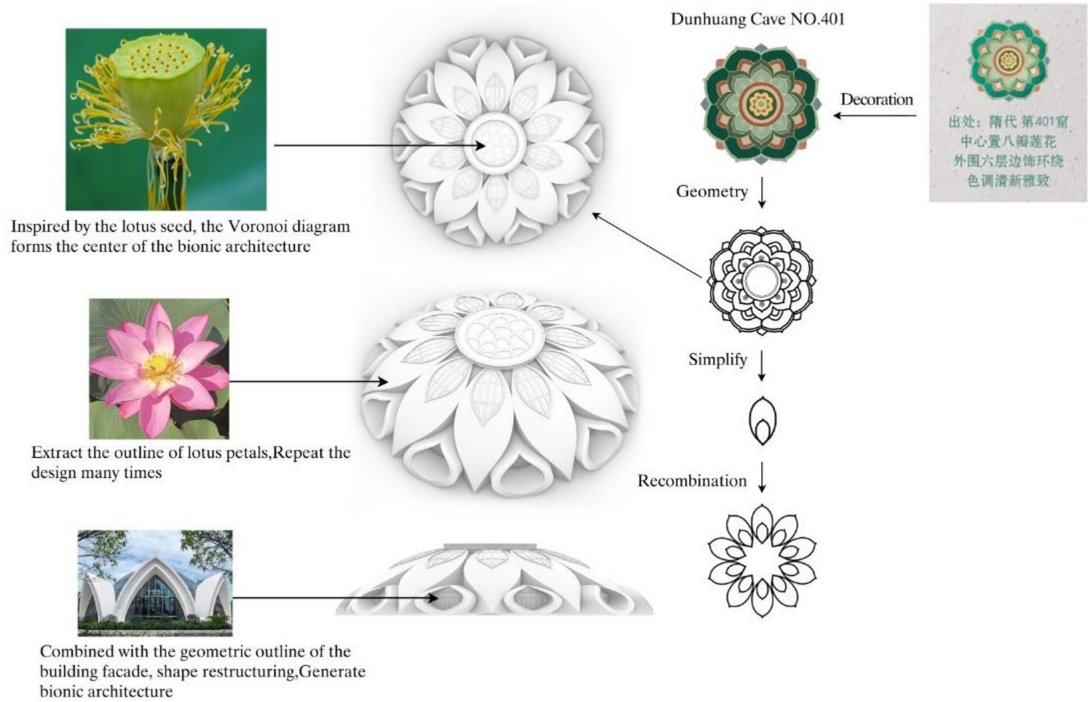


Figure 165 *Lotus bionic parametric architecture 1 mind map*
Note. Researchers draw their own, 2024

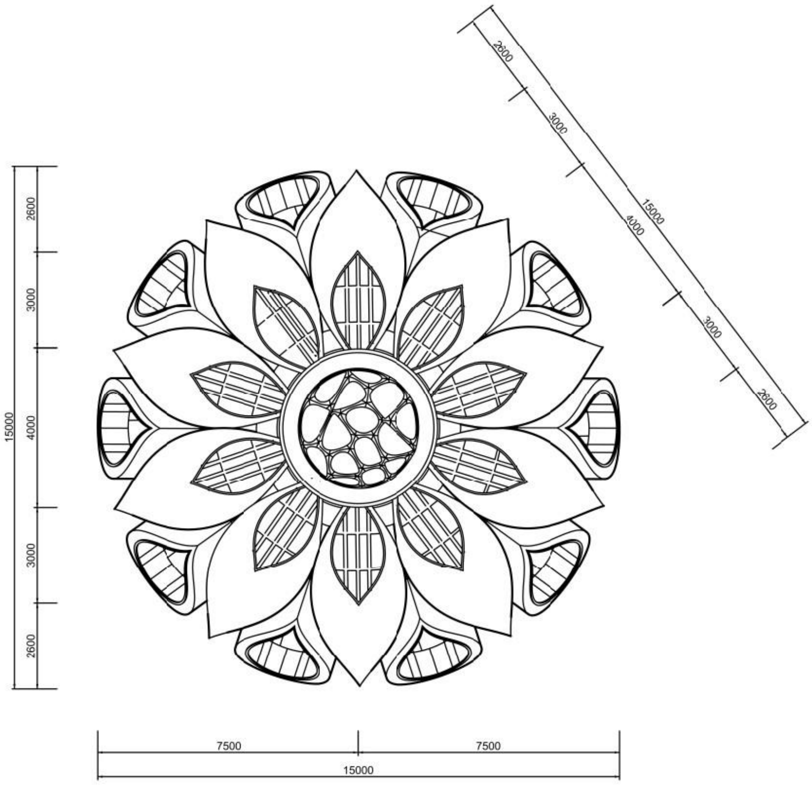


Figure 166 *Lotus bionic parametric building 1 plan*
Note. Researchers draw their own, 2024

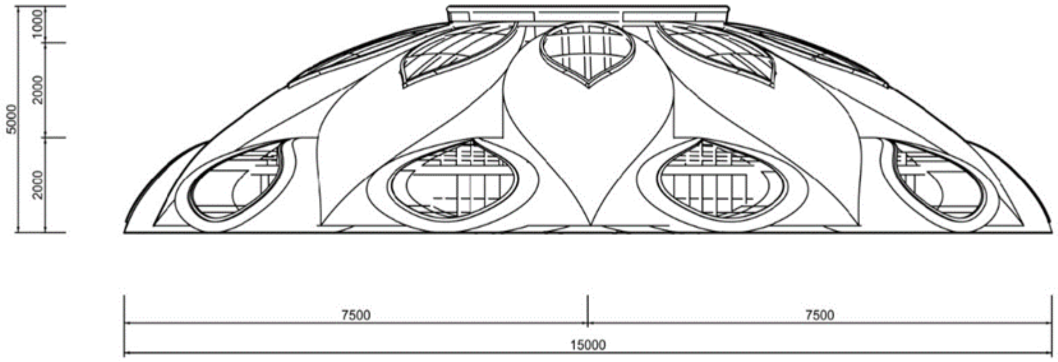


Figure 167 *Lotus bionic parametric building 1 elevation*
Note. Researchers draw their own, 2024

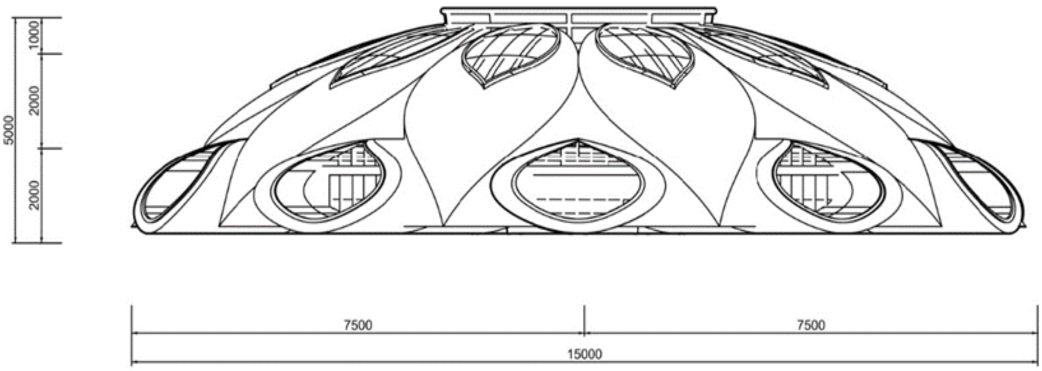


Figure 168 *Lotus bionic parametric building 1 side elevation*
Note. Researchers draw their own, 2024

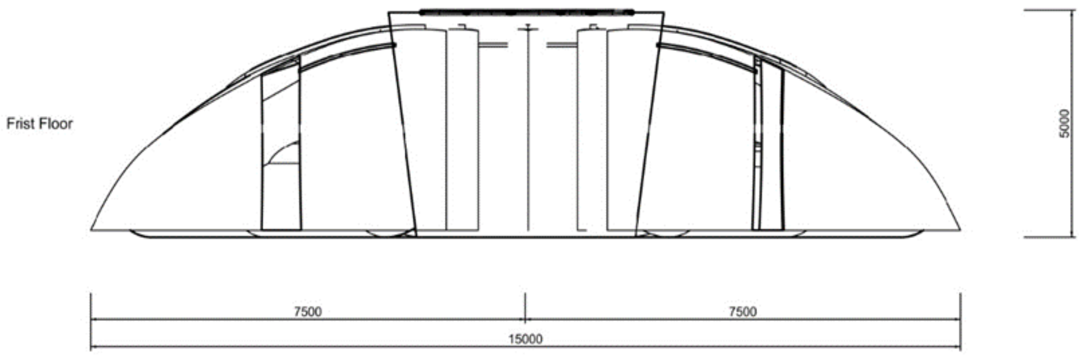


Figure 169 *Lotus bionic parametric building 1 sectional view*
Note. Researchers draw their own, 2024

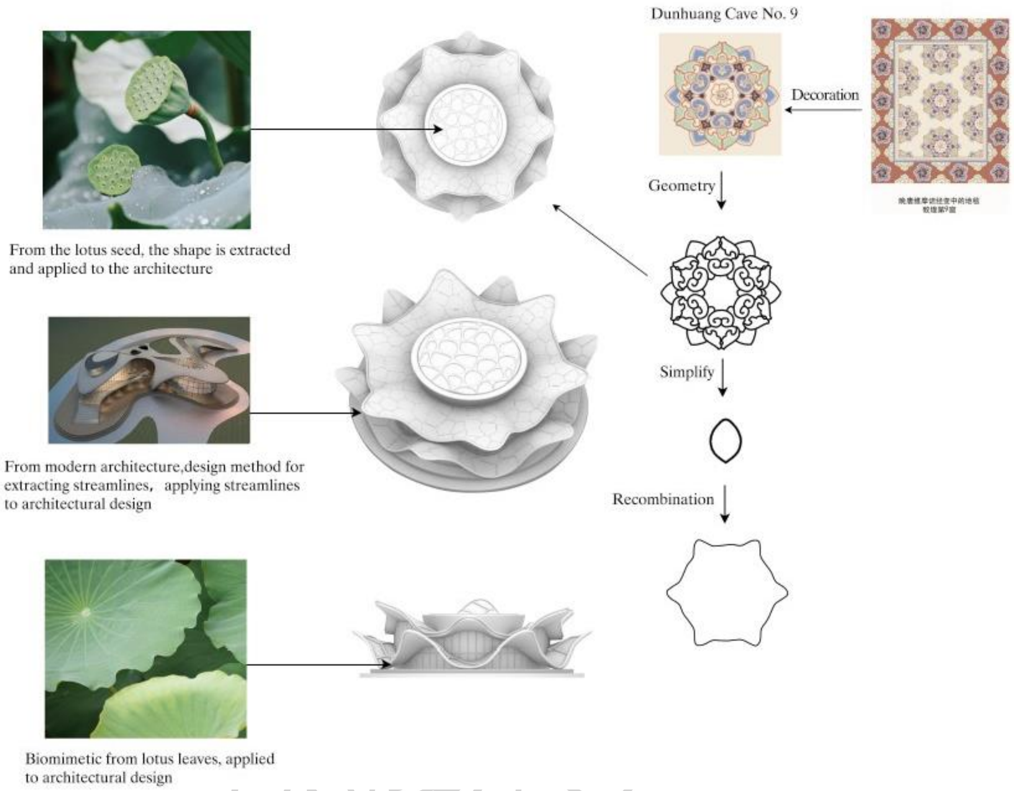


Figure 170 *Lotus bionic parametric architecture 2 mind map*
Note. Researchers draw their own, 2024

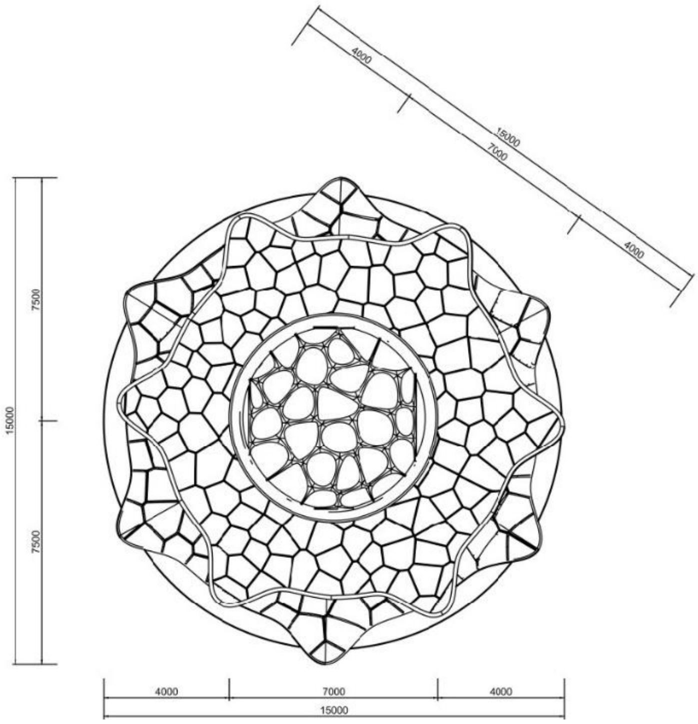


Figure 171 *Lotus bionic parametric building 2 plan*
Note. Researchers draw their own, 2024

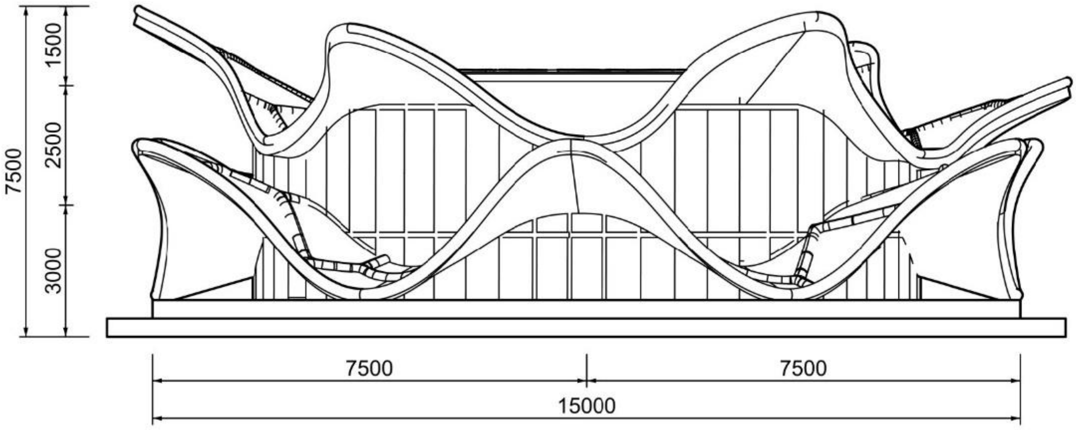


Figure 172 *Lotus bionic parametric building 2 elevation*
Note. Researchers draw their own, 2024

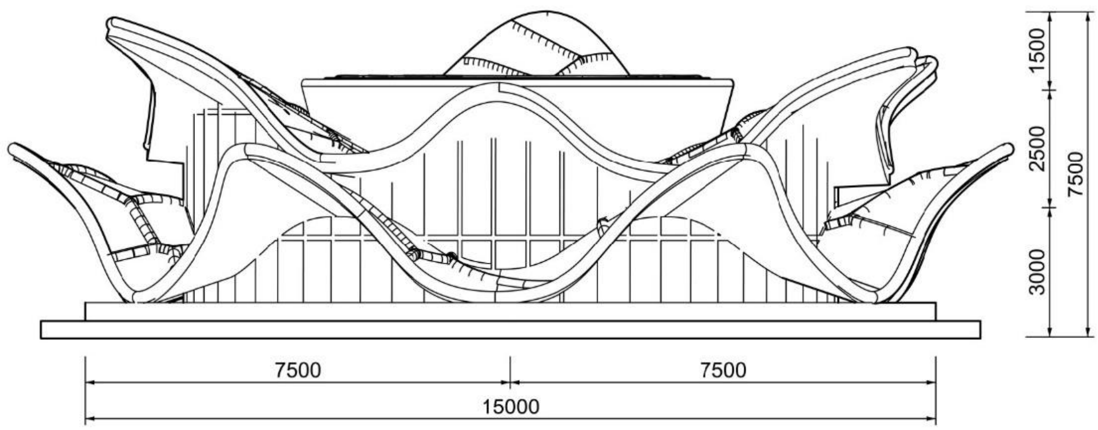


Figure 173 *Lotus bionic parametric building 2 side elevation*
Note. Researchers draw their own, 2024

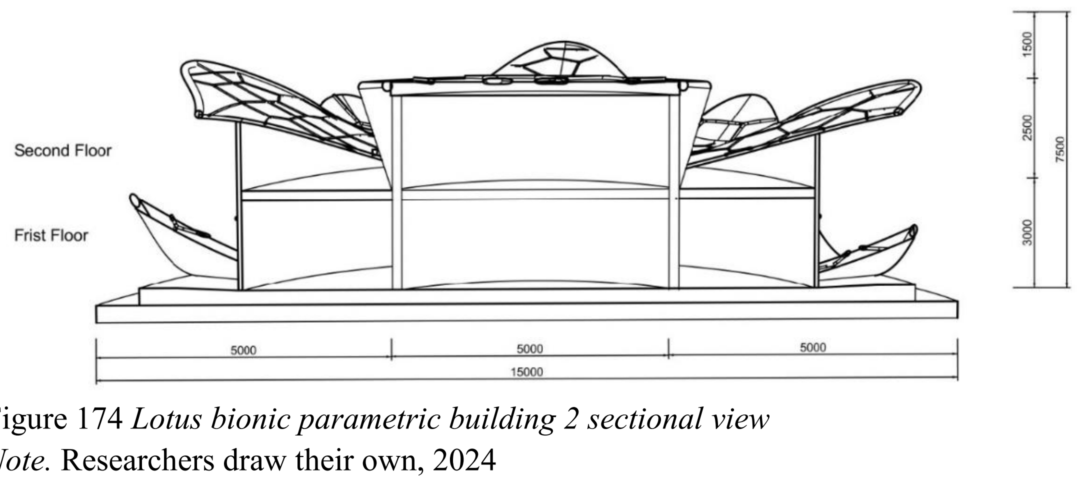


Figure 174 *Lotus bionic parametric building 2 sectional view*
Note. Researchers draw their own, 2024

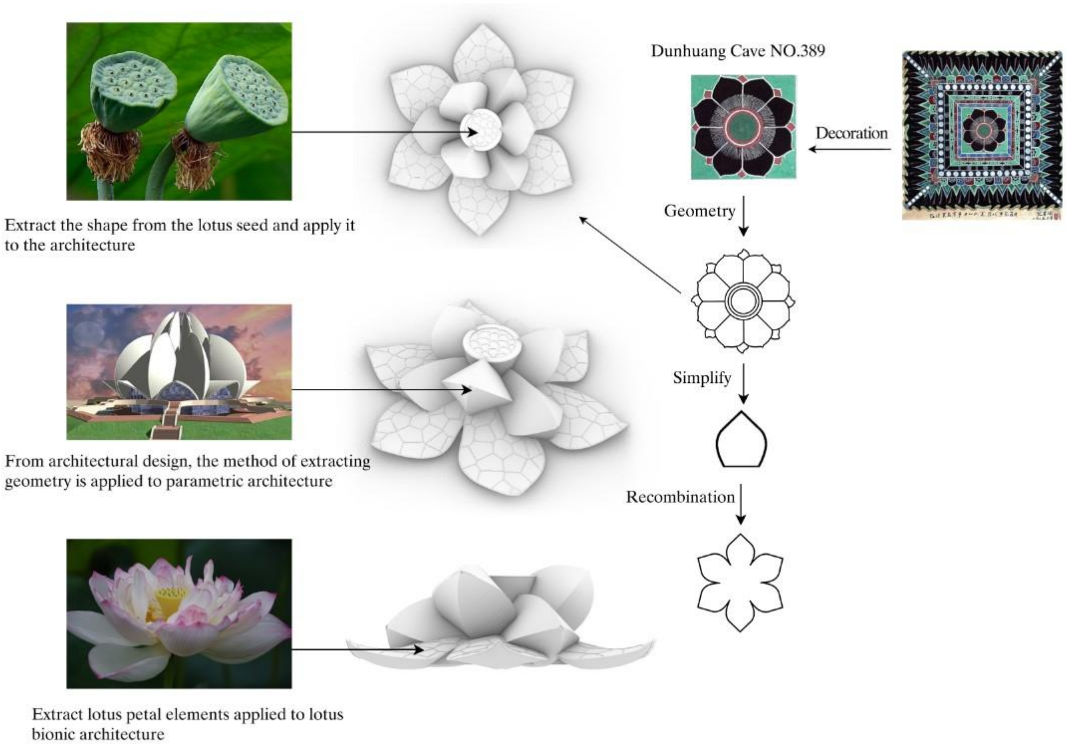


Figure 175 *Lotus bionic parametric architecture 3 mind map*
Note. Researchers draw their own, 2024

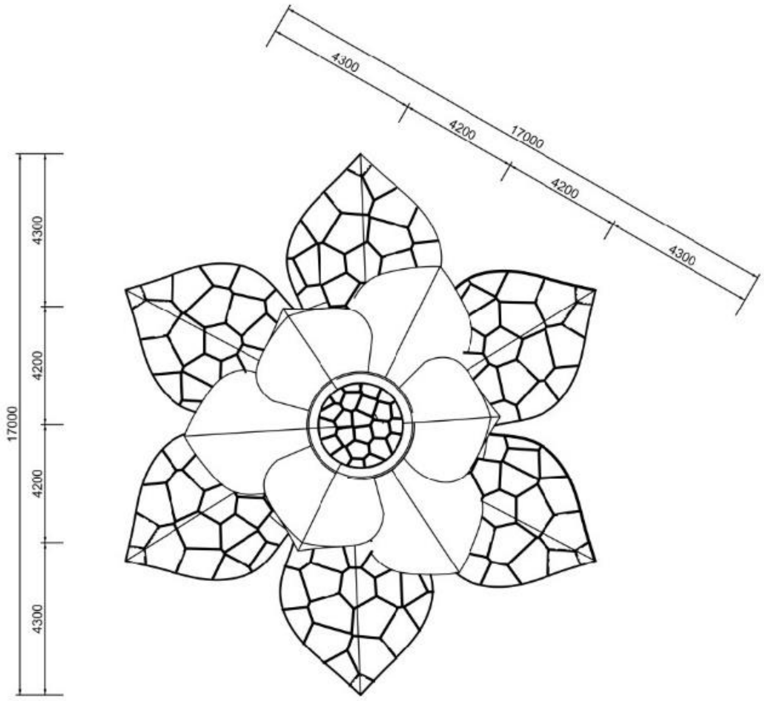


Figure 176 *Lotus bionic parametric building 3 plan*
Note. Researchers draw their own, 2024

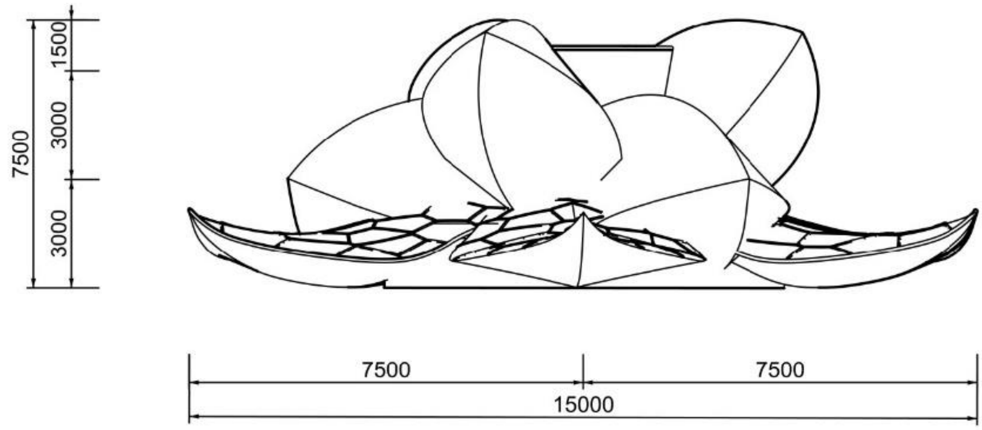


Figure 177 *Lotus bionic parametric building 3 elevation*
Note. Researchers draw their own, 2024

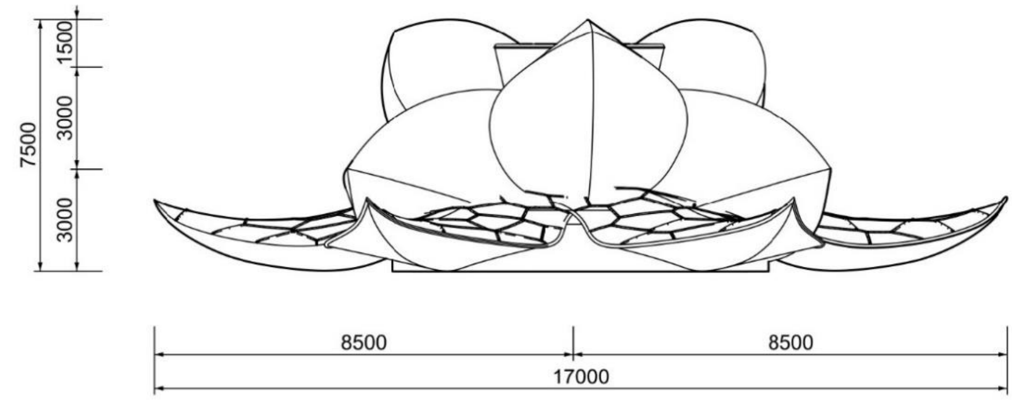


Figure 178 *Lotus bionic parametric building 2 side elevation*
Note. Researchers draw their own, 2024

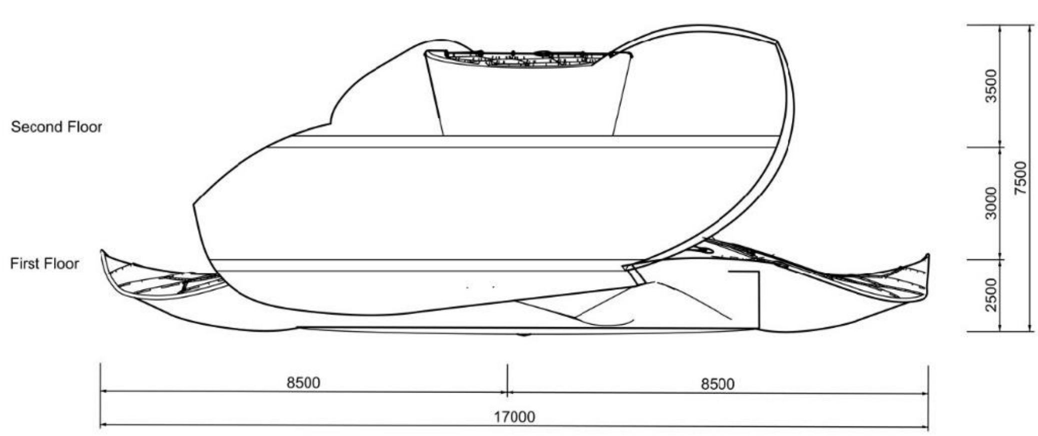
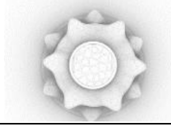
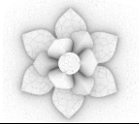


Figure 179 *Lotus bionic parametric building 3 sectional view*
Note. Researchers draw their own, 2024

Summarize research content through exhibitions and interviews, participants compared the above three Lotus bionic parametric building models, choose the best work.

Table 24 *Comparison table of three lotus bionic parametric building models*

Project	Content	Option One	Option Two	Option Three
Model plane				
Model facade				
Model perspective				
Aesthetics	Appearance Design	9	9	9
	Proportion And Form	7	8	7
	Color Selection	8	8	8
	Material Texture	8	9	7
Structural	Space Allocation	7	8	6
	Usage Efficiency	8	9	7
	Comfort	8	9	7
	Convenience	8	8	7
Feature	Carrying Capacity	8	8	7
	Seismic Performance	8	9	7
	Wind Resistance	10	9	9
	Structural Stability	8	9	7
Sustainability	Energy Efficiency	8	9	8
	Material Selection And Reuse	8	8	7
	Water Resources Utilization	9	9	8
	Environmental Impact	7	8	7
Economy	Construction Cost	9	9	8
	Operating Costs	9	9	9
	Maintenance Cost	9	9	8
	RoI	8	9	7
Light	Brightness	9	7	8
	Color Temperature	8	8	7
	Efficiency	8	9	8
	Color Reproduction Index	7	7	7
Spatial Planning	Space Efficiency	8	9	7
	Space Layout Design	7	8	7
	Space Functionality	8	9	8
	Space Streamline Design	7	8	7

Space Comfort	9	9	8
Total Score	235	247	217

Note. Researchers draw their own, 2024

Based on suggestions from participants, from the model plane, model elevation, and model perspective, scores are given based on content indicators such as aesthetics, structure, and functionality; ratings are on a scale of 1 to 10,10 represents the best, and 1 means the worst. The formulas by which rainwater falls and creates water flow usually involve hydrology and fluid mechanics. Flow velocity of free surface flow, manning's formula, $V = \frac{1}{n} \cdot R^{2/3} \cdot S^{1/2}$, V is the water velocity, n is the manning coefficient, Which represents the resistance coefficient of the water flow under specific terrain and surface conditions, R is the ratio of the wetted perimeter to the area of the flow section, also known as the wetted perimeter radius, S is the slope of the flow, which is the ratio of the elevation change of the flow to the horizontal distance of the flow. Participants believed that in natural rainfall drainage speed, streamlined and wavy buildings, curved buildings, and geometric buildings, the wavy building surface has an undulating shape, which causes water to flow rapidly across the surface, thereby speeding up natural drainage and making it not easy to stay. Therefore, option 2 is selected as the final specific case study analysis conclusion of lotus bionic parametric architectural design.

4.6 CONCLUSIONS OF THE RESEARCH ON LOTUS BIONIC PARAMETRIC COLLABORATIVE DESIGN OF CONTEMPORARY CHINESE ARCHITECTURE

Mr. Ieoh Ming Pei, the master of Chinese architecture, once said that the purpose of architecture is to enhance life, not just the objects admired in space. Architecture must integrate human activities and improve their quality. Based on digital technology, the design of the lotus bionic parametric building, with many distinctive, innovative elements, a new architectural language, a new architectural space experience, a new artistic experience, a new design approach, and a brand new construction mode. The parametric design method allows the building to achieve creative freedom and construction precision. Found a new support point for architectural aesthetics, presenting a new aesthetic era. The lotus bionic parametric building adopts a technical system under digital control; innovation creates unprecedented aesthetic value and lets science and technology shine with the light of art.

From the perspective of the development of architectural disciplines, after experiencing the high development of modern architecture, architects and even society have reached a consensus that architecture should be more humane and the environment be more friendly. The former means that architectural design should be more based on human behavior and comfort requirements, considering dynamic changes and spiritual feelings. Architecture should be where events happen, the space where activities are carried out, etc. The latter means that architectural design should be based more on various environmental conditions and fully consider multiple artificial and natural factors in and around the construction site; simultaneously, it saves energy and protects the environment.

As an interdisciplinary subject, bionic design needs to be integrated with many disciplines; this paper uses existing systematic natural subject knowledge to serve the design, take the plant lotus in nature as an example, digest understanding of the natural subjects of the lotus plant, transformed into plant elements for bionic design, integrating the two fields of humanities and nature, the concept of lotus plant modeling elements are extracted. The creation of lotus plant modeling element data will be used by researchers or designers when conducting bionic design. It provides a convenient way to select bionic objects and detailed knowledge of lotus plants, presented systematically, and expands designers' horizons and sources of inspiration.

With the booming development of digital art and technology, the parametric design method, compared with the traditional design method, is more efficient and flexible and has automatable features, broad application prospects, and practical significance. It facilitates collaboration among design teams, improves work efficiency, improves design quality, and provides more creative and optimization possibilities for designers or architects; it has more practical application value.

As society moves towards a new digital era, architectural design tends to be personalized and customized, and the type and depth of non-standard customization will further leap forward. Also, based on a complete system digital model with human-machine collaboration, various parameter-defined component units can be customized in the construction field. Cost and construction period: After the limitations of the process are reduced, architecture responds to the environment and place with more accessible forms and spaces, realizing nature through more precise digital control and more brilliant construction methods, creating ecological, high-performance buildings of the future.

CHAPTER 5

CONCLUSION DISCUSSION AND RECOMMENDATIONS

Chapter 5 summarizes the contents of the previous four chapters, combining lotus plant bionic design with parametric technology development, natural beauty with modern technology, and an innovative application method that integrates collaborative design in architecture. Improve the feasibility of applying bionic parametric technology to buildings, promote continuous innovation in Chinese architectural design, and lead the development trend in architectural design. Stimulate the creativity of Chinese architectural designers, transforming natural ecology into innovative architectural forms and prompting them to incorporate ecological sustainability into their design scope and create more environmentally conscious architectural works.

China needs to be more active in pursuing scale and speed of development; this has led to some homogenization problems and cultural loss in urban construction. Architectural designers unthinkingly follow market development and must think more about urban development. This urgently requires architectural designers to pay more attention to ecological, environmental protection, cultural inheritance, quality, and safety to achieve high-quality, sustainable Chinese architecture.

5.1 CONCLUSION

5.1.1 SYSTEMATIC RESEARCH ON THE INNOVATIVE DESIGN OF PLANT LOTUS PATTERNS

Research content on the innovative design of plant lotus patterns, a large amount of image data was collected as support for the data and particular research on traditional lotus patterns from different periods was conducted. It is necessary to complete historical and cultural research on the lotus pattern, pattern type analysis, inheritance and evolution, aesthetic value analysis, application development discussion, etc. There are relatively few special studies on lotus patterns in different periods. To ensure the completeness and accuracy of research materials, the researchers used a combination of extensive literature research and fieldwork, investigation and evidence collection in multiple places, and mutually complementary essential information databases. They provided a guarantee for the completion of the research on the innovative design system of plant lotus patterns.

5.1.2 SYSTEMATIC RESEARCH ON PARAMETRIC TECHNOLOGY DEVELOPMENT MODELS

In parametric modeling, there are many powerful tools available to researchers. Among them, Rhino Grasshopper is a widely used plugin that provides researchers with an intuitive and powerful interface and enables the creation of complex parametric models in Rhino 3D modeling software. Researchers can construct an organic, highly controllable building model by connecting various components and algorithms. Beyond Rhino Grasshopper, some other modeling software and programming languages, such as Generative Components, Dynamo, Python, etc., can be used for parametric modeling. What these tools have in common is that they provide researchers with more flexibility and control, allowing for more fine-tuning of building designs.

5.1.3 SYSTEMATIC RESEARCH ON 3D PRINTING TECHNOLOGY

Based on lotus flower, based on 3D printing technology, exploring and evaluating the production process of bionic parametric architectural designs in contemporary China, it aims to provide specific theoretical support and methodological guidance for the later development of this field. 3D-printed concrete is a technology that is leading the construction industry's transformation and has become an important development direction in the construction field. Vigorously promoting green buildings and green construction technologies, collaborative construction industrialization, innovative construction, and green construction are the current development trends in the construction industry. Concrete 3D printing technology relies on mold-free manufacturing, a high degree of molding freedom, high construction efficiency, a high degree of intelligent automatic integration, ample room for error, advantages of green, low carbon, and low dependence on labor, integrating prefabricated building technology, this undoubtedly brings new opportunities to the traditional construction model. As technology advances, there is reason to expect that 3D-printed concrete technology will play a more extensive and vital role.

5.1.4 SYSTEMATIC RESEARCH ON LOTUS BIONIC PARAMETRIC ARCHITECTURAL DESIGN EXPERIMENTS AND DESIGN PRACTICES

Corbusier once said architecture manifests willpower, and design is about creating an order. We have always felt that such words are still practical for us when doing architecture in the current context. The general steps for bionic design of architectural forms are derived from general architectural design procedures.

First of all, it is an analysis of lotus biomorph ology, select and simplify, based on the relevant information obtained during the design preparation stage, the design positioning of the building, design requirements and how the building is used, analysis results of usage environment, function, structure, materials, etc., choose from lotus creatures or lotus patterns to match your architectural design requirements. Specifically, it is the lotus shape corresponding to the architectural components, features, structure, directional determination, and description of aesthetic imagery and other features, and integrated with the architectural concept to form the lotus bionic design concept of the target building, then seek in lotus bio, search for objects related to bionic concepts, by observing, cognition, research to screen and identify content that is inspiring and useful for bionic design. After selecting the bionic object, to further understand the characteristics of the lotus flower form, a comprehensive analysis of the lotus shape from all aspects is needed to understand the functions of the lotus form and have a thorough understanding of structures and their characteristic properties. Based on the architectural design requirements, simplified form extracts morphological features required for architectural design.

Secondly, design and application of lotus biomorph ology. Under the guidance of bionic design concepts, relying on the researcher's sensibility and intuitive way of thinking, simplify the lotus shape obtained in the previous stage, used in architectural design concepts, integrating the main characteristics of the lotus shape into the functional, structural system of the architectural form, so that it can be reflected in specific architectural forms, and use rational and reasoning thinking to verify and revise.

Again, bionic design proposal and effectiveness evaluation. After completing various imaginative sketches of early design ideas, building elements must be the core factors related to comprehensive architectural design; first, perform one or more analyses, evaluate, and then select valuable sketches that may be developed. After interviews and revisions, a suitable design plan that aligns more with the architectural concept and design goals is obtained. Period, perform feature matching on architectural bionic form prototypes, and verify the accuracy and effectiveness of morphological feature imitation.

Analysis of the results from the above design experiment and design practice process, the transformation of lotus morphological characteristics into architectural morphological characteristics have gone through a selection of morphological traits, analysis, simplified, and then apply the complex process, the choice of lotus shape is the first step in bionic shape design. It is related to whether the bionic design can be consistent with the expected effect and whether the building-related information can be effectively conveyed. Considering the characteristics of the lotus shape, it is also necessary to consider the requirements of architectural form design. Therefore, it is difficult for researchers to grasp it properly. Consequently, it is difficult for researchers to learn correctly. Imposing the lotus shape on the architectural form, the structure of the building was deliberately changed to cater to the lotus shape, which may cause problems with the functional structure of the building. However, insisting on the functional structure of the building will fail to achieve the lotus building's meaning and symbolic bionic purpose.

5.2 DISCUSSION

5.2.1 STATEMENT OF THE STUDY

The Lotus bionic parametric architectural design uses a hybrid research method, including a literature survey method, combining qualitative and quantitative analysis methods, case study, design practice, expert consultation method, etc. Four objectives and four hypotheses were identified.

The first goal is to study traditional Chinese Buddhist lotus patterns and inherit the meaning of Chinese cultural elements and functions of folk customs.

The second goal is to study advanced digital parametric technology in contemporary China and ways to improve designer productivity.

The third goal is to conduct lotus bionic parametric architectural design experiments and practices that benefit Chinese architectural designers and college students.

The fourth goal is to combine construction engineering manufacturing production, environmentally friendly materials, and 3D printing technology to achieve sustainable development of ecological buildings.

The first assumption is respect for nature, creating something as smooth as nature, a symmetrical architectural form.

The second assumption is cultural inheritance, which is traditional Chinese lotus plant elements with historical and artistic value.

The third hypothesis is that technology leads and rational design can be realized using the latest digital parametric technology.

The fourth assumption is to follow the guidance and provide learning guidance for contemporary Chinese architectural designers.

The design practice was held in 3 workshops, namely the traditional Chinese Buddhist lotus pattern design workshop. Parametric modeling design workshop. Lotus bionic parametric architectural design workshop.

The traditional Chinese Buddhist lotus pattern design workshop is divided into two groups: AB. At the same time, one group underwent workshop training; the other group needed to be trained to complete the lotus pattern design. I discovered that the students who participated in the workshop expressed their creative stimulation and diverse expressions of lotus patterns, and all had unique insights. 80% of the students who did not participate in the workshop failed to meet the requirements for lotus pattern design.

The parametric modeling design workshop is divided into two groups: AB. At the same time, one group underwent workshop training; the other group was not trained in a complete parametric modeling design. It was found that students who participated in the workshop were faster in parametric modeling than those who did not participate in the workshop. Parametric modeling dramatically improves the efficiency of design work.

The Lotus Bionic Parametric Architectural Design Workshop is divided into two groups: AB. At the same time, one group underwent workshop training; the other group was not trained and completed the Lotus bionic parametric architectural design. It was found that the students who participated in the workshop were proficient in using drawing techniques and design methods. Students who did not participate in the seminar had specific design problems.

Through a comparative analysis of three workshops, the feasibility of the method was verified, and design efficiency and quality were improved. The workshop was a success.

During the expert interviews, seven experts and leaders were interviewed in-depth, namely Wang Ruixia, a professor at Nanjing Forestry University in China. Huang Haibo, Dean of the School of Art and Design, Changzhou University, China. Peng Wei, Dean of the School of Art and Design of Changzhou Institute of Technology. Yu Jie is a professor at the School of Art and Design of Changzhou Institute of Technology. Li Xiongwei is a professor at Changzhou Engineering Vocational and Technical College in China. Qi Jinsong is a professor at the School of Art and Design of Changzhou Institute of Technology. Chen Liqun is the president of Changzhou Technical College in Jiangsu Province.

In an interview with Huang Haibo, he proposed that the current research on Chinese lotus patterns is fundamental; this greatly emphasizes the inheritance of Chinese traditional culture. The disadvantages are the lack of designers of lotus patterns and the difficulty of re-designing lotus patterns.

In an interview with Peng Wei, he proposed methods for generating designs using parameters and rules, which has many advantages, especially the flexibility and innovation of parameters; you can find different designs for complex shapes and structures, the formation efficiency of free-form surfaces is also very high, this is difficult to achieve with traditional generation methods. The disadvantage is that parametric design is challenging to use, and designers have specific requirements for algorithm knowledge. It is difficult for beginners to complete an independent architectural design project.

In an interview with Yu Jie, she proposed that the lotus pattern has profound cultural and religious significance in many cultures. Generally accepted in different cultures, it can be applied to various occasions and has high flexibility. The disadvantage is that when designing, consider your target audience's cultural background; cultural sensitivities must be regarded to avoid misuse or disrespect.

In the interview with Li Xiongwei, he proposed that biomimetic parametric architectural design combines natural inspiration and advanced technology, provides innovative and efficient design solutions, and has significant functional optimization and sustainability advantages. However, construction and R&D costs are high, which may delay the project cycle.

In the interview with Qi Jinsong, he proposed that automatic calculation of algorithms for generative design is beneficial for manual drawing and model adjustment time and improves design work efficiency. At the same time, parametric control of design details is excellent. However, the limitation of the algorithm is that the design results are subject to the set parameters and rules, which may limit the designer's freedom and creativity.

In an interview with Chen Liqun, he proposed that the rich biological forms in nature inspire designers' creativity and imagination. The designed Lotus building is unique, innovative, highly recognizable, and visually impactful. From the perspective of school construction and use, enhancing the school's brand and cultural image is very helpful. The limitation is that the construction cost will be much higher than the ordinary cost. The school will consider whether to adopt this option from an economic perspective.

In-depth interviews with experts conclude that they all agree with the research on Lotus bionic parametric architectural design; it will play a perfect role in promoting the development of China's future architectural trends.

The lotus bionic parametric design of contemporary Chinese architecture is an innovative concept deeply inspired by traditional Chinese culture. This design concept integrates the shape of the lotus and the beauty of nature into architectural art through digital technology tools and computer calculation methods to achieve unique and stunning architectural creations.

The Lotus bionic parametric architectural design process explores a scientific approach to architectural design and construction. The core of digital parametric technology itself is science; the central content of parametric design and development is to have a parametric model; there is a relationship; taking this relationship as the core, parameter information can be changed, and the output results can be altered. The understanding of parametric architectural design in scientific research or design is algorithm design. Morphogenesis, performance simulation, algorithm optimization, data analysis. This is particularly important for researchers because, at different stages, different economic conditions, different parties, architectural design requirements are constantly changing; the most prominent feature of the parametric platform is that after establishing the model, as long as the input information changes, the calculation results of the model can change accordingly, and timely output, demonstrate superiority, visual programming that transforms text into images. Another advantage of parametric design is that machining and construction become more accessible, and the way information is delivered is entirely digital. The first is controllable; architects become controllable over-processing because the processed files are the design files. The second is, more precisely, information transferred directly from one link to another. From another perspective, for architects, this is a primary historical mission. Using this method promotes industry and upgrading the processing and construction industries.

In practical application, lotus bionic parametric design does not just stop at the appearance of the building; it also covers building materials, optimization of energy utilization, and sustainability. Researchers believe that by biomimetic parameterization, buildings can better adapt to their surroundings and realize intelligent utilization of resources; this has promoted contemporary Chinese architecture towards intelligence, moving in the green direction. The lotus bionic parametric design is not only breathtakingly beautiful, but it is also a successful dialogue between tradition and modernity in contemporary architecture.

5.2.2 RESEARCH DESIGN EXPERIMENT AND DESIGN PRACTICE PROCESS

The lotus bionic parametric building design uses a mixed research approach to collect quantitative and qualitative data. The study consisted of four phases.

The first stage is quantitative research, which involves questionnaires, collecting a large amount of quantitative data on traditional Chinese lotus patterns and parametric techniques, calculating the final data, and applying it to the second phase of research questions.

The second stage is qualitative research, through literature review, case study, field observation, in-depth interviews, and other methods used to explore and verify theories. It is concluded that the lotus bionic parametric architectural design in contemporary China is of research value.

The third stage is to design experiments; based on the results of the first and second phases, the researchers conduct design experiments on the lotus bionic parametric building. At the same time, the concepts and methods of promoting lotus bionic parametric architectural design in art design education should be researched.

The fourth stage is design practice, mainly applying research results in design. The fourth phase of innovative design practice research and the third phase of design experiments are carried out simultaneously.

Based on the design practice research of these four stages, after statistical data analysis, to sum up and conclude, select the most popular Lotus bionic parametric architectural design, carry out detailed analysis, make an analysis chart of specific learning steps, the research design process is edited into curriculum standards and presented in the form of text. They preliminarily conceived the architectural form through hand-drawn sketches or computer-drawn bionic lotus patterns. Set parameters in the parametric design software platform and perform model building and iterative optimization. Detailed architectural design and construction of 3D concrete printing of building structure models ensure the safety and stability of the building's ground structure. Provide learning references for designers and students majoring in Chinese architecture.

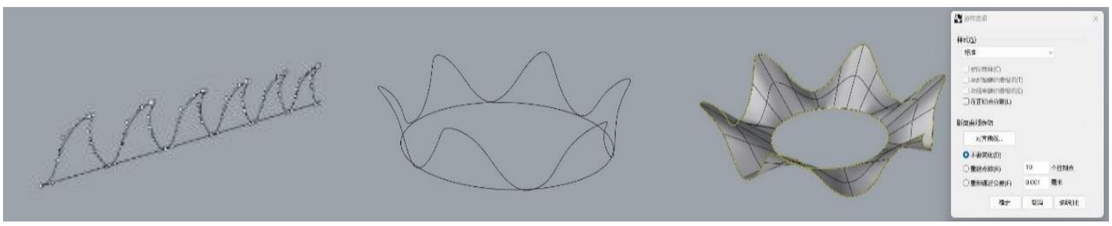


Figure 180 *Lotus bionic parametric architectural design step 1*
Note. Researchers draw their own, 2024

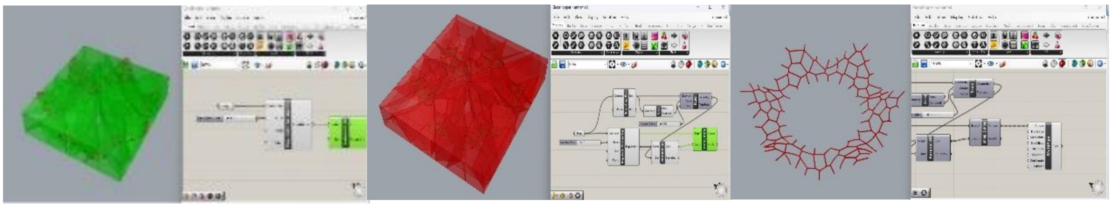


Figure 181 *Lotus bionic parametric architectural design step 2*
Note. Researchers draw their own, 2024

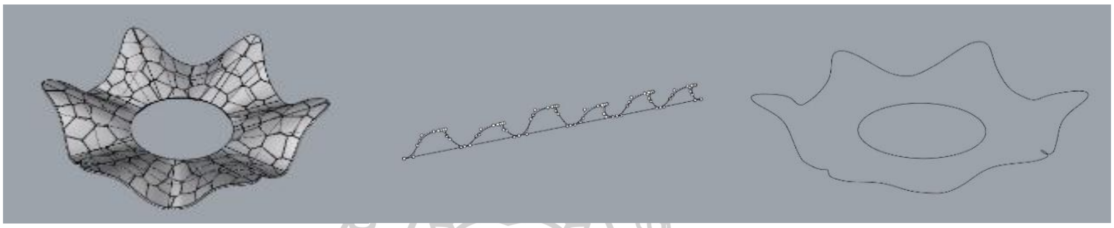


Figure 182 *Lotus bionic parametric architectural design step 3*
Note. Researchers draw their own, 2024

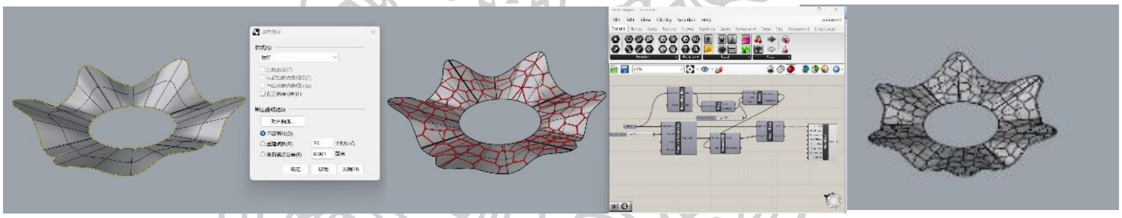


Figure 183 *Lotus bionic parametric architectural design step 4*
Note. Researchers draw their own, 2024

Figure 184 *Lotus bionic parametric architectural design step 5*
Note. Researchers draw their own, 2024

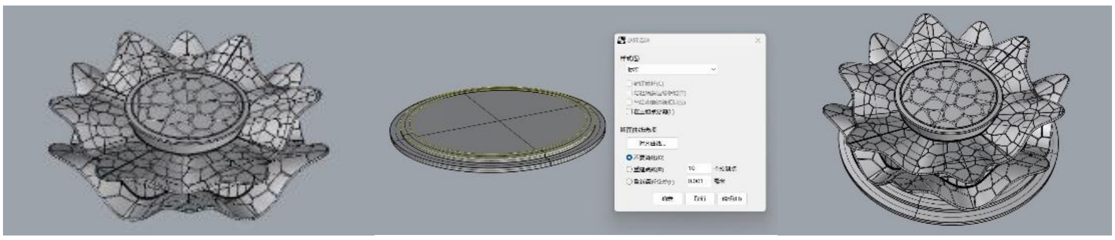


Figure 185 *Lotus bionic parametric architectural design step 6*
Note. Researchers draw their own, 2024

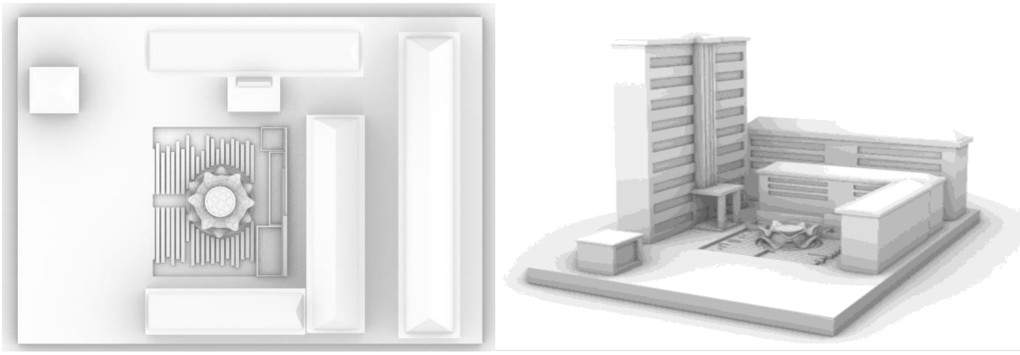


Figure 186 *Lotus bionic parametric architectural design step 7*
Note. Researchers draw their own, 2024

Bionic parametric architectural design is promoted and popularized in the form of art design education; it provides a way for the inheritance of traditional culture; based on this research, the researcher proposed a theoretical framework for design practice; this framework is suitable for the application of bionic parametric building design by Chinese architects.

The contemporary Chinese Lotus bionic parametric architectural design represents the deep integration of modern architecture and traditional culture and is an innovative application of natural forms and traditional cultural elements. This design method combines advanced parametric design technology with the aesthetic characteristics of lotus flowers in nature; it has a significant visual impact and excels in functionality and sustainability.

As a natural element symbolizing purity and elegance, the lotus has profound symbolic significance in traditional Chinese culture. Through parametric design technology, researchers accurately simulated the shape of a lotus flower and precisely controlled and optimized the structure, ventilation, lighting, and other aspects of the building. The lotus-shaped building structure can maximize airflow and improve the natural ventilation inside the building, thus improving the energy efficiency and comfort of the building. Integrating its aesthetic elements into architectural design makes the works modern and rich in cultural heritage. This design approach also excels functionally. Such a design can attract the public's attention and spread and display the charm of Chinese culture on a global scale.

In addition, lotus bionic parametric architectural design has obvious advantages in terms of sustainability. Designs that imitate nature can improve buildings' environmental adaptability and reduce resource consumption and environmental impact. By introducing natural elements, the ecological benefits of the building can be improved, and a healthier environment can be created.

However, this design approach also faces some challenges. Applying parametric design technology requires a high level of professional knowledge and skills. Designers need to master complex software tools and algorithms, which places higher requirements on their technical level. The complexity of bionic design may increase construction difficulty and cost, especially when realizing complex geometric shapes, which require high-precision construction technology and equipment support. In addition, rationally applying lotus bionic design to different cultural and regional backgrounds also requires designers to continue to explore and innovate in practice.

Contemporary Chinese Lotus bionic parametric architectural design is an innovative design method that combines natural aesthetics, traditional culture, and modern technology. Not only does it have significant aesthetic and functional advantages, but it also excels in sustainability. Despite facing specific challenges, through continuous technological progress and design innovation, this design method will undoubtedly play an increasingly important role in future architectural design and become an essential force in promoting the development of architectural design in China and worldwide.

5.3 RESEARCH COMPLEXITIES ENCOUNTERED IN LOTUS BIONIC PARAMETRIC ARCHITECTURAL DESIGN

During the research process of Lotus bionic parametric architectural design, many complex points were encountered, and the researchers proposed solutions to the complex points respectively.

5.3.1 INTERDISCIPLINARY LEARNING STAGE

In the learning stage of knowledge accumulation, research on lotus bionic parametric architectural design is comprehensive design research involving multiple disciplines and fields. I need to study biology in depth, computer science, and basic knowledge in architecture and other fields. Also, they need to have artistic aesthetic quality, sensitivity, and aesthetic vision for architectural aesthetics.

For knowledge disseminators to understand Chinese traditional culture and folk culture, it is necessary to have theoretical knowledge related to bionic parametric architectural design; a practical understanding of computer software development is also required. Therefore, knowledge communicators must have rich knowledge reserves and teach design-related knowledge to learners at different levels.

Learners must have solid basic knowledge related to architectural design, be passionate about architectural design, have strong practical ability, and continuously improve professional and technical levels through learning.

5.3.2 DESIGN EXPERIMENT STAGE

Design experiment stage, innovative attempts and explorations, establish experimental digital models, and guide subsequent design decisions; the goal is to achieve the pleasantness of the lotus bionic form, make people closer to the architectural form, complete the unity of the bionic design of the lotus architectural form and the ecological design concept of nature. Learners master the basic knowledge of design, observe more, think more, acquire new knowledge of design and the structure of the lotus body, and express it innovatively. Bionic parametric design is logical and regular, can adjust and adapt, explore and verify design feasibility, try different ideas and solutions, and evaluate the pros and cons. According to the natural and social attributes of people and researchers, the flexibility and adaptability of bionic parametric architectural design can meet individual needs to the greatest extent. Experimentally generating lotus-shaped bionic designs can help harmonize the relationship between people, architecture, and nature. Researchers have tried many times to create models, encountering the difficulty of too large model volume, only with limited algorithmic resources, maximizing the use of resources, and implementing the Voronoi diagram of the building. To satisfy the public's various aspirations for architecture, the natural bionic form of the lotus contains the vitality of life and advanced physical and spiritual needs. The parametric architecture of the lotus shape creates a natural affinity; it can arouse the public's subconscious awareness of cherishing the beauty of life and satisfy the public's psychological and spiritual needs for relaxation and pleasure.

5.3.3 DESIGN PRACTICE STAGE

The design practice stage, based on the lotus bionic parametric architectural design experiment, summarizes various exploration and innovation experiences in design experiments, paying attention to the implementation of design, establishing humans and nature, the building’s dialogue platform, paying attention to the project application of the design and verify the feasibility of the design.

The development of construction production in human society and advancing science and technology solve substantive issues. Resolving the opposition between man, architecture, and nature, various human behaviors seriously threaten the ecological balance of nature. Achieve design goals, the value of the symbiosis philosophy of harmony between man and nature, calling on people and buildings, coordination, and balance between ecological and artificial nature. Change the fixed functional mode of form and spatial environment through design practice, inhibiting the self-adjustment and adaptive relationship between humans and nature.

In the design practice stage, researchers combined the characteristics of lotus bionic parametric architectural design, creating an architectural form with typical lotus characteristics. Continuously adjust and optimize parameters during the design process, the functional and aesthetic needs of the project were met.

In the design practice stage, researchers emphasize the integration of lotus bionic parametric architecture with the surrounding environment, pay attention to ecological friendliness and adaptability, and consider the energy efficiency of the building, material sustainability, and its impact on the surrounding environment by optimizing design solutions, reduce the adverse effects of buildings on the environment.

In the practical stage, the Lotus bionic parametric building model is generated through 3D printing technology simulation, with construction engineers, multi-party cooperation and communication among the construction team, solve the design and construction technical problems existing in the construction implementation process, ensure the feasibility and implement ability of the design plan, ensure the quality and safety of buildings, ensure projects are completed as planned.

5.4 ANALYSIS OF RESEARCH RESULTS

As an emerging architectural design concept, lotus bionic parametric architectural design, researchers are designing theory, technology applications, and ecological sustainability. A series of research results have been achieved in practical case analysis and other aspects. Researchers start with cultural concepts and scheme design from a production perspective. These research results provide an essential theoretical and practical basis for the development and innovation in architectural design. Researchers use traditional culture as their thinking, using digital technology as a means, taking art and design education methods as the goal; it provides new ideas and methods to create more aesthetically valuable and eco-friendly architectural works, providing helpful research references for contemporary Chinese architectural designers.

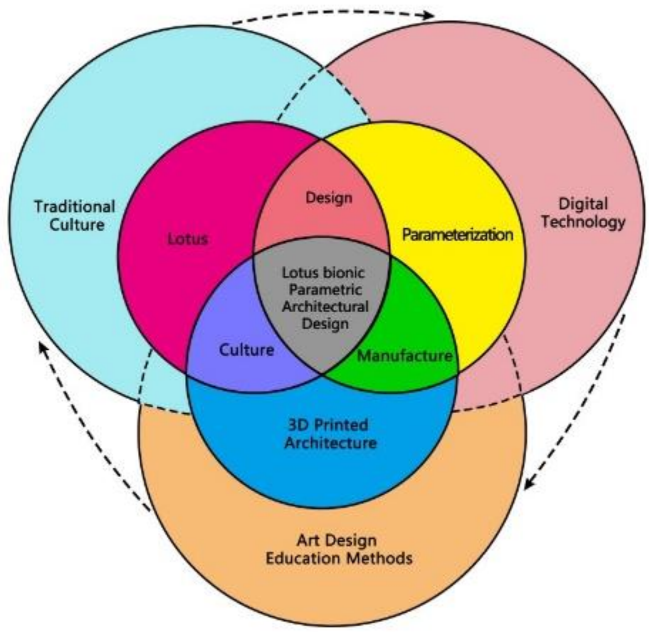


Figure 187 *Theoretical framework of research results*
Note. Researchers draw their own, 2024

Research results of lotus bionic parametric architectural design, including lotus plant pattern bionic design, parametric modeling design, and 3D printing technology, these four aspects are generated by bionic parametric buildings.

Lotus plant pattern bionic design provides a new research idea and designs more high-performance plant pattern structures. With the development of science, a more in-depth study of the natural world, imitating, copying, and recreating, proposing more theories and techniques, and using bionic technology create more wealth for human society. At the same time, as natural resources continue to be scarce today, the development of all walks of life adheres to the principle of coordinated development of environmental protection, using bionic technology to create bionic structures that better integrate with the environment.

Parametric technology development and design, through digital means, concrete the principles of bionics into controllable design parameters, making buildings more flexible and practical. This comprehensive application not only achieves the restoration of the lotus in form but also pursues efficiency and adaptability similar to nature in terms of function and structure. Parametric technology development and design change the entire perspective of traditional architecture from design to construction. According to the different participation times of computer technology in the project, the summary can be divided into the following stages: design concept stage, design development stage, design and construction stage, house management stage, and econometric stage. Parametric design is based on the characteristics of the building, which, at different stages of the project, play an important role. Provide an integrated production process from design to construction, prompting the birth of a new architectural production process and promoting the formation of new construction production industries. In lotus bionic parametric architectural design, parametric technology plays a key role. The researchers simulated various parts of the lotus by adjusting parameters, petal shape, the geometric structure of lotus pods, etc. This simulation can restore the appearance of the lotus and be more able to pass parameter changes and achieve rich and diverse architectural forms. It makes the whole design livelier and more dynamic.

3D printing technology, the most widely used and economically feasible method of 3D concrete printing, can be delivered via a pumping system, extruded in layers through the nozzle of the 3D printer. After deposition, it keeps its shape stable under the gravity load of subsequent 3D concrete printing layers; no formwork support is required. Compared with traditional concrete, 3D-printed concrete has been successfully used to make bridges, houses, and buildings such as bus stops. As a new type of automation, the cornerstone of digital technology, it brings many benefits to construction, such as highly flexible architectural design, no template manufacturing, faster construction, better working condimaterialsaving ateriamaterials.

Bionic parametric building generation is one of the innovative architectural design methods; its operation process is a link in the entire architectural design cycle. Therefore, the process of bionic parametric design also follows the procedures of architectural design; there are basic procedures, and there are also system programs. The most prominent feature of the basic program of bionic design is flexibility and freedom. At the same time, in parametric architectural design, the researchers looked at the landscape, shading requirements, climate environment, and building structure, many factors such as human needs are used as parameters that affect the design, and convert the influencing parameters into image light and dark values in the computer, the final control bitmap is generated. Then, use a computer scripting language, set up the corresponding algorithm program, and translate the bitmap's light and dark relationship values into architectural shapes, open window size, structural form, etc. It makes the bionic parametric architectural design scientifically generate the architectural form.

5.5 LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH ON CHINESE ARCHITECTURAL DESIGN

5.5.1 Research LIMITATIONS

Research limitations are mainly reflected in social and cultural factors, technical factors, economic factors, and other aspects.

Regarding social and cultural factors, parametric design ideas mainly did not comply with thousands of Chinese architectural ideas, using complexity science and postmodern post-deconstruction philosophy. Significant deficiencies exist in people's ideological realm, and most people have different levels of appreciation. Parametric design has many applications in architectural design, landscape garden design, and industrial product design. There are successful cases in clothing design and other industries, and it has received widespread attention from many people.

Technical factors mainly involve the transformation from the concept to the implementation stage, construction technology, material processing, etc.

Regarding economic factors, parametric buildings are generally several or even dozens of times more expensive than traditional construction projects.

5.5.2 RESEARCH RECOMMENDATIONS

The refinement of Lotus bionic parametric architectural design, how to meet user requirements in more detail, and how to create a closer relationship between people and the environment, can only be achieved through refined design and humanized means. The most prominent feature of lotus bionic parametric architecture is the use of new technology to achieve a more humane design. The created places bring people and nature closer and, at the same time, more beautiful and accurate. Humanization meets people's dynamic requirements; they are constantly changing. This is reflected in the fact that the architecture should be irregular, dynamic, and flowing, so the building needs to have continuity and dynamic. People don't just have a relationship with buildings; it should also be related to the surrounding environment; architecture should act as a mediator between people and the environment and communicate the two together. The higher requirement is that the building be dynamic, satisfy people simultaneously, meet environmental requirements, and put all these things together; this is the ideal contemporary Chinese architects have pursued in the 21st century.

Lotus bionic parametric architecture truly combines human dynamics with the environment, and a new kind of architecture was realized. Look at lotus bionic parametric architecture from different angles; although the actual height of the building is not very high, it is very harmonious with the surrounding environment. People feel relaxed when walking by. If we imagine turning this building into a very tall volume, it will feel like it is far away from you, but the Lotus bionic parametric building is rounded; at the same time, you will think that it is very close to you, this is because the continuous surface used gives people a sense of intimacy. Humans and nature are closely connected. As we see nature, there is no separation between people and the environment because of buildings; they are merging. This design is an excellent example of man, nature, and the environment from a general architectural perspective.

China's future architectural design is very simple, create a free, relaxed, and smooth atmosphere, in buildings, you won't feel separated from nature. The Chinese call it artistic conception, Chinese gardens focus on the creation of this kind of artistic conception and experience it is about pursuing the feeling of integrating into a specific place.

REFERENCES

Bushra, N. (2022). A comprehensive analysis of parametric design approaches for solar integration with buildings: A literature review. *Renewable and Sustainable Energy Reviews, 168*, 112849. doi:https://doi.org/10.1016/j.rser.2022.112849

Castro, J. E. (2009). Functionalism (Including Structural Functionalism). In R. Kitchin & N. Thrift (Eds.), *International Encyclopedia of Human Geography* (pp. 277-282). Oxford: Elsevier.

Cavallaro, C., Cutello, V., Pavone, M., & Zito, F. (2024). Machine Learning and Genetic Algorithms: A case study on image reconstruction. *Knowledge-Based Systems, 284*, 111194. doi:https://doi.org/10.1016/j.knosys.2023.111194

Chacón, R., Posada, H., Ramonell, C., Jungmann, M., Hartmann, T., Khan, R., & Tomar, R. (2024). Digital twinning of building construction processes. Case study: A reinforced concrete cast-in structure. *Journal of Building Engineering, 84*, 108522. doi:https://doi.org/10.1016/j.jobe.2024.108522

Chan, C.-S. (2012). Phenomenology of rhythm in design. *Frontiers of Architectural Research, 1*(3), 253-258. doi:https://doi.org/10.1016/j.foar.2012.06.003

Chen, L., Zhang, L., Wu, Y., Xu, G., & Li, B. (2024). Isogeometric Size Optimization Design Based on Parameterized Volume Parametric Models. *Computer-Aided Design, 169*, 103672. doi:https://doi.org/10.1016/j.cad.2023.103672

Chen, Y., Zhang, Y., Liu, Z., Zhang, W., Pang, B., Zhang, Y., & Wang, D. (2024). Quantitative surface quality evaluation for 3D-printed concrete with coarse aggregate through 3D scanning. *Case Studies in Construction Materials, 20*, e03077. doi:https://doi.org/10.1016/j.cscm.2024.e03077

Costa, S. D., Barcellos, M. P., Falbo, R. d. A., Conte, T., & de Oliveira, K. M. (2022). A core ontology on the Human–Computer Interaction phenomenon. *Data & Knowledge Engineering, 138*, 101977. doi:https://doi.org/10.1016/j.datak.2021.101977

Daneshvari, A. (1998). Simulations and dissimulation in postmodern architecture: The case of Los Angeles: chaos and the mythopoeic mind. *Cities, 15*(3), 173-183. doi:https://doi.org/10.1016/S0264-2751(98)00005-5

Daoling Chen, P. C., Sone Simatrang, Eakachat Joneurairatana and Veerawat Sirivesmas, & (2021). <Innovative design of caisson lotus pattern in Dunhuang.pdf>. *Humanities, Arts and Social Sciences Studies*.

Dixit, S., & Stefańska, A. (2023). Bio-logic, a review on the biomimetic application in architectural and structural design. *Ain Shams Engineering Journal, 14*(1), 101822. doi:https://doi.org/10.1016/j.asej.2022.101822

Dong, Z.-c., Zhao, Z., Liu, C.-w., Luo, J.-h., Yang, J., Huang, W.-h., . . . Luo, D. (2005). Floral Patterning in Lotus japonicus *Plant Physiology, 137*(4), 1272-1282. doi:10.1104/pp.104.054288

Goncharova, T. (2023). Bionics in architecture and geometric modelling of thin shell surfaces. *E3S Web of Conferences, 389*, 06002-06002.

Grosman, S., Macorini, L., & Izzuddin, B. A. (2023). Parametric nonlinear modelling of 3D masonry arch bridges. *Advances in Engineering Software, 185*, 103514. doi:https://doi.org/10.1016/j.advengsoft.2023.103514

Gruber, P., & Imhof, B. (2007). Transformation: Structure/space studies in bionics and space design. *Acta Astronautica, 60*(4), 561-570. doi:https://doi.org/10.1016/j.actaastro.2006.09.032

Guo, M. (28-12-2022). <A study of cultural and creative practices based on the bronze of the Lotus Crane square pot.pdf>. *Highlights in Art and Design*(Vol. 1 No. 3 (2022)). doi: https://doi.org/10.54097/hiaad.v1i3.4060

Harris, K. (2014). Deleuze and Research Methodologies. *Emotion, Space and Society, 12*, 112-113. doi:https://doi.org/10.1016/j.emospa.2013.12.016

Jan, K., Ulrich, S., & Thomas, S. (2019). *Biomimetics for Architecture : Learning From Nature*. Basel: Birkhäuser.

Jing, W., Zhen, M., Guan, H., Luo, W., & Liu, X. (2022). A prediction model for building energy consumption in a shopping mall based on Chaos theory. *Energy Reports, 8*, 5305-5312. doi:https://doi.org/10.1016/j.egyr.2022.03.205

Junior, W. K., & Guanabara, A. S. (2005). Methodology for product design based on the study of bionics. *Materials & Design, 26*(2), 149-155. doi:https://doi.org/10.1016/j.matdes.2004.05.009

Lamnatou, C., Moreno, A., Chemisana, D., Reitsma, F., & Clariá, F. (2018). Ethylene tetrafluoroethylene (ETFE) material: Critical issues and applications with emphasis on buildings. *Renewable and Sustainable Energy Reviews, 82*, 2186-2201. doi:https://doi.org/10.1016/j.rser.2017.08.072

Li, N. J. H. W. H. L. X. H. W. (17-19 November 2010). <Application of Bionic Design in Product Form Design.pdf>. *2010 IEEE 11th International Conference on Computer-Aided Industrial Design & Conceptual Design 1*. doi:10.1109/CAIDCD.2010.5681318

Li, S., Foliente, G., Seo, S., Rismanchi, B., & Aye, L. (2021). Multi-scale life cycle energy analysis of residential buildings in Victoria, Australia – A typology perspective. *Building and Environment, 195*, 107723. doi:https://doi.org/10.1016/j.buildenv.2021.107723

Liu amei, s. m., wu song,wang guanfei,chen yingzhi. (2022). Preliminary Study on the Application Technology of Lotus and Waterlily Cultivars in Shanghai Outdoor Exhibition Garden of the 10th China Flower Expo. *Hans Journal of Agricultural Sciences, 12*(07), 603-617. doi:10.12677/hjas.2022.127086

Lotfabadi, P., Alibaba, H. Z., & Arfaei, A. (2016). Sustainability; as a combination of parametric patterns and bionic strategies. *Renewable and Sustainable Energy Reviews, 57*, 1337-1346. doi:https://doi.org/10.1016/j.rser.2015.12.210

Lyu, M., Gong, G., & Li, C. (2021). A case study on organization of roof-tile production during the Tang Dynasty: Focusing on tile ends with Lotus patterns unearthed from Ximing Temple. *Archaeological Research in Asia, 25*, 100248. doi:https://doi.org/10.1016/j.ara.2020.100248

Moulinec, H. (2022). A simple and fast algorithm for computing discrete Voronoi, Johnson-Mehl or Laguerre diagrams of points. *Advances in Engineering Software, 170*, 103150. doi:https://doi.org/10.1016/j.advengsoft.2022.103150

Nowak, A. (2020). Architectural and structural optimization research of structural forms topologically transformed. *Procedia Manufacturing, 44*, 394-401. doi:https://doi.org/10.1016/j.promfg.2020.02.278

Pellegrino, P. (2006). Semiotics of Architecture. In K. Brown (Ed.), *Encyclopedia of Language & Linguistics (Second Edition)* (pp. 212-216). Oxford: Elsevier.

Rodríguez-Cuadrado, J., & San Martín, J. (2024). Design of Random and Deterministic Fractal Surfaces from Voronoi Cells. *Computer-Aided Design, 169*, 103674. doi:https://doi.org/10.1016/j.cad.2024.103674

Rosser, J. B. (2022). Complexity and aesthetics: How arts, sciences, and economics coevolve. *Chaos, Solitons & Fractals, 157*, 111905. doi:https://doi.org/10.1016/j.chaos.2022.111905

Stenning, K., & Gurr, C. (1997). Human–formalism interaction: Studies in communication through formalism. *Interacting with Computers, 9*(2), 111-128. doi:https://doi.org/10.1016/S0953-5438(97)00012-X

Su, Z., Zhou, F., Liang, J., Liu, A., Wang, J., Liang, J., . . . Yang, J. (2024). Fractal theory based identification model for surface crack of building structures. *Engineering Structures, 305*, 117708. doi:https://doi.org/10.1016/j.engstruct.2024.117708

Surman, J., Stráner, K., & Haslinger, P. (2014). Nomadic concepts in the history of biology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences, 48*, 127-129. doi:https://doi.org/10.1016/j.shpsc.2014.08.001

Wang, J., Zhang, P., Feng, J., & Cai, J. (2024). Experimental study and design approach on 3D printed concrete walls under eccentric axial compression. *Case Studies in Construction Materials, 20*, e02892. doi:https://doi.org/10.1016/j.cscm.2024.e02892

Wang, L., Wang, F., Li, R., & Wang, Q. (2024). Interfacial constitutive model of 3D printed fiber reinforced concrete composites and its experimental validation. *Case Studies in Construction Materials, 20*, e02807. doi:https://doi.org/10.1016/j.cscm.2023.e02807

Wang, X., & Song, B. (2022). Application of bionic design inspired by bamboo structures in collapse resistance of thin-walled cylindrical shell steel tower. *Thin-Walled Structures, 171*, 108666. doi:https://doi.org/10.1016/j.tws.2021.108666

Wang, Z., Long, C., Huang, L., & Hu, S. (2024). Affective product form bionic design based on functional analysis. *Expert Systems with Applications*, 123746.

doi:https://doi.org/10.1016/j.eswa.2024.123746

Weibang, L. (2023). <Relationship Between the Image of Lotus in Fire Tea and Zen.pdf>. *Agricultural Archaeology*.

Xinyu, J. (2023). Design Integration and Evolution of Dunhuang Lotus Patterns. *Design, 08*(04), 3688-3698. doi:10.12677/Design.2023.84455

Yu, H., Zhang, J., Zhang, S., & Han, Z. (2023). Bionic structures and materials inspired by plant leaves: A comprehensive review for innovative problem-solving. *Progress in Materials Science, 139*, 101181. doi:https://doi.org/10.1016/j.pmatsci.2023.101181

Yuan, Y., Yu, X., Yang, X., Xiao, Y., Xiang, B., & Wang, Y. (2017). Bionic building energy efficiency and bionic green architecture: A review. *Renewable and Sustainable Energy Reviews, 74*, 771-787. doi:https://doi.org/10.1016/j.rser.2017.03.004

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