The Application of Parameterization Technology in Furniture Design Analysis

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Abstract: Objective On the basis of clarifying the basic concepts of parametric design, analyze the research status and development trend of parametric design of furniture, summarize the opportunities and challenges in this direction, and provide reference for related research and innovative design. Methods Outline the basic principles and main features of furniture parametric design, and analyze the advantages of parametric technology in furniture design; use the literature data visualization software and select CNKI database as the source of analytical data to sort out the relevant literature; sort out the application fields of parametric technology in furniture design; and explore the emerging trends in the field of furniture parametric design. Conclusion On the basis of clarifying the basic concepts of furniture parametric design, we sort out the current research and practice progress of furniture parametric technology applied in the fields of ergonomics, structural optimization, customization and user interaction, and digital manufacturing, and put forward the potentials of innovative research of this technology in the four fields of artificial intelligence and machine learning, biological design and bionics, integration of AR and VR technology, and new material driving, and finally make an outlook on the future research directions are envisioned.

Keywords: *Parameterization technique; Furniture design; Structural optimization; Digital manufacturing*

Today, with the rapid advancement of a new wave of technological revolution, China is witnessing a pronounced trend toward the transformation and upgrading of its traditional manufacturing industries. As a significant direction for future technological development, parametric design is playing an increasingly important role in the furniture industry[1,2].As one of China's traditional pillar industries, the furniture sector has experienced remarkable growth over the past decade. According to statistics, in 2021, China had 6,647 furniture enterprises above the designated size, generating a total main business revenue of RMB 800.46 billion, representing a year-on-year increase of 13.5%[3].Despite this rapid expansion, the furniture industry continues to face persistent challenges, including limited independent innovation capacity and a high degree of product homogenization. In the face of a new technological revolution, traditional industries must pursue transformation in order to sustain development. In this context, parametric technology has emerged as one of the most effective pathways for driving the transformation and upgrading of the furniture industry[4,5].

I. INTRODUCTION

1.1 Definition and Principles of Parametric Design

A parameter refers to a variable quantity or attribute whose value may change under different circumstances. In computer science, a parameter is a value passed to a function or method to control its behavior and output. Parametric design, as an automated design methodology grounded in programming techniques, has gradually evolved alongside continuous advances in computer technology[6].In the context of furniture design, parametric design refers to an automated design approach that employs parametric software or programming techniques to generate three-dimensional models within a visualized environment by manipulating relevant parameters or algorithms. By adjusting these parameters, designers can flexibly modify attributes such as dimensions, form, and material, thereby enabling customized and personalized furniture design[7].

Parametric design encompasses two principal dimensions: the parameterization of design methods and the parameterization of design thinking[8].At present, within practical furniture design and manufacturing processes, parametric design is primarily applied to two areas: furniture form generation and structural optimization. The fundamental principle underlying its application in furniture design is to translate design elements—such as shape, dimensions, and spatial relationships—into quantifiable parameters, establish logical relationships among these parameters, and encode the design scheme into specific algorithmic rules. As a result, modifying the relevant parameters allows the computer to automatically generate corresponding design outcomes.

1.2 Historical Background and Evolution of Parametric Design

The development of parametric design can be traced back to the 1960s. Ivan Sutherland first introduced the concept of using constraints to facilitate component generation in the Sketchpad system[9]. In the late 1970s, parametric technology underwent further refinement. Richard C. Hillyard proposed the concepts of variable geometry and geometric constraints, which were subsequently advanced by David C. Gossard and his research team[10,11].During the mid-1980s, with the rise of Artificial Intelligence, Hiroaki Suzuki began integrating AI methods—such as geometric reasoning and neural networks—into design through parametric techniques. This period also marked the application of parametric methods to solid modeling and form generation[12]. In the 1990s, parametric theory became more sophisticated. Jae Yeol Lee proposed a graph-based geometric reasoning approach for knowledge representation, characterized by its conceptual simplicity and computational efficiency, which led to its widespread practical adoption[13].Today, parametric design has matured into a robust and continuously evolving field. It has been widely adopted across numerous disciplines, providing essential tools and methodologies for achieving personalized, efficient, and sustainable design solutions. Its ongoing development continues to play a pivotal role in advancing contemporary design theory and practice. A summary of the major stages in the evolution of parametric design is presented in Table 1.

Tab.1 parametric development process induction[14]

Time	Notable Figures	Research Findings
1960s－1970s	Sutherland	A Part Design Method Based on Constraint-Based Methods
Late 1970s－1980s	Robet Light and Gossard	Variable Geometry Method—Modifying the model by changing dimensional variables
Mid-1980s to early 1990s	Suzuki	The application of technologies such as geometric reasoning and neural networks in the field of physical modeling
1990s－present	Jae Yeo Lee	Representing knowledge-based geometric reasoning methods using diagrams

1.3 Parametric Modeling Tools and Software

With the continuous development of the furniture industry, parametric software has become one of the essential tools for furniture design and manufacturing, evolving in parallel with advances in digital technology. At present, a range of parametric design software packages—including AutoCAD, TopSolid, SolidWorks, ThinkDesign, 2020 Design, and Rhinoceros 3D (particularly with the Grasshopper plugin)—have become widely adopted across the furniture industry.

Each of these software platforms offers distinct advantages and specialized capabilities for different application contexts. To better address the practical needs of furniture design and production, a functional evaluation was conducted for several representative software packages. This assessment considered their professional suitability, practical applicability, strengths, and limitations, and provides a comparative analysis of their performance in furniture-related applications (see Table 2).

Tab.2 Comparison of Parametric Design Applications

Software Name	Manufacturers and Features	Key Features	Disadvantages
AutoCAD	A 2D drafting software program developed by Autodesk, a U.S.-based company.	Two-dimensional design typically uses points, lines, and planes to abstractly represent objects and construct furniture models.	The design is inefficient; if a change is made in one place, the preceding and following lines must be modified as well.
TopSolid	An integrated CAD, CAM, and PDM software suite developed by the French TOPSOLID Group.	Building on the design module, specialized woodworking tools were developed; the software is capable of 3D machining of arbitrary surfaces and 2D machining [15].	It has a certain learning curve, and while model editing is efficient, changes made in 2D are not automatically updated in 3D.
SolidWorks	Developed by Dassault, it is a Windows-based 3D mechanical design software.	It is easy to learn, offers a variety of design methods, allows new parts to be saved as standard components, and supports parametric modeling [16].	Without a dedicated woodworking module, designing complex parts is difficult, and functionality is severely limited.
ThinkDesign	Think3, a company founded in Italy, offers a highly efficient and innovative 3D design software.	A solution covering the entire furniture design process, based on a unified data platform, featuring parametric design and seamless interoperability between 2D and 3D models.	The learning curve is steep, and the technologies involved are often quite challenging.
2020 软件	The 2020 software is a panel furniture cutting list software developed on the basis of 2D CAD.	A 2D CAD-based panel furniture cutting list software that is easy to learn and use, with fast rendering and high efficiency [17].	Parametric digital models only support planar machining of points and lines; they cannot handle surface

			machining.
Grasshopper	A visual programming language developed by Meneel, which runs on the Rhino platform, is one of the leading software tools for parametric design [18].	It is easy to use, focuses on modeling, has low hardware requirements, offers excellent compatibility, and allows for quick adjustments to the model structure [19].	It's easy to get started, but it takes a while to master.

1.4 Analysis of Current Research on Parametric Furniture Design

(1)Data Processing and Research Methodology.This study primarily employs knowledge mapping as its analytical framework, with parametric furniture design as the focal research topic. The China National Knowledge Infrastructure (CNKI) journal database was used as the primary source for literature retrieval, while VOSviewer was utilized for visual knowledge-map analysis. A total of 84 Chinese journal articles related to topics such as "the application of parametric technology in furniture design" and "parametric furniture design" were identified from the CNKI database. The selected literature spans the period from March 30, 1999, to October 20, 2023.

(2)Analysis of Research Hotspots in Parametric Furniture Design. Keyword co-occurrence analysis provides an effective means of identifying major research themes and scholarly priorities within a given field[20]. Using VOSviewer, a keyword co-occurrence analysis was conducted on the collected literature, generating a map of high-frequency keywords and their clustering patterns in the field of parametric furniture design (see Table 3). The results indicate that topics such as parametric design and customized furniture have emerged as major research hotspots in recent years.

Tab.3 Parametric Furniture Design High Frequency Co-occurrence Keywords

No.	Keywords	Co-occurrence count	Total connection strength
1	Parameterization	27	31
2	Furniture Design	20	25
3	Parametric Design	31	23
4	Computer-Aided Design	8	14
5	Furniture	9	13
6	grasshopper	6	12
7	Modular	9	10
8	Panel furniture	7	9
9	Design	6	8
10	solidworks	5	7
11	Parametric technology	4	6
12	Modular design	5	6
13	Computer	3	6
14	cad	6	5
15	Mass Customization	4	5
16	Ming-style furniture	3	5
17	Mortise-and-tenon joint	3	5
18	Topsolid	3	4
19	Custom development	5	4
20	Street furniture	5	4

Cluster 1: This cluster is centered on keywords such as "parametric design," "furniture design," Grasshopper, and "digital design." At present, parametric furniture design is largely developed on the basis of Grasshopper, with research focusing on furniture form generation and design workflows. This approach has helped break away from conventional furniture design paradigms and has accelerated the industry's transition toward digital design. Zhou Zhengya[7], for example, provided an overview of parametric technology and its advantages in furniture design, proposed strategies for its application, and conducted exploratory practice through case studies, thereby offering preliminary evidence for the feasibility of applying parametric design in furniture development. Zhu Yi examined the value of parametric design from both macro- and micro-level perspectives[2]. Fu Yang, using innovative bamboo materials, employed parametric design methods to determine the optimal dimensions of chair legs and seat surfaces—two critical components in chair design—thus providing an evidence-based and effective design methodology for furniture development[19].

Cluster 2: This cluster focuses on keywords such as "mass customization," "modular design," "panel furniture," and "computer-aided design." In recent years, customized furniture has emerged as a major trend in the furniture industry. The transformation of furniture enterprises increasingly depends on the parametric design and manufacturing of furniture products. Wu Zhihui and colleagues analyzed the connotations and developmental trends of enterprise digital transformation, digital product design and manufacturing, and digital design for customized home furnishings[1]. Pan Xianfeng developed a parametric design and mechanical analysis system for panel furniture through the integrated secondary development of SolidWorks and ANSYS, addressing issues such as low design efficiency and inconsistent product quality in contemporary panel furniture production[21]. Zhong Shilu, using wooden door products as an example, explored workflows and methodologies for establishing component model libraries and product-family assembly templates through parametric three-dimensional design based on constraint blocks in TopSolid[22]. His work was grounded in principles of product serialization, standardization, and modularization.

Cluster 3: This cluster is characterized by keywords such as "mortise-and-tenon structure," "Ming-style furniture," "classical furniture," and "finite element analysis." Here, parametric design serves as a technical means for the study of traditional furniture, offering new pathways for the preservation, inheritance, and revitalization of traditional furniture culture. Zhang Lei discussed the current state and significance of preserving Chinese classical furniture[23]. Against the backdrop of computer-aided design, he integrated parametric technology to describe the processes of data acquisition, data processing, parametric modeling, and database construction for classical furniture. By combining digital design and manufacturing technologies, his approach enables the physical restoration of classical furniture artifacts. Wang Shuai proposed a parametric design method for mortise-and-tenon components[24]. Depending on the structural characteristics of different mortise-and-tenon joint types, he adopted either dimension-driven modeling or programming-based modeling. This work is of considerable significance for achieving the serialization, standardization, and industrialized production of mortise-and-tenon furniture.

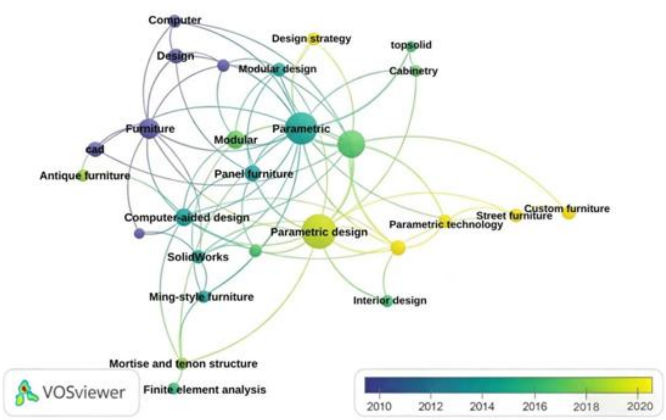


Fig.1 Furniture Parametric Design Study Keyword Co-occurrence Clustering Labeling View

1.5 Importance and Advantages of Parametric Furniture Design

Parametric technology offers significant advantages in furniture design. It fosters innovative design methodologies, accommodates personalized user needs, optimizes structural performance, improves design efficiency, and shortens production cycles. These benefits have contributed to its growing adoption within the furniture industry.

(1) Innovating Furniture Design Methodologies. Traditional furniture design typically follows a linear process in which ideas are directly translated into design solutions. In such approaches, design thinking is often centered on a predetermined outcome. By contrast, parametric design adopts a nonlinear framework based on digital variables and systems-oriented, ecological thinking. This process is highly logical, minimizes manual intervention, and remains fully visualized throughout. Designers can dynamically adjust parameters at any stage, allowing for continuous refinement until the desired design outcome is achieved[25].

(2) Meeting Users' Personalized Needs. The parametric approach enables highly individualized design outcomes, making it particularly well suited to contemporary lifestyles and increasingly diversified manufacturing demands. The openness and interactivity of the parametric design process allow designers to better understand users' preferences and functional requirements. As a result, furniture products can be tailored to specific needs, enhancing both innovation and personalization while significantly improving user satisfaction[25,26].

(3) Optimizing Furniture Structures. Parametric technology serves as a powerful tool for structural optimization in furniture design. By leveraging computational mathematical algorithms, designers can optimize structural topology, geometry, and dimensional configurations to achieve superior performance. This approach enhances strength, stability, and material efficiency while preserving aesthetic quality and ergonomic comfort[27].

(4) **Improving Design Efficiency.** Integrating parametric technology into furniture design transforms multiple design factors into quantifiable variables. Consequently, every aspect of the product becomes traceable, editable, and systematically manageable. Designers can modify any stage of the design process by adjusting relevant parameters, automatically generating alternative solutions. This substantially improves design efficiency and reduces unnecessary repetitive work[28].

(5) **Shortening the Production Cycle.** Parametric technology can encompass the entire lifecycle of furniture development—from initial concept generation and design development to manufacturing and production. It enables the establishment of a fully integrated design-to-manufacturing workflow, thereby supporting highly efficient production processes. For example, three-dimensional coordinate measurement and scanning can be used to capture the geometry and surface texture of a physical object. Through parametric reconstruction, a virtual model can then be generated and subsequently manufactured using digital fabrication technologies such as CNC machining and 3D printing. This integrated workflow significantly reduces the overall production cycle of furniture products (see Figure 2)[29].

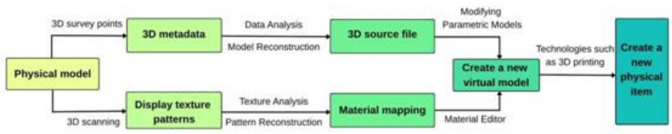


Fig.2 Flowchart for conversion of original and new physical

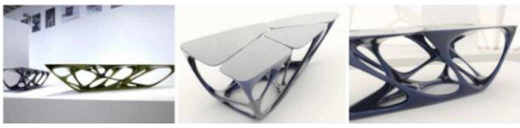
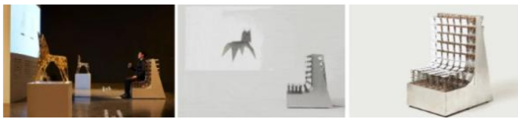
II. APPLICATIONS OF PARAMETRIC TECHNOLOGY IN FURNITURE DESIGN

In furniture design, parametric technology is generally applied through two distinct design approaches: parametrically enabled design and parametrically driven design. Parametrically enabled design relies on parametric software to rapidly generate furniture models based on predefined geometric commands and dimension-driven modifications. In contrast, parametrically driven design places greater emphasis on establishing topological relationships among data, constructing a comprehensive parametric system, and formulating computational rule sets. This latter approach offers a much higher degree of flexibility and creative freedom, thereby expanding the possibilities for innovation in furniture design[25].

2.1 Case Studies of Parametric Furniture Design

The application of parametric design in furniture enables the creation of products that embody both technological sophistication and aesthetic appeal. It supports a wide diversity of styles and is particularly well suited to meeting contemporary demands for variety, customization, and personalization in furniture products[30]. Throughout the evolution of parametric furniture design, numerous designers have explored its potential from multiple perspectives, including form, structure, functionality, and materiality (see Table 4).For example, Russian designer Oleg Soroko created the Falcon Bench, a design composed of laminated plywood sections arranged sequentially. Through parametric variation, the bench achieves a gradual morphological transformation that evokes the changing postures of a falcon. As a leading figure in parametric design, Zaha Hadid designed the Mesa Table using architectural structural thinking and problem-solving strategies, offering a new conceptual direction for parametric furniture design. Similarly, Chinese designer Zhang Zhoujie developed the Sensor Chair, which uses computer programming to collect anthropometric data through the interaction between the human body and embedded sensors. By capturing bodily dimensions and movement in real time, the system automatically generates a parametric chair tailored to the user's posture and physical characteristics. Another notable example is CHAIR N°ONE, designed by Martin Oberhauser. This chair is the first to incorporate recycled glass and concrete into a 3D-printed furniture piece. By integrating innovative materials with parametric technology, each chair acquires a unique form and material expression.

Tab.4 Comparative analysis of parametric furniture design cases

Name	Author	Materials	Design features	Case study images
"Falcon" Bench	Oleg Soroko	Plywood	Biomimetic design, Dynamic curves	
Mesa table	Zaha Hadid	polyurethane	Fluidity: Reflections on Architectural Structure	
Sensor Chair	Zhang Zhoujie	Metal	Custom-made chairs	
CHAIR N°ONE	Martin Oberhauser	Recycled glass and concrete	Parametric modeling, 3D printing with new materials	

2.2 Ergonomics and Comfort

As material living standards continue to improve, consumer expectations for furniture have become increasingly sophisticated. To meet the diverse needs of users, the application of ergonomics in furniture design has advanced to a higher level. Ergonomic design in furniture primarily emphasizes users' physiological and psychological responses during product use[31-33].The application of parametric technology in ergonomics can be broadly categorized into three major areas.**First, comfort analysis and comfort-oriented design.** Biomechanical modeling, body-pressure distribution, and related ergonomic assessment methods provide critical parameters for parametric furniture design. By analyzing interface pressure distribution, spinal loading, and intervertebral disc stress, designers can establish objective criteria for evaluating furniture comfort. These data-driven insights enable the development of furniture products that offer enhanced comfort and support[34].**Second, the development of dynamic parametric human models.**By linking anthropometric data with the morphological parameters of furniture products, designers can create furniture that better accommodates human physiology. Adjustments to body-model data automatically update the corresponding product-form parameters and reconstruct the digital model in real time. This approach allows rapid customization to accommodate variations in body size, posture, and individual user requirements, thereby supporting highly personalized furniture design (see Figure 3)[35,36].**Third, improvements in design efficiency and design success rates.**Through computer-aided technologies, parametric methods can simulate the pressure distribution exerted on different parts of the body during furniture use, enabling comprehensive comfort evaluation. Designers can then refine furniture forms promptly based on simulation results, significantly reducing the need for repeated prototyping and physical testing. Moreover, the visualization of ergonomic parameters in three-dimensional graphical form allows for early-stage evaluation of furniture designs, facilitating more informed decision-making and substantially improving overall design efficiency.

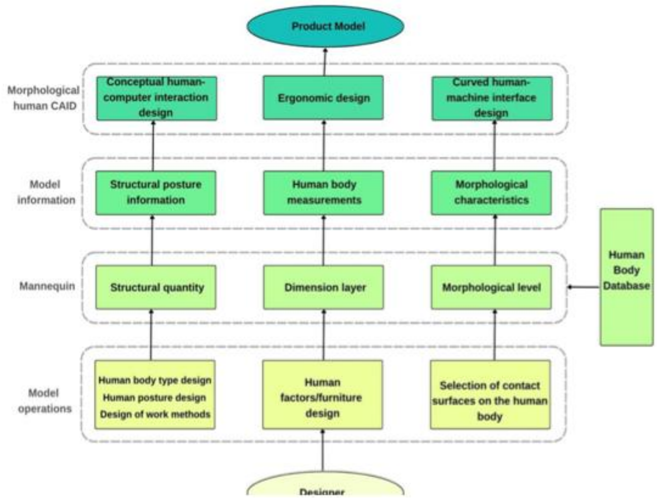


Fig.3 The use of mannequins in the man-machine design

process

2.3 Structural Significance and Optimization

The application of parametric technology in furniture structural optimization primarily encompasses two major aspects: optimizing material utilization and enhancing structural analysis and engineering performance. **First, optimization of material utilization.** By establishing parametric models that incorporate both structural dimensions and material properties, designers can employ optimization algorithms to identify the most effective parameter combinations and optimal material-processing configurations. This enables the selection of the most efficient material usage strategy based on specific functional requirements and design constraints, thereby minimizing material waste and improving resource efficiency in furniture production. **Second, structural analysis and optimization techniques.** At present, the principal methods used in parametric structural optimization for furniture include finite element analysis and topology optimization. Finite Element Analysis (FEA) involves the use of simulation software to evaluate the mechanical behavior and stress distribution of furniture structures, allowing designers to determine optimal structural solutions[37].Topology Optimization, by contrast, is a load-driven structural design methodology that assists designers in optimizing product configurations during the design stage. By defining objective functions and constraint conditions, mathematical optimization techniques are used to identify the optimal material distribution within prescribed design-variable limits[38]. Through these methods, parametric technology enables designers to refine furniture forms and determine optimal dimensional configurations, thereby significantly reducing design costs while enhancing structural performance and material efficiency[39].

2.4 Customization and User Interaction

Parametric technology significantly enhances the efficiency and automation of customized furniture design, reducing repetitive work for designers while placing the user at the center of the design process. It enables more comprehensive and responsive services tailored to individual needs[40]. Its application in customized furniture is particularly evident in three key areas.

(1) **Improving Design Efficiency in Customized Furniture.** Parametric modeling is fundamentally based on dimensional constraints. In traditional customized furniture design, three-dimensional models are typically generated from two-dimensional drawings with fixed dimensions. Any subsequent modification often requires extensive redrawing, increasing both designers' workload and users' waiting time[41]. By incorporating dimensional constraints and parameter-driven mechanisms, parametric modeling allows designers to modify and edit models simply by adjusting relevant parameters. This eliminates the need for repetitive redrawing and greatly improves the efficiency of the customization process[42].

(2) **Enhancing User Experience and Engagement.** Customized furniture design is inherently user-centered and experience-oriented. Parametric design offers strong visual interactivity, enabling users to participate directly in the design process. Through collaboration with designers, users can help create furniture that precisely reflects their personal preferences and requirements. This participatory process not only enhances user engagement and satisfaction but also contributes to a higher degree of personalization in the final product[43].

(3) **Shortening the Production Cycle of Customized Furniture.** With the support of established model libraries and three-dimensional parametric design systems, new design solutions can be generated rapidly and accurately. By selecting an appropriate base model from the database and adjusting its parameters according to user requirements, customized furniture solutions can be produced within a significantly shorter timeframe. Moreover, this approach facilitates seamless integration with intelligent manufacturing systems, enabling more efficient, higher-quality production pathways and advanced manufacturing methods (see Figure 3).

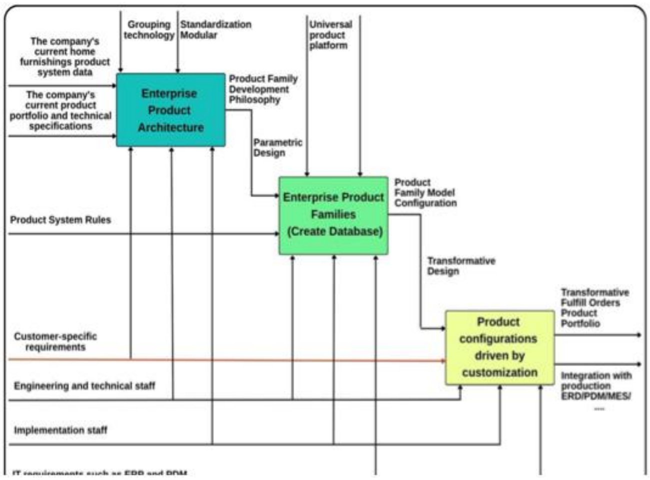


Fig. 4 An approach of parametric 3D design for intelligent manufacturing

2.5 Digital Manufacturing

With the continuous advancement of manufacturing science and technology, along with the rapid emergence of new industrial paradigms such as information-based manufacturing and intelligent manufacturing, furniture design and production have increasingly come to rely on computer systems and numerically controlled equipment. Parametric technology plays a pivotal role in accelerating the furniture industry's transition toward digital manufacturing, primarily in two respects. **First, parametric technology promotes the transformation of furniture manufacturing toward digital production models.** The ultimate purpose of design is to create products that serve both individuals and society. Traditional furniture manufacturing methods are often unable to meet the fabrication requirements of the complex geometries generated through parametric design. Consequently, the realization of such designs increasingly depends on intelligent manufacturing technologies. With the rise and maturation of digital technologies, many of the constraints previously imposed by conventional production processes have been overcome. This has greatly expanded the possibilities for furniture design and implementation, creating a more integrated and seamless product chain that links design directly to manufacturing. **Second, parametric design and digital manufacturing constitute an interdependent and mutually reinforcing system.** The integration of parametric design with digital fabrication technologies—as well as the adoption of robotic manufacturing and mass customization—has propelled furniture design toward greater intelligence, personalization, and efficiency. Digital manufacturing has become the inevitable direction of development for the furniture industry. As digital technologies permeate every stage of furniture design and production, parametric design will continue to serve as a key driver in advancing the industry's transformation toward fully digital and intelligent manufacturing systems.

III. EMERGING TRENDS IN THE APPLICATION OF PARAMETRIC TECHNOLOGY TO FURNITURE DESIGN

As advanced technologies continue to evolve, parametric technology is increasingly being integrated with other cutting-edge innovations. This convergence will better address the needs of furniture design, manufacturing, and consumer experience. By combining with emerging technologies, parametric design is poised to play an even more transformative role in the future development of the furniture industry. Integration with Artificial Intelligence and Machine Learning has the potential to significantly enhance design automation, improve manufacturing efficiency, and reduce production costs. Through data-driven optimization and intelligent decision-making, these technologies can further refine the parametric design process and enable more adaptive, responsive, and efficient production systems. The convergence of parametric design with bio-design and Biomimetics offers new opportunities for structural innovation. By drawing inspiration from natural forms, systems, and growth patterns, designers can improve existing furniture structures and develop more efficient, resilient, and aesthetically compelling products. This integration is particularly advantageous for the design and fabrication of complex furniture forms. Furthermore, the incorporation of Augmented Reality (AR) and Virtual Reality (VR) technologies is expected to introduce novel design methodologies and richer interactive experiences. These technologies can facilitate immersive visualization, real-time customization, and enhanced communication between designers, manufacturers, and consumers. Finally, the combination of parametric technology with advanced manufacturing processes and innovative materials will accelerate the realization of complex furniture forms. By bridging the gap between digital conception and physical production, this integration will make it increasingly feasible to transform sophisticated parametric designs into tangible, manufacturable products.

3.1 Integration of Artificial Intelligence and Machine Learning

With the introduction of the Industry 4.0 initiative and the Made in China 2025 strategy, manufacturing systems worldwide are transitioning from mechanization and automation toward greater intelligence and informatization. In this context, parametric technology continues to evolve through integration with emerging technologies. Its convergence with Artificial Intelligence and Machine Learning is expected to generate substantial benefits across the entire furniture industry value chain.**First, optimized material utilization.**AI-driven optimization algorithms and material response models can be integrated into parametric design systems to identify the most efficient structural configurations. This enables the development of furniture designs that maximize structural performance while minimizing material consumption, thereby reducing waste and lowering production costs.**Second, intelligent manufacturing and production.**The integration of parametric technology with artificial intelligence and automated machinery enables furniture manufacturing processes to become increasingly intelligent and autonomous. Production lines can be automatically monitored, controlled, and optimized, allowing for dynamic scheduling, reduced human error, and significant improvements in operational efficiency and production quality.**Third, digital marketing and customer engagement.**Furniture products can be presented and marketed through digital platforms using multimedia and interactive visualization technologies. Designers can communicate design outcomes to clients more effectively, allowing customers to better understand, evaluate, and experience products before purchase. In addition, furniture enterprises can leverage AI-based analytics to examine customer purchasing behavior and preferences, thereby delivering more personalized, targeted, and effective marketing strategies.

3.2 Integration of Bio-Design and Biomimetics

The fundamental principle of biomimetics is to draw inspiration from biological systems by applying biological principles, structures, and mechanisms to engineering, technology, and design. In furniture design, biomimetic approaches enable designers to emulate advantageous biological characteristics in both form and structure, thereby optimizing structural performance, enhancing strength, and creating innovative furniture typologies with distinctly organic qualities[44].Parametric design tools provide powerful means for simulating biological forms and developing biomimetic furniture. They offer significant advantages in the design and fabrication of geometrically complex products. The integration of parametric technology with bio-design and biomimetics can be understood through three primary dimensions.

(1)**Innovative Biomorphic Form Design.** At present, the most common application of biomimicry in product design focuses on form generation inspired by natural organisms (see Figure 5)[45]. Parametric technology enables designers to translate complex biological forms and structures into computational algorithms. By transforming natural morphologies into parametric systems, designers can create furniture with unique visual identities, dynamic forms, and an inherent sense of vitality[46].

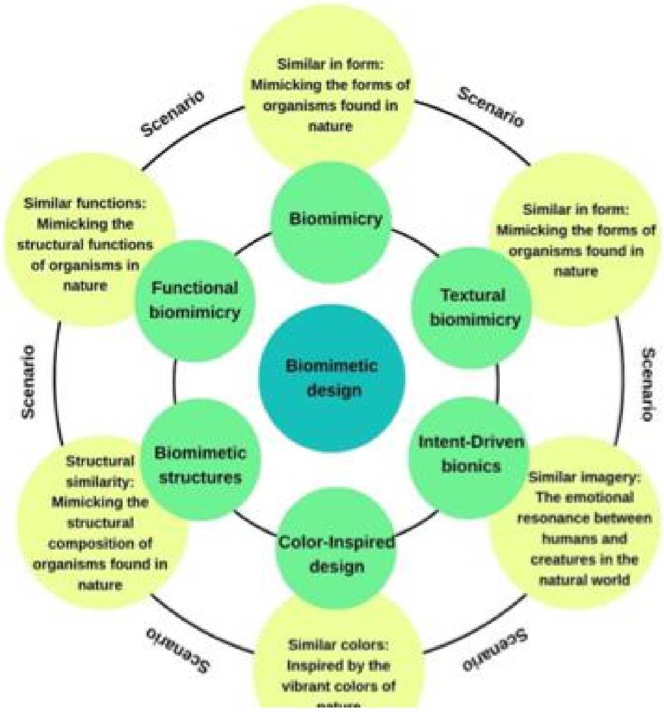


Fig. 5 Categories of product shape bionic design

(2) Structural Principles and Organizational Logic. Natural forms are governed by intrinsic structural laws and organizational principles. Every biological structure embodies internal patterns, often manifested through concepts such as the Golden Ratio, symmetry, rhythm, and hierarchical organization. In furniture design, parametric programming does more than merely imitate natural appearances or growth phenomena; it captures and reconstructs the underlying logic of biological development. These principles permeate the entire design process, enabling a harmonious integration of form, structure, and function[47].

(3) Biomimetic Ecological Design. Nature has undergone a long evolutionary process, yielding highly efficient systems of resource utilization, self-repair, and ecological balance. These characteristics provide profound insights for sustainable design. Applying parametric technology throughout the furniture production lifecycle makes it possible to emulate nature's developmental principles, thereby promoting the coordinated and sustainable advancement of human needs, environmental stewardship, and industrial innovation.

3.3 Integration of Augmented Reality (AR) and Virtual Reality (VR)

Although Virtual Reality technology in China is still in its early stages of development, its considerable application potential—together with that of Augmented Reality—suggests a broad future market within the furniture industry. Parametric technology will provide essential technical support for the deep integration of furniture design with AR and VR, thereby driving transformative changes in design methodologies and user engagement.

(1) **Immersive Visualization and Design Exploration.** AR and VR enable highly immersive and intuitive design visualization. Designers can observe, manipulate, and evaluate digital models within virtual environments, gaining a more comprehensive understanding of scale, proportion, and spatial relationships. Virtual simulation allows designers to experiment with and refine design solutions in ways that would be difficult or impossible in physical settings. This capability facilitates rapid testing, iterative optimization, and more effective validation of design feasibility and performance.

(2) Enhanced Collaborative Design and Remote Cooperation. AR and VR technologies significantly improve collaborative design workflows by enabling multiple participants to work together within a shared virtual environment. Design teams can present ideas, exchange feedback, and view or edit models in real time. Regardless of geographical location, designers and stakeholders can actively participate in discussions and decision-making processes, thereby reducing the constraints of time and physical distance.

(3) Improved Interaction Between Designers and Users. The integration of AR and VR substantially enhances communication and interaction between designers and end users. Through AR, virtual furniture models can be superimposed onto users' real environments, creating a mixed-reality experience that seamlessly combines virtual and physical spaces. This allows users to better understand a product's form, dimensions, material characteristics, and compatibility with its surrounding environment. By adjusting parameters such as placement, size, and style in real time, users can intuitively assess the impact of different design options on their living spaces. As a result, designers and users can collaborate more effectively and arrive at mutually informed design decisions[48].

3.4 Material-Driven Parametric Design

Advances in emerging technologies and novel materials have provided furniture designers with unprecedented creative opportunities. Alongside the development of new materials and manufacturing technologies—particularly the widespread adoption of 3D printing—parametric design has found increasingly diverse applications. The emergence of advanced materials allows designers to exploit their unique properties and performance characteristics to create furniture forms that are more innovative, distinctive, and functionally sophisticated. At the same time, 3D printing enables these complex forms to be physically realized. The integration of parametric design with new technologies and materials significantly accelerates the transformation of complex conceptual designs into tangible products[49].

(1) 3D Printing as an Enabler of Parametric Design. Traditional manufacturing processes often impose limitations on the fabrication of geometrically complex forms and intricate structures. By contrast, 3D printing makes it possible to directly translate parametric design concepts into physical products. This capability supports the production of highly complex, customized, and structurally sophisticated furniture forms. Furthermore, as 3D printing technologies continue to advance and printable materials become increasingly diverse, even greater possibilities are emerging for the realization of dynamically varied parametric furniture designs.

(2) Efficient Integration of Smart Materials and Parametric Design. Smart Materials are materials capable of sensing and responding to external stimuli. Examples include shape-memory alloys and other active materials. These materials can alter their shape, stiffness, or other physical properties in response to environmental changes, enabling adaptive and optimized structural behavior. By incorporating smart materials into parametric design systems, designers can achieve more efficient material utilization, enhanced structural adaptability, and reduced energy consumption. This integration not only improves product performance but also minimizes material waste, contributing to more sustainable and resource-efficient furniture design and manufacturing.

IV. CHALLENGES AND FUTURE DIRECTIONS

4.1 Limitations and Challenges in Implementing Parametric Technology in Furniture Design

Parametric design has become one of the most important design methodologies in the furniture industry. It has been widely discussed and applied in areas such as ergonomics, structural optimization, customized furniture, and digital manufacturing. Nevertheless, its implementation continues to face several significant limitations and challenges. **First, it requires a high level of technical expertise.** Parametric design demands that designers possess a solid understanding of programming, algorithms, and computational logic. Because it relies heavily on computer science and mathematical methods for the processing and management of design parameters, designers must continuously update their technical knowledge and adapt to rapidly evolving digital tools and methodologies. **Second, achieving a balance between design flexibility and manufacturability remains challenging.** While parametric design enables highly flexible and personalized solutions, practical production considerations—such as manufacturing efficiency, assembly feasibility, and process reliability—must also be taken into account. Parameter settings therefore need to reconcile multiple factors simultaneously, including aesthetics, functionality, cost, and production viability.**Third, there is substantial dependence on specialized software and hardware.** Successful implementation of parametric design requires advanced software platforms and supporting hardware infrastructure. These systems demand ongoing updates, maintenance, and technical support, often involving considerable financial investment and organizational commitment. **Fourth, the management of extensive parameter sets and databases can be complex.** Parametric design systems require the development, organization, and maintenance of large-scale parameter libraries and databases. Managing these resources effectively can be time-consuming and resource-intensive, posing additional operational challenges for design teams and manufacturing enterprises.

4.2 Future Trends and Potential Developments

Looking ahead, parametric design in furniture is expected to evolve toward deeper interactivity, greater intelligence, enhanced personalization, and stronger sustainability. These trends will further expand its role across the entire furniture industry.

(1) Advancing Toward Greater Interactivity. Future furniture design will increasingly center on user needs and prioritize enhanced user experience. Parametric design technologies will continue to evolve in ways that strengthen user participation, service responsiveness, and interactive engagement. Users will play a more active role in the design process, with parametric systems enabling them to independently select, customize, and adapt furniture solutions according to their specific preferences and requirements. As a result, the design process will become more collaborative, participatory, and user-driven.

(2) Driving the Development of Personalized Furniture Design. As living standards continue to improve, consumer demand is shifting from purely material satisfaction toward emotional and experiential fulfillment. Consequently, personalized products are becoming increasingly desirable. Parametric design is particularly well suited to addressing this demand by providing efficient and scalable solutions for mass personalization. Supported by advances in Artificial Intelligence, parametric design will lower the technical barriers to customization, enabling a transition from production-driven consumption to consumer-driven production. In this model, users will increasingly influence both design decisions and manufacturing outcomes, helping to bridge the gap between standardized production and the desire for individualized living environments.

(3) Accelerating the Transition Toward Intelligent Manufacturing. Parametric design will further promote the transformation of furniture manufacturing toward intelligent production systems. By standardizing data structures and information flows throughout the customized furniture design process, parametric technologies can reduce manual intervention and enable seamless integration between design and manufacturing. This will facilitate a fully integrated workflow—from conceptual design to production—thereby making furniture manufacturing more efficient, precise, and intelligent.

(4) Promoting Sustainable and Green Development in the Furniture Industry. Compared with traditional design methods, parametric design places greater emphasis on harmony between human-made products and the natural environment. Through precise alignment of design, demand, and production, it minimizes material waste and reduces the consumption of environmental resources. Guided by principles of ecological coexistence, parametric design can generate furniture with multifunctional capabilities, organic forms, and improved material efficiency. By moving beyond the constraints of conventional formalism, it will help steer the furniture industry toward more sustainable, environmentally responsible, and resilient modes of development.

In sum, parametric furniture design represents a major direction for the future of the industry. As parametric technology continues to permeate every stage of the furniture value chain, it will serve as a powerful catalyst for innovation, transformation, and sustainable growth.

CONCLUSION

With the continuous advancement of science and technology, the traditional furniture industry is facing significant challenges of transformation and upgrading. In response to the growing demands for intelligence, personalization, efficiency, and sustainability, parametric technology is emerging as a key driving force for the future development of the furniture industry. Current research in China indicates that the application of parametric technology in furniture form generation and design programming, the parametric design and manufacturing of customized furniture, and the preservation and reinterpretation of traditional furniture culture have become important and rapidly expanding areas of study. These developments highlight the broad applicability and transformative potential of parametric approaches across both contemporary innovation and cultural heritage contexts. Therefore, continued efforts should be made to refine design standards for parametric furniture, establish more systematic design methodologies, and explore innovative workflows that integrate design, engineering, and manufacturing. Such efforts will help improve the practicality, efficiency, and accessibility of parametric design in real-world furniture production. Looking ahead, the integration of parametric technology with emerging fields such as Artificial Intelligence, biomimetic design, and Virtual Reality will open new frontiers for furniture design and manufacturing. This convergence will not only expand creative possibilities and enhance user experiences, but also provide strong technical support for the digital transformation of the furniture industry. Ultimately, parametric technology will continue to reshape the relationship between design, production, and consumption. As it becomes increasingly embedded throughout the furniture value chain, it will serve as a powerful engine for innovation, intelligent manufacturing, and sustainable development, driving the furniture industry toward a more advanced, flexible, and environmentally responsible future.

References

[1] Wu, Z., & Ye, Z. (2023). Development trends in digital transformation and digital product design in home furnishing enterprises. *Wood Science and Technology*, 37(3), 1–11.

[2] Zhu, Y. (2019). Current status and prospects of parametric furniture design. *Furniture & Interior Design*, (12), 60–61.

[3] China's furniture industry: Enterprises above designated size achieved cumulative revenue of RMB 800.46 billion in 2021. (2022). *China Wood-Based Panels*, 29(4), 46–47.

[4] Hui, X., Wu, Z., & Liu, Z. (2020). Evaluation of parametric 3D design software applications in the customized home furnishing industry. *Furniture*, 41(1), 14–18.

[5] Bai, L., & Zhu, X. (2023). Application of parametric technology in furniture design. *Furniture*, 44(3), 22–26.

[6] Song, J., Chen, Q., Chen, L., et al. (2022). Research on furniture design based on parametric and additive manufacturing technologies. *China Forest Products Industry*, 59(6), 52–56.

[7] Zhou, Z., & Zhang, Z. (2020). Research on the application of parametric technology in furniture design. *China Forest Products Industry*, 57(4), 33–37.

[8] Oxman, R. (2017). Thinking difference: Theories and models of parametric design thinking. *Design Studies*, 52, 4–39.

[9] Sutherland, I. E. (1963). Sketchpad: A man-machine graphical communication system. In *Proceedings of the Spring Joint Computer Conference* (pp. 329–346).

[10] Hillyard, R. C., & Braid, I. C. (1978). Analysis of dimensions and tolerances in computer-aided mechanical design. *Computer-Aided Design*, 10(3), 161–166.

[11] Light, R. A., & Gossard, D. C. (1982). Modification of geometric models through variational geometry. *Computer-Aided Design*, 14(4).

[12] Suzuki, H., Ando, H., & Kimura, F. (1990). Geometric constraints and reasoning for geometrical CAD systems. *Computers & Graphics*, 14(2), 211–224.

[13] Lee, J. Y., & Kim, K. (1996). Geometric reasoning for knowledge-based parametric design using graph representation. *Computer-Aided Design*, 28(10), 831–841.

[14] Liu, Z. (2018). *Research on the theory and application of furniture flat-pack design* (Doctoral dissertation, Central South University of Forestry and Technology).

[15] Liu, Y., Wu, Z., & Tong, Y. (2020). Digital design of customized solid wood furniture based on TopSolid and Kujiale software. *Furniture*, 41(2), 62–66, 99.

[16] Yuan, H. (2017). Application of SolidWorks parameter-table modeling in general mechanical design. *Information Recording Materials*, 18(3), 40–41.

[17] Guo, W., Xiong, X., Tang, Y., et al. (2018). Information interaction technology for mass-customized wardrobes based on 2020 software. *Journal of Forestry Engineering*, 3(2), 153–158.

[18] Zhang, X., Li, X., Ji, X., et al. (2021). Application of Grasshopper in rapid parametric modeling of prestressed concrete continuous beams. *Urban Architecture*, 18(33), 7–11.

[19] Yi, G., & Chen, W. (2022). Future-style design based on Grasshopper parametric modeling. *Hunan Packaging*, 37(2), 17–21.

[20] Zhang, F., Zhang, J., Cao, T., et al. (2023). A review of digital cultural and creative product design research. *Packaging Engineering*, 44(12), 1–15, 117.

[21] Pan, X., Tao, L., Lu, M., et al. (2023). Design and analysis of panel furniture based on secondary development integrating SolidWorks and ANSYS. *Machinery Manufacturing and Automation*, 52(2), 131–134.

[22] Zhong, S., & Zhang, H. (2021). Application of parametric 3D design in customized home furnishing products for intelligent manufacturing. *Wood Science and Technology*, 35(6), 20–25.

[23] Zhang, L., Zhu, P., & Lu, K. (2018). Research progress in digital preservation methods for classical furniture. *Computer Engineering and Applications*, 54(18), 26–33, 44.

[24] Wang, S., Liu, W., & Zheng, P. (2023). Parametric design of mortise-and-tenon furniture components based on secondary development of SolidWorks. *Computer Applications and Software*, 40(3), 28–32.

[25] Zhu, X. (2023). Research on parametric design of office furniture based on health-oriented design concepts. *Art and Design (Theory)*, 2(6), 82–85.

[26] Deng, W., Wang, T., & Ye, H. (2022). Product innovation design methods based on parametric thinking. *Packaging Engineering*, 43(8), 76–84.

[27] Ren, L., Du, Y., Ma, S., et al. (2014). A survey of visual analytics for big data. *Journal of Software*, 25(9), 1909–1936.

[28] Wang, L. (2016). Exploring the impact of parametric technology on product design. *Packaging Engineering*, 37(16), 10–13.

[29] Zhang, Q. (2014). *Research on the practical application of reverse engineering in innovative product design* (Master's thesis, Taiyuan University of Technology).

[30] Jia, R., & Liu, Y. (2021). Application of parametric design in product design: A case study of speaker design. *Industrial Design*, (5), 30–31.

[31] Ding, L. (2016). The role of ergonomics in furniture design. *Home Drama*, (9), 265–266.

[32] Gehl, J. (2002). *Life Between Buildings* (H. Ren, Trans.). Beijing: China Architecture & Building Press.

[33] Zhou, Z. (2009). Parametric design of office chairs based on ergonomics. *Anhui Literature*, (11), 237.

[34] Dai, Z. (2021). *Research on the design philosophy and parametric application of the Kukkapuro chair* (Master's thesis, Guangdong University of Technology).

[35] Luo, L., Liu, X., & Lu, C. (2005). A parametric human modeling system for ergonomic design. *Computer Engineering and Applications*, (34), 16–18.

[36] Lu, C., Li, G., & Liu, X. (2009). Product ergonomic design driven by parametric human models. *Packaging Engineering*, 30(5), 207–208, 233.

[37] Zhao, L., & Ren, Y. (2019). Gear mold design and finite element simulation based on UG and ANSYS. *Coal Mine Machinery*, 40(12), 180–182.

[38] Zhou, Y., Li, L., & Zhang, Z. (2018). Research progress in furniture topology optimization. *China Forest Products Industry*, 45(8), 1–4.

[39] Fu, Y., & Fang, H. (2016). Parametric design of reconstituted bamboo chairs. *China Forest Products Industry*, 43(12), 38–42.

[40] Chen, Y., & Yu, X. (2021). Application of digital design technology in customized furniture. *Furniture & Interior Design*, (4), 26–29.

[41] Yang, Z. (2021). *Research on precise modeling methods for rail transit lines based on BIM technology* (Master's thesis, Guilin University of Electronic Technology).

[42] Song, J. (2018). Theoretical research on product parametric design methods under personalized demand. *Furniture & Interior Design*, (5), 18–19.

[43] Liu, X., & Yu, Y. (2020). Research on customized furniture design based on user experience. *Design*, 33(5), 79–81.

[44] Liang, J., & Sun, M. (2023). Digital design and construction of biomimetic shell structures based on biological prototypes. *Architecture and Culture*, (7), 38–40.

[45] Luo, S., Zhang, Y., Bian, Z., et al. (2018). Current status and progress of product form bionic design research. *Journal of Mechanical Engineering*, 54(21), 138–155.

[46] Zhao, F., Li, M., Wang, X., et al. (2023). Research on parametric generation of bionic products under deconstruction–reconstruction thinking. *Packaging Engineering*, 44(22), 52–61.

[47] Dai, X. (2017). *Research on the application of parametric design in household product design* (Master's thesis, Beijing University of Technology).

[48] Yuan, B. (2023). Research on the influence of digital information technology on modern interior design. *Art Market*, (11), 94–95.

[49] Liu, X. (2019). Research on the application of 3D printing in furniture products. *Furniture & Interior Design*, (12), 26–27.