Exploration of the Integration of 3D Printing Technology and CAD Collaborative Design in Ceramic Design

Xinyu Zhang[1] and Wei Li[2]

[1]School of Fine Arts, Jingdezhen Ceramic University, Jingdezhen 333403, China, andyandniya@163.com
[2]Museum, Jingdezhen Ceramic University, Jingdezhen 333403, China, liwei@jcu.edu.cn

Corresponding author: Wei Li, liwei@jcu.edu.cn

Abstract. The application of three-dimensional (3D) printing technology in personalized ceramic design and production is characterized by flexibility, efficiency, and precision, thus offering significant value for the evolving patterns and directions of ceramic creation. The intricate and meticulous nature of drawing in ceramic production demands exceptional precision, rendering traditional mapping techniques inadequate for contemporary production needs. The integration of computer-aided design (CAD) software has significantly boosted the efficiency and creativity of ceramic production. To further propel the progress of ceramic design, this article introduces a novel design approach that combines 3D printing technology with CAD collaborative design. This hybrid method leverages the strengths of both technologies, fostering innovation in ceramic design. Additionally, this article incorporates the genetic algorithm (GA) to optimize the design scheme. By employing GA, we can achieve design optimization while maintaining performance, thereby enhancing the efficiency and quality of ceramic design. Experimental outcomes demonstrate that the method outlined in this article effectively elevates the efficiency and quality of ceramic design.

Keywords: Ceramic Design; 3D Printing Technology; Cad Collaborative Design
DOI: https://doi.org/10.14733/cadaps.2024.S26.101-114

1 INTRODUCTION

Metal ceramic composite materials have the advantages of both metals and ceramics, combining the toughness and bending resistance of metals with the heat resistance and oxidation resistance of ceramics, and have a wide range of applications. 3D printing technology, based on digital model files, uses printing-forming equipment to print layer by layer, ultimately completing the target product. Traditional metal printing equipment based on laser sintering principles is expensive, has high consumables costs, and is limited to metal materials. The slurry direct writing printing equipment has many advantages, such as simple structure, low cost, and no need for preheating during the forming process. Bonilla et al. [1] analyzed the importance of rheology in the design of ceramic slurries. It is based on the principle of slurry direct writing 3D printing moulding and determines the material extrusion driving mode and equipment movement mode. At the same time, a metal-ceramic slurry direct writing printing experimental platform was designed and built. The printability was tested, achieving low-cost printing of metal-ceramic composite materials at room temperature. The existing metal-ceramic composite materials are mostly formed using laser-selective sintering technology. During the moulding process, selective sintering of printed materials is achieved through laser, which requires a significant amount of thermal energy to keep the metal-ceramic material in a molten state. This method has strong limitations and low selectivity for printing materials, so it is necessary to explore a new 3D forming process for metal-ceramic composite materials to make up for the above shortcomings. Buchanan and Gardner [2] proposed a new 3D printing moulding process and implemented low-temperature, low-cost 3D printing of high-temperature resistant materials based on this moulding process. The method of using slurry direct writing 3D printing to prepare metal ceramic products. The main research content is the preparation of metal-ceramic slurry, exploration of printing and forming process parameters, and the process parameters of degreasing sintering. It explores a process route for metal ceramic printing and moulding, which can solve the problems of high moulding and equipment costs for metal-ceramic composite materials.

3D printing technology has the advantages of high model freedom, low material waste, high precision of finished product dimensions, and no need to manufacture moulds in advance, allowing for arbitrary modification of models. However, the use of 3D printing technology to prepare ceramic cores is still in the exploratory stage and has not been widely applied. The silicon-based ceramic core prepared has a high shrinkage rate during firing and poor high-temperature performance. Butt [3] studied the effects of printing parameters, sintering parameters, and strengthening treatment on the performance of 3D-printed silicon-based ceramic cores. And add a certain amount of silicate as an additive to improve the high-temperature performance of the core. The particle size of ceramic powder has a significant impact on the stability of its dispersed state in photosensitive resin when preparing 3D printing paste. When the ceramic particle size decreases, the flow resistance and viscosity of the printing slurry will also increase. It is usually desired to prepare a slurry with high solid content and low viscosity. The fluidity and stability of the slurry are important factors determining the printing forming effect and the quality of the ceramic core. Chakraborty and Biswat [4] selected ceramic particles with a particle size of around 35um when printing ceramic cores using the SLA method.

Silicon carbide ceramics are important structural materials with extensive applications in industrial production and high-tech fields. However, traditional silicon carbide ceramic processing technology requires the use of moulds in the process of preparing ceramic billets. This makes the entire production cycle time-consuming and costly and poses significant limitations in manufacturing ceramic components with complex shapes and composite structures. Chen et al. [5] combined CAD collaborative design with extrusion-free forming technology, providing a new solution for 3D printing of ceramic materials. The emergence of ceramic 3D printing technology has overturned the traditional ceramic manufacturing mode in the manufacturing of complex structures and composite performance ceramic components. There is enormous potential for development in areas such as integrated moulding, lightweight design, shortened research and development cycles, and reduced product costs. Direct writing moulding technology and UV curing moulding technology have received widespread research and attention due to their advantages of simple process, wide material applicability, and high moulding accuracy, respectively. Fan et al. [6] proposed two new methods for preparing silicon carbide ceramic composites based on 3D printing technology combined with reactive infiltration sintering. Firstly, the preparation of silicon carbide composite slurry for direct writing moulding was carried out. A water-based silicon carbide ceramic slurry with shear thinning behaviour was prepared using sodium alginate as a binder and silicon carbide powder, shortcut carbon fibre, and carbon black as raw materials, using the strategy of adding binders to improve the modulus of the slurry. The slurry prepared with 2% sodium alginate solution has the highest modulus and the best bonding performance. The amount of carbon black added does not affect the viscosity of the slurry; When the carbon black content is 15vol%, the initial modulus of the slurry is the highest. As the content of short-cut carbon fibre increases, the viscosity of the slurry decreases, and the shear stress first increases and then decreases. The viscosity of the slurry is the lowest when the content of short-cut carbon fibre is 25 vol%. The slurries with different amounts of carbon black and short-cut carbon fibre have high dispersibility and exhibit typical shear thinning behaviour, which can meet the needs of direct writing moulding.

Silicon carbide ceramics are an important structural ceramic material with excellent properties such as high strength and hardness, high thermal conductivity, low coefficient of expansion, wear resistance, corrosion resistance, and thermal shock resistance. It has important application value and potential in aerospace, automotive parts, microelectronics and other fields. Traditional ceramic processing and forming technology requires the use of moulds, which makes the entire production cycle time-consuming and costly, making it difficult to manufacture ceramic components and composite structures with relatively complex shapes. Therefore, Faramarzi et al. [7] analyzed that a moulding method that can achieve the shape and performance design of ceramic components has become an urgent need in industrial production. The emergence of ceramic 3D printing has overturned the traditional ceramic manufacturing mode and has enormous development potential in the manufacturing of complex structures and composite performance ceramic components. It is expected to fundamentally solve the problems of difficult forming of complex ceramic components and long production cycles, and promote the personalized and industrialized development of advanced ceramics. Graf et al. [8] used photopolymerization forming technology (SLA) to print silicon-based ceramic core blanks, which were coated with a small amount of binder. Subsequently, degreasing, sintering, and strengthening treatments were carried out to obtain the ceramic core on the substrate. The various properties of silicon-based ceramic cores prepared under different material ratios, printing parameters, sintering processes, and strengthening processes were measured by head pulling. Determine appropriate raw material ratios, and printing parameters, as well as degreasing, sintering processes, and core strengthening processes. It has developed a silicon-based ceramic core with high precision, high bending strength, high working temperature, and good thermal stability.

Hu et al. [9] used organic photosensitive resin as a liquid precursor, adopted precursor conversion technology and combined it with digital light processing (DLP) to 3D print and shape the precursor resin formula. The printed precursor polymer was cracked under a specific temperature program and successfully synthesized SiOC ceramics. The designed resin formula has excellent flowability (machinability viscosity 0.068 Pas), suitable for 3D printing moulding and can achieve ceramics, making it easy to prepare ceramic materials with complex shapes. The formula does not contain solvents, avoiding ceramic cracking and environmental pollution caused by solvent evaporation. By studying the optimal formulation and composition of photosensitive resin precursors, the optimal duration of post-curing treatment, and the optimal temperature program for cracking. The complex structure of SiOC ceramic material prepared by it has a smooth surface and no obvious visible cracks.

SiOC ceramic materials are widely used in aerospace, industrial manufacturing, biomedical and other fields due to their unique physical and chemical properties, such as high compressive strength, high hardness, high-temperature resistance, conductivity and thermal conductivity. However, ceramic materials are difficult to process, and traditional processing techniques require high economic and time costs. 3D printing moulding technology, due to its rich advantages, can overcome the difficulties of traditional technology. Compared with traditional techniques, 3D printing technology has a simple process, short cycle, and low cost in the preparation process, and the ceramic materials prepared have fewer defects compared to traditional preparation methods. In addition, preparing ceramic materials with complex shapes is also something that traditional preparation methods do not possess. In addition, the use of organic precursor conversion technology to prepare ceramic materials is receiving increasing attention. The combination of this technology with 3D printing not only has the advantages of simple process, low cost, and complex moulding but also allows for molecular-level design to customize special ceramic products [10].

However, relying solely on CAD technology is still difficult to meet the high-precision and high-efficiency production needs of the ceramic industry. Therefore, this article proposes a new design method that combines 3D printing technology with CAD collaborative design, fully utilizing the advantages of both to achieve innovation in ceramic design. By introducing 3D printing technology, prototypes of ceramic products can be quickly and accurately manufactured, providing designers with real-time feedback and verification, and further optimizing design solutions. Meanwhile, CAD technology can provide accurate 3D model data for 3D printing, ensuring that the printed product meets design requirements.

To further enhance the efficiency and quality of ceramic design, this article also introduces GA for scheme optimization. GA is an optimization algorithm based on natural selection and genetic mechanisms, which simulates the process of biological evolution to find the optimal solution to a problem. In ceramic design, GA can be used to optimize the structure, size, and material properties of ceramic components to achieve optimal performance. Through the application of GA, design optimization can be achieved while ensuring design performance, further enhancing the efficiency and quality of ceramic design. This article aims to promote the innovative growth of the ceramic industry by combining 3D printing technology with CAD collaborative design and introducing GA for scheme optimization.

The innovation points of this article are as follows:

(1)This article combines 3D printing technology with CAD collaborative design to achieve innovation in ceramic design. Through this method, designers can more efficiently and accurately complete the design work of ceramic products, improving design efficiency and precision.

(2)This article introduces GA for optimizing ceramic design schemes. Through the application of GA, this article can precisely optimize the structure, size, and material properties of ceramic components, further improving the performance and quality of ceramic products.

(3)This article integrates advanced technologies such as 3D printing technology, CAD collaborative design, and GA into the field of ceramic design, achieving cross-domain fusion innovation. This innovative method not only promotes the transformation and upgrading of the ceramic industry but also provides useful references and inspiration for the innovative growth of other traditional industries.

This article first introduces the background and significance of the research, and then delves into the application of 3D printing technology and CAD in ceramic design. On this basis, this article further proposes an innovative ceramic design method that integrates 3D printing technology and CAD. To verify the effectiveness and feasibility of this method, experimental verification was conducted. Finally, in the conclusion section, the main findings and innovative points of this article are summarized, and future research directions and suggestions are pointed out, including further optimizing algorithms, expanding application areas, and improving production efficiency.

2 RELATED WORK

In the application of CAD collaborative design in architectural ceramic design, Leschok et al. [11] constructed complex and refined architectural ceramic facade models through professional CAD software. Ceramic materials are widely used in modern aerospace, high-temperature-resistant materials, and high-tech materials. Generally, this type of ceramic is produced by high-temperature sintering after powder solidification. However, the above methods make it difficult to produce fibres, films, and ceramic components with complex shapes. However, with the application of 3D printing technology in ceramic production, ceramic materials have achieved a huge leap in geometric flexibility, making the production of various external dimensions easier. Although these technologies have outstanding advantages, the preparation process involved typically requires small and uniformly dispersed particles to obtain high-resolution, good surface quality, and high-strength ceramic materials. In today's increasingly high demand for the functionality of ceramics, how to design ceramic functions at the molecular level has become a focus of research in recent years. Liu et al. [12] quickly generated multiple design schemes using CAD software and verified their feasibility through 3D printing technology. The precursor conversion method often involves the following steps in production: first, impregnating fibre preforms with precursor solution or melt, drying or curing to obtain ceramic precursor polymer (PDC), and finally cracking to obtain ceramic materials. If you want to obtain fibre-reinforced composite materials, you can repeat the impregnation cracking process. This method is not only easy to operate, but can also be designed at the molecular level to prepare precursors for ceramic substrates that meet specific needs and special structures. In recent decades, this type of material has attracted people's attention to high-quality materials and processing performance. Ozkan et al. [13] investigated the mixture design and characterization of 3D printed turbine blade investment casting ceramic cores using LCD screen printers. It is based on the forefront of ceramic preparation technology, researching organic precursor formulas suitable for 3D printing. This formula does not use solvents, so it has less environmental pollution. By strictly controlling the quality ratio of the photosensitive resin system and the temperature program of cracking during production, ceramic cracking and environmental pollution can be avoided. The precursor resin formula designed has many advantages. For example, good fluidity, which is very suitable for 3D printing. We can use this feature to print precursor ceramic materials with complex shapes. Finally, we will crack the precursor to obtain the ceramic product. The finished product can still maintain its original shape without deformation and cracking [14].

Somanath et al. [15] explored how 3D printing and manufacturers can jointly promote the innovative application of ceramic composite materials in digital manufacturing. Due to the presence of photosensitive materials in the printing paste, the entire experiment needs to be conducted in a UV-free environment. Before starting the printer, a series of preparation work needs to be done. First, use computer 3D modelling software such as CAD, UG, Solidworks, etc. to design and establish a 3D model according to actual requirements, and convert it into STL format files. Choose a printing platform of appropriate size and stick magnetic suction paper on it. Scrape the edges of the magnetic suction paper into an inclined plane for easy feeding of the scraper during printing. Due to the layering of resin and ceramic powder during the static storage of the prepared printing paste, it is necessary to stir for about 20 minutes each time to mix the ceramic powder and resin evenly, and the printing paste will have good fluidity. After pouring the printing paste into the material bin, scrape the upper surface of the paste into an inclined plane to prevent printing defects caused by bubbles during feeding and uneven scraper feeding during printing. Run the scraper test program and repeatedly adjust the scraper position until the printing layer thickness meets the requirements twice in a row. Zhu et al. [16] achieved precise control during the UV curing process by designing specific photosensitive groups, thereby ensuring the microstructure and properties of ceramic materials. After preparation, adjust the laser power and printing parameters according to the printing materials, import STL format printing files and corresponding supporting files (printing standard test blocks without support) for slicing processing, and obtain the scanning path. Set the printing platform to the initial position, run the printer to start printing, and use wavelength-specific ultraviolet light along the path for line scanning to cure the ceramic slurry containing liquid photosensitive resin. After completing one layer of solidification, the printing platform lowers the height by one layer of thickness and repeats the above process layer by layer to obtain a three-dimensional solid product. After printing, take out the test block, recover the remaining paste, carefully clean the test block and printer, measure the size of the test block with a vernier caliper, and record it.

3 THE APPLICATION OF 3D PRINTING TECHNOLOGY AND CAD IN CERAMIC DESIGN

3.1 3D Printing Technology

The different printing parameters have a significant impact on printing quality, especially printing accuracy. The size of ceramic core test blocks will affect the results of later performance testing. In order to obtain the optimal parameters for printing standard test blocks using the UV-cured 3D printer used in this experiment and maximize printing efficiency, the effects of moulding parameters, placement questions, and adding Z-axis compensation on the dimensional accuracy of printing standard test blocks were tested. The printing laser is ultraviolet light with a wavelength of 355nm, with a laser power of 110mW, and a single-layer thickness of 0.05mm. Measure the sample size using a vernier calliper and compare it with a two-dimensional model to determine the printing parameters for the best printing quality. The standard sample size specified by the industry standard is 120 × 10 × 4mm and 60 × 10 × 4mm, respectively. The printed model size of the scaled test block is 124.20 × 10.41 × 4.12mm and 62.10 × 10.41 × 4.12mm, respectively. The Z-axis compensation of the printing equipment used in this experiment is 0.23mm. After adding Z-axis compensation, the printing model size of the test block is 124.20 × 10.41 × 3.89mm (hereinafter referred to as the long test block) and 62.10 × 10.41 × 3.89mm (hereinafter referred to as the short test block), respectively. The printing device has two moulding parameters, namely support and part. The size of the light spot varies, and the printing accuracy also varies. For ceramic test blocks that cannot be supported. Due to its small size and simple shape, support was chosen as the first printing moulding parameter, with a laser power of 110mW. Figure 1 shows the working principle of 3D printing.

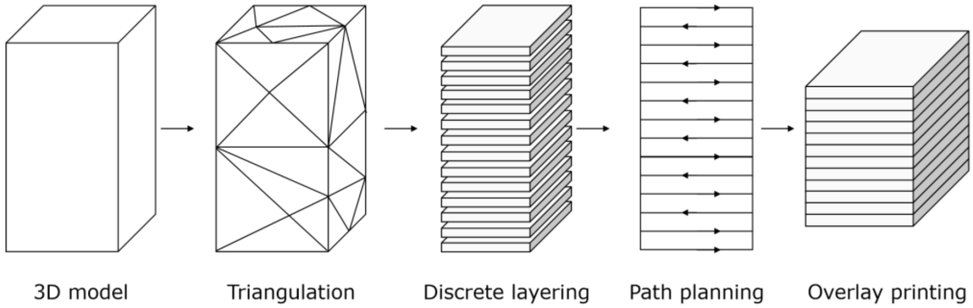

Figure 1: Working principle of 3D printing.

3.2 CAD

Computer-aided design Auto CAD is playing a powerful potential role in the design, drafting, and manufacturing of daily ceramics. People have introduced computer-aided design technology into the field of the daily ceramic industry in order to improve technology and efficiency. The advantages of computer-aided design technology will efficiently assist ceramic processes, making it more convenient, efficient, and standardized for the production and development of daily ceramics. It also improves production efficiency in industrial ceramic production processes. Computer-aided design blends the artistic and scientific qualities of daily ceramics, making art increasingly scientific and practical, serving human daily life. In the context of the rapid development of diverse cultures in the production of daily ceramics, art and science have permeated, combined, and inspired each other, promoting the healthy and civilized development of daily ceramics.

CAD/CAM technology is a revolution in traditional clinical repair and treatment procedures. It constructs the restoration model using specific program software after intraoral scanning, and then converts the digital model into automated mechanical cutting technology, achieving a rapid restoration production process and reducing the patient's visit time and frequency. Due to the increasing demand for aesthetics and the development of CAD/CAM systems in recent years, machinable ceramic materials have become a commonly used clinical material for oral restoration and treatment. It has a wide range of applications, including veneers, inlays, full crowns, and fixed bridges. In addition, CAD/CAM ceramics also possess excellent aesthetic properties, good biocompatibility, and stable physical and chemical properties. Figure 2 shows one application of CAD in ceramic design.

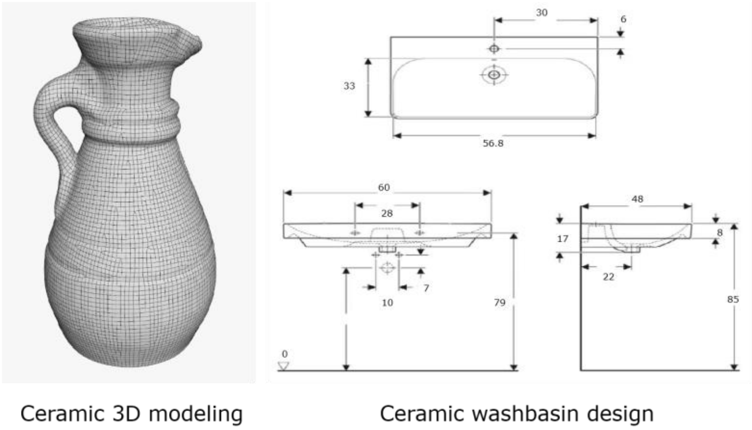

Figure 2: Application of CAD in ceramic design.

4 CERAMIC DESIGN METHOD INTEGRATING 3D PRINTING TECHNOLOGY AND CAD

4.1 Method Design

This article studies the application of computer-aided Design Auto CAD in the production of modern daily ceramics enterprises, focusing on the scientific application of Computer Aided Design Auto CAD in drawing and its macro leading role in the industrialization of daily ceramics. The scale of modern ceramic enterprises continues to grow, and the degree of mechanization continues to improve. Their productivity far exceeds that of traditional manual workshops. To avoid the drawbacks of modern production of daily ceramics, it is necessary to follow the scientific nature of ceramic production. The scientific design concept of Computer Aided Design Auto CAD leads the development of daily ceramics towards scale and industrialization. The advantages of Computer Aided Design Auto CAD software promote the scientificity of ceramic production, with precise design dimensions and convenient operation, providing a scientific production basis for daily ceramic production. Further research will be conducted on the structural drawing of computer-aided design Auto CAD in the production of daily ceramics, to verify the macro leading role of computer-aided design Auto CAD in the production of daily ceramics and the scientific nature of computer-aided design Auto CAD drawing. This article strongly points out that science and technology are the primary productive forces. Under the premise of respecting education, knowledge, talents, and science, we vigorously advocate and develop the science and technology of daily ceramics to promote the scientific and healthy development of China's daily ceramic economy industry. There is no more terrifying backwardness than ignorance. The development of the daily ceramic industry has a long history in China. In the era of rapid technological development, the development of the daily ceramic industry is deeply influenced by science and technology and is undergoing revolutionary changes.

4.2 Algorithm Selection

STL file is a file format used to represent the surface geometry of a 3D model. It mainly consists of a series of triangular patches, each of which is defined by three vertices and a normal vector. In STL files, there is a certain mathematical relationship between vertices, edges, and patches, which can be described by the Euler formula. Euler's formula is an important theorem in geometry, which describes the relationship between the number of vertices V, edges E, and faces F of polyhedra (including three-dimensional models). For the 3D model described in the STL file, this formula can be expressed as:

$$V + F - E = 2 \quad (1)$$

Among them V are the number of vertices, E the number of edges, F is the number of faces. In the STL file, each patch is a triangle, so F is also equal to the number of triangular patches.

When the display ratio of the model in the visualization window does not match the actual requirements, a series of transformation operations need to be performed on the model, including zooming in, zooming out, translation, and rotation, to ensure that the model can adapt to the display requirements of the window and print in the best slicing direction during the 3D printing process. Scaling operations can be achieved by adjusting the scale factor of the model. Assuming the scale factor of the original model is 1, if the model needs to be enlarged, the scale factor can be set to a value greater than 1; If you need to shrink the model, you can set the scale factor to a value less than 1 but greater than 0. If the scaling amount of the model along the three dimensions of x,y,z 3 is Δs_x , Δs_y , Δs_z , then the scaling matrix is

$$M_s = \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

The translation operation can be achieved by changing the position of the model in the coordinate system. This usually involves adding or subtracting a certain offset on the x,y,z axis to move the model to the centre of the window or other suitable position. The translation matrix M_t is as follows:

$$M_t = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \Delta x & \Delta y & \Delta z & 1 \end{bmatrix} \tag{3}$$

In the formula, $\Delta x, \Delta y, \Delta z$ is the translation amount.

The rotation operation is crucial for adjusting the slicing direction of the model. In most cases, the initial direction of the STL model may not be the optimal slice direction for 3D printing. Therefore, it is necessary to rotate the model to find the optimal slicing direction, optimize the printing process, and reduce the use of supporting structures. The specific rotation angle needs to be determined based on the geometric shape of the model and printing requirements. Usually, the optimal slicing direction can be found by observing the orientation of the model in the visualization window and attempting different rotation angles. Let the rotation angles of the model around the x,y,z axis be α,β,γ , and since the Z axis direction is the slice direction (default), only the model is rotated along the axial direction. The rotation matrix is shown in formulas (4) and (5).

$$M_{rx} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$M_{ry} = \begin{bmatrix} \cos\beta & 0 & -\sin\beta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\beta & 0 & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Translate, scale, and rotate the point set V_{set} in the original STL model to update the point set V_{set}' :

$$V_{set}' = V_{set} \cdot M_t \cdot M_s \cdot M_{rx} \cdot M_{ry} \tag{6}$$

The design of ceramic laminated structures is a complex problem that involves the optimization of multiple variables and possible structural combinations. The design of this structure must take into account the characteristics of stress distribution to ensure that the structure has sufficient strength and stability under given working conditions. GA, as an optimization tool, has some unique advantages. It simulates the process of natural evolution, searching for the optimal solution through operations such as selection, crossover, and mutation. In the design of ceramic laminated structures, GA can be used to search for the optimal stacking method. By defining appropriate fitness functions to evaluate the performance of different stacking methods, GA can search for the optimal or approximately optimal solution among a large number of possible solutions. This method can not only reduce computational complexity but also improve optimization quality and meet the requirements of complex structural design. Consider interface failure, but generally, the length of interlayer cracking is relatively small, making it difficult to cause large-scale interlayer sliding. Without considering the influence of residual thermal stress, according to this model, when the laminated beam does not fail, its maximum load can be written as:

$$P_{\max} = \frac{4\sigma_1 \sum_{k=1}^{n} E_i^{\ k} I_k}{E_i L Z_0} \quad i = 1,2 \tag{7}$$

Among them, σ_1 represents the tensile strength of the ceramic layer; E_i represents the elastic modulus of ceramics; I_k represents the moment of inertia of the k layer material; L is the length of the beam; Z_0 is the distance from the bottom layer to the neutral axis.

Introducing penalty functions in GA is a common technique for handling constrained optimization problems. The penalty function is used to penalize solutions that do not meet the constraint conditions, thereby reducing the fitness of these solutions during the evolution process and reducing the likelihood of them being selected for inheritance to the next generation. In this way, the algorithm can more efficiently explore the feasible solution space while retaining excellent genes and ultimately converge to the optimal solution that meets the constraint conditions. The fitness function of this article is established as formula (8):

$$f_i\ X\ = f_i\ X\ + D * \sum_{1}^{N} \max\ abs\ H_i\ X\ < CITE, 0 \tag{8}$$

Among them, $f_i\ X$ are the objective function, D a relatively large constant, $D = 1000000000$, $CITE$ is the calculation precision, and $CITE = 1E - 5$ and $H_i\ X$ are the constraint conditions.

5 RESULT ANALYSIS AND DISCUSSION

To validate the efficacy of the method introduced in this article, we will proceed with experiments. Illustrated in Figure 3 is a comparison of time durations across various methods in the ceramic design process. Evidently, the method outlined in this paper exhibits a shorter design duration, thereby establishing its efficiency. As the workload escalates, both our proposed method and the traditional approach demonstrate a gradual increase in time consumption. Nevertheless, it is noteworthy that the growth rate of time consumption for our proposed method is considerably slower than that of the traditional method. This signifies that our method retains its high efficiency even when confronted with a substantial workload, whereas traditional methods may encounter significant time constraints. This advantage holds particular significance in practical applications, especially for intricate tasks like ceramic design, which often involve processing vast amounts of data and multiple iterations of optimization. The method described in this article accomplishes design tasks swiftly, thereby enhancing work efficiency and minimizing costs.

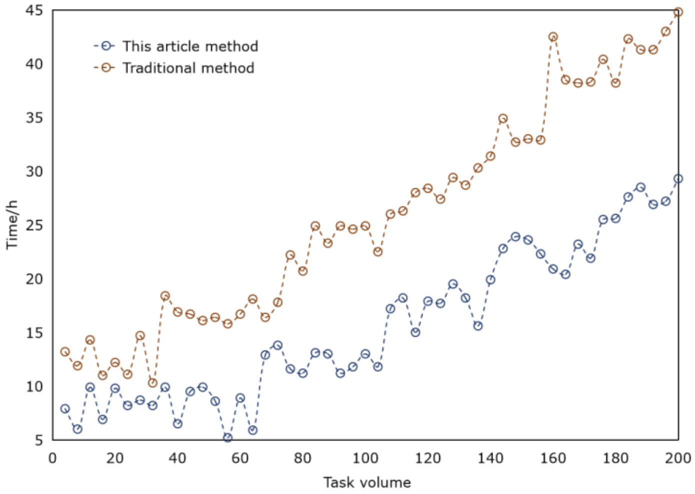

Figure 3: Comparison of design time consumption.

Table 1 shows the evaluation of ceramic preparation processes using traditional methods and our method. It can be seen from the table that our method has significant advantages over traditional ceramic preparation processes in multiple aspects. Firstly, 3D printing technology can significantly shorten production cycles and improve production efficiency. Secondly, 3D printing simplifies the preparation process and reduces the requirement for craftsman qualifications. In addition, ceramic 3D printing technology can meet the needs of personalized product customization. Finally, ceramic 3D printing technology can also help enterprises control costs. By reducing material waste and labour costs, as well as improving production efficiency, enterprises can better control production costs.

Evaluation dimension	*Method of this article*	*Traditional method*
Simplification of production processes	4	2
The degree of reduction in the production cycle	5	3
Degree of openness to process qualifications	4	1
Convenience of production process intervention	4	3
Production cost control	2	4

Table 1: Evaluation of ceramic preparation processes using traditional methods and our method (point).

Figure 4 shows the precision comparison of different methods in the ceramic design process. It can be observed from the figure that compared to traditional methods, the ceramic design precision of our method is higher. Although the design precision of traditional methods can meet basic design requirements to a certain extent, its precision is often limited as the complexity of the design increases. In contrast, the method used in this article adopts advanced algorithms and technologies, which significantly improve the precision of ceramic design.

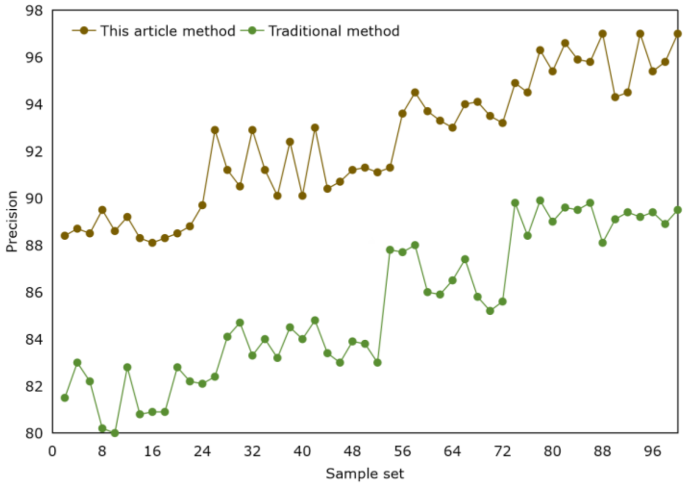

Figure 4: Comparison of design precision.

Figure 5 shows the comparison of satisfaction levels after designing ceramics using different methods. It is evident from the figure that ceramics designed using the method described in this article have higher satisfaction levels. This article focuses more on user experience and personalized needs in the design process, and can accurately design according to the specific requirements and preferences of users. This makes the designed ceramic products more in line with user expectations and needs, thereby improving user satisfaction.

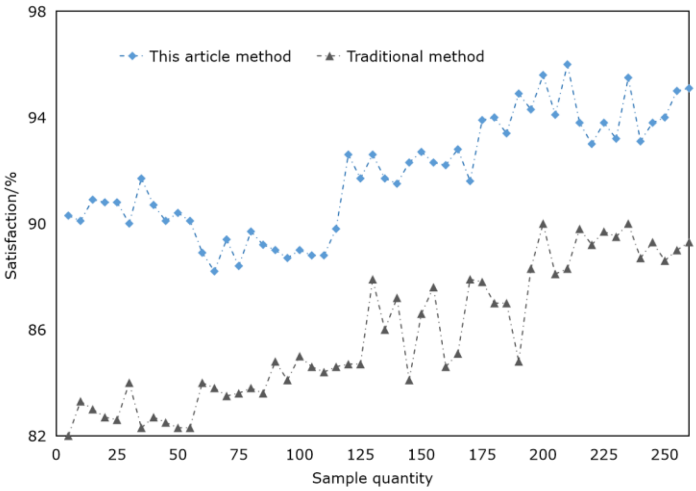

Figure 5: Satisfaction comparison.

Figure 6 shows the comparison of recall rates among different methods in ceramic design. It can be clearly seen from the graph that the method proposed in this paper has a higher recall rate in ceramic design and performs better than traditional methods. In ceramic design, a high recall rate means that the design system can more comprehensively capture user needs and intentions, reducing omissions and errors. This is crucial for ensuring the integrity and precision of the design.

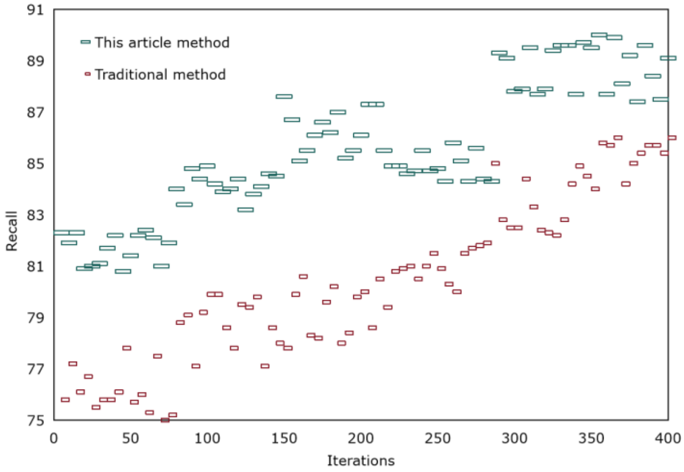

Figure 6: Comparison of recall rates.

Figure 7 shows the comparison of material utilization rates when using different methods for ceramic design. It can be clearly seen from the graph that compared to other methods, the material utilization rate of our method is higher. High material utilization means that ceramic raw materials can be more effectively utilized in the production process, reducing material waste and ultimately lowering production costs.

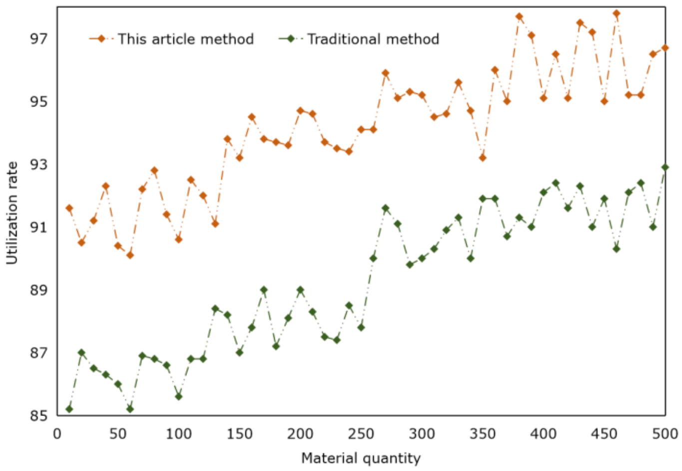

Figure 7: Comparison of material utilization.

6 CONCLUSIONS

The application of 3D and CAD technologies in the design and growth of ceramic handicrafts has significant advantages and broad application prospects. These technologies not only inherit the artistic connotation of traditional ceramic craftsmanship but also integrate modern aesthetic elements, greatly enhancing the innovation and diversity of design. The new ceramic design method proposed in this article closely combines 3D printing technology with CAD collaborative design, fully leveraging the technical advantages of both. Accurate model design is achieved through CAD software, combined with 3D printing technology to achieve rapid printing of the model, greatly improving the precision of design and production efficiency. At the same time, to optimize the design scheme further, this article introduces GA, which further enhances the efficiency and quality of ceramic design. The experimental results show that the design method proposed in this article can effectively enhance the efficiency and quality of ceramic design, bringing new ideas and directions for the field of ceramic handicraft design and growth.

Although this article has achieved certain results in integrating 3D and CAD technology in ceramic design, further research and improvement are still needed in algorithm optimization, material selection, printing technology, design evaluation, and application field expansion. Through continuous efforts and innovation, we believe that these technologies will bring more breakthroughs and growth opportunities for ceramic design.

Xinyu Zhang, https://orcid.org/0009-0000-9721-925X
Wei Li, https://orcid.org/0009-0008-4384-8534

REFERENCES

[1] Bonilla, C.-J.; Avila, L.-M.-A.; Rodriguez, F.-E.-L.: 3D printable ceramic pastes design: Correlating rheology & printability, Journal of the European Ceramic Society, 2022(13), 2022, 42. https://doi.org/10.1016/j.jeurceramsoc.2022.06.029

[2] Buchanan, C.; Gardner, L.: Metal 3D printing in construction: A review of methods, research, applications, opportunities and challenges, Engineering Structures, 180(1), 2019, 332-348. https://doi.org/10.1016/j.engstruct.2018.11.045

[3] Butt, J.: Exploring the interrelationship between additive manufacturing and Industry 4.0, Designs, 4(2), 2020, 13. https://doi.org/10.3390/designs4020013

[4] Chakraborty, S.; Biswas, M.-C.: 3D printing technology of polymer-fiber composites in textile and fashion industry: A potential roadmap of concept to consumer, Composite Structures, 248(1), 2020, 112562. https://doi.org/10.1016/j.compstruct.2020.112562

[5] Chen, J.-S.; Bao, E.-Q.; Huang, D.-Z.: Extrusion freeforming-based 3D printing of ceramic materials, Materials Transactions, 61(11), 2020, 2236-2240. https://doi.org/10.2320/matertrans.MT-M2020167

[6] Fan, J.; Xu, X.; Niu, S.; Zhou, Y.; Li, X.; Guo, Y.; Luo, Y.: Anisotropy management on microstructure and mechanical property in 3D printing of silica-based ceramic cores, Journal of the European Ceramic Society, 42(10), 2022, 4388-4395. https://doi.org/10.1016/j.jeurceramsoc.2022.03.059

[7] Faramarzi, H.; Arzani, M.; Khosravanian, A.; Mahdavi, H.; Bakhtiari, O.; Mohammadi, T.: An overview of practical aspects of the design and application of polymeric/ceramic supports in supported liquid membranes for gas separation, Industrial & Engineering Chemistry Research, 62(32), 2023, 12443-12461. https://doi.org/10.1021/acs.iecr.3c00830

[8] Graf, D.; Qazzazie, A.; Hanemann, T.: Investigations on the processing of ceramic filled inks for 3D inkjet printing, Materials, 13(11), 2020, 2587. https://doi.org/10.3390/ma13112587

[9] Hu, Y.; Zou, B.; Xing, H.; Liu, J.; Chen, Q.; Wang, X.; Li, L.: Preparation of Mn–Zn ferrite ceramic using stereolithography 3D printing technology, Ceramics International, 48(5), 2022, 6923-6932. https://doi.org/10.1016/j.ceramint.2021.11.248

[10] Kovacev, N.; Li, S.; Essa, K.: Effect of the preparation techniques of photopolymerizable ceramic slurry and printing parameters on the accuracy of 3D printed lattice structures, Journal of the European Ceramic Society, 41(15), 2021, 7734-7743. https://doi.org/10.1016/j.jeurceramsoc.2021.08.052

[11] Leschok, M.; Cheibas, I.; Piccioni, V.; Seshadri, B.; Schlüter, A.; Gramazio, F.; Dillenburger, B.: 3D printing facades: Design, fabrication, and assessment methods, Automation in Construction, 152(1), 2023, 104918. https://doi.org/10.1016/j.autcon.2023.104918

[12] Liu, P.-Y.; Liou, J.-J.; Huang, S.-W.: Exploring the barriers to the advancement of 3D printing technology, Mathematics, 11(14), 2023, 3068. https://doi.org/10.3390/math11143068

[13] Ozkan, B.; Sameni, F.; Bianchi, F.; Zarezadeh, H.; Karmel, S.; Engstrøm, D.-S.; Sabet, E.: 3D printing ceramic cores for investment casting of turbine blades, using LCD screen printers: The mixture design and characterization, Journal of the European Ceramic Society, 42(2), 2022, 658-671. https://doi.org/10.1016/j.jeurceramsoc.2021.10.043

[14] Soltanzadeh, P.; Su, J.-M.; Habibabadi, S.-R.; Kattadiyil, M.-T.: Obturator fabrication incorporating computer-aided design and 3-dimensional printing technology: a clinical report, The Journal of Prosthetic Dentistry, 121(4), 2019, 694-697. https://doi.org/10.1016/j.prosdent.2018.06.019

[15] Somanath, S.; Wakkary, R.; Ettehadi, O.; Lin, H.; Behzad, A.; Eshpeter, J.; Oogjes, D.: Exploring the composite intentionality of 3D printers and makers in digital fabrication, International Journal of Design, 16(3), 2022, 77-95. https://doi.org/10.57698/v16i3.005

[16] Zhu, N.; Hou, Y.; Yang, W.; Wen, G.; Zhong, C.; Wang, D.; Zhang, L.: Preparation of complex SiOC ceramics by a novel photocurable precursor with liquid crystal display (LCD) 3D printing technology, Journal of the European Ceramic Society, 42(7), 2022, 3204-3212. https://doi.org/10.1016/j.jeurceramsoc.2022.02.026