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Computer-Aided Design AND APPLICATIONS

Integrating Ceramic Design CAD and Virtual Reality Based on 3D Printing

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Abstract. Based on 3D printing and VR (Virtual reality) technology, this paper developed a ceramic CAD (Computer-aided design) design system with SolidWorks as the carrier and VC++ as the development tool. The system integrates user interface design, ceramic model design, 3D printing preview and export, VR display and other functional modules, which can meet the needs of ceramic designers, manufacturers and end users. The experimental results show that the system can significantly improve the efficiency and quality of ceramic design and provide users with an immersive design experience. Through the 3D printing preview function, users can find and repair potential printing problems in time, such as insufficient supporting structure and loss of model details. The actual printing results verify that the model file exported by the system is consistent with the preview effect and the printing quality is good. This fully proves the reliability of this system. Compared with other design processes, the system is more flexible and intuitive, which is helpful in promoting the innovative development of the ceramic industry. In the future, the system performance will be further optimized, the VR display function will be enriched, and the whole chain digital management scheme of the ceramic industry will be explored.

Keywords: Ceramic CAD Design System; 3D Printing; Virtual Reality; Design Efficiency; Digital Transformation
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1 INTRODUCTION

With the continuous development of science and technology, 3D printing and VR technology are widely used in various fields. The quality control of ceramic parts in the 3D printing process is crucial to ensuring product performance and reliability. In response to these issues, Chen et al. [1] conducted in-depth research on low-contrast defect detection methods based on deep learning, providing a new solution for quality control in the ceramic industry. Due to the high hardness, high melting point, and complex microstructure of ceramic materials, their curved parts are prone to various defects during the 3D printing process. The detection of these defects has always been a challenge in the industry, mainly due to the low contrast between the defects and the ceramic background, blurred edges, and the low efficiency of traditional detection methods. This model preprocesses the images of ceramic curved parts through deep learning techniques, effectively reducing the degree of blurring on the surface. This algorithm can enhance the detailed information of images at different scales, especially the feature information of prominent defect areas. Meanwhile, the average detection time of this method for a single image is only 0.67 seconds, demonstrating extremely high detection efficiency. This step provides clearer image data for subsequent defect detection, improving the accuracy and efficiency of detection. As a representative of China's traditional culture, ceramics can not only improve design efficiency but also create more novel and unique ceramic works by incorporating these advanced technologies into its design and production process. Due to the brittleness of the material itself, 3D-printed ceramic parts are often prone to various defects on the surface during the printing process or subsequent processing stages, such as cracks, protrusions, etc. Chen et al. [2] proposed a deep learning-based anti-interference detection method for surface defects of ceramic parts. These defects not only affect the aesthetics of the product but may also affect its performance and safety. In the stage of identifying interference factors, we introduced the Multi-Mode Feature Layer Fusion PSP Network (MFLF-PSP Network) model. In the interference factor repair stage, they proposed the Parallel Spatial Channel Attention Mechanism (PSCAM) - RFR network model. This model is based on the results of interference recognition and fills and repairs the area where the interference factor is located at the pixel level. In the defect detection stage, they utilized the constructed Inception SSD network model. This model is based on deep learning technology and can quickly identify and locate defects on ceramic surfaces. Additive manufacturing (such as 3D printing) technology provides new possibilities for the manufacturing of ceramic materials. Chung et al. [3] proposed an innovative surface defect monitoring system for printing processes based on high-viscosity composite resins. Each type of defect may have varying degrees of impact on the performance of the final printing structure. By using methods such as cropping, dimensionality reduction, and RGB pixel standardization, we can effectively extract key information from images while removing redundant and noisy data. By training and testing the preprocessed images, they successfully achieved a classification accuracy of up to 99%, fully demonstrating the effectiveness and reliability of this method. This system combines advanced image processing and convolutional neural network (CNN) algorithms to monitor and maximize the ceramic powder content in real time, effectively reducing or avoiding the generation of surface defects.

The elegance and uniqueness of ceramic art patterns not only reflect the cultural charm of ancient Greece and Rome but also have always been a beloved creative element for modern artists. However, the quality requirements for small-sized multi-colour square inlaid ceramic materials used for 3D ceramic printing are also more stringent. However, due to the small size, multiple colours, and easy surface reflection of these ceramic materials, existing detection methods are unable to meet the requirements of high efficiency and precision. The rapid development of three-dimensional digital technology has made it widely used in many fields, and now it also provides new methods and approaches for the restoration of cultural relics. Dong et al. [4] conducted innovative research on ceramic cultural relic restoration methods using the non-contact, high-precision, and high-efficiency features of 3D laser scanning, 3D model reconstruction, 3D printing, and other technologies in 3D digitization technology. It aims to improve the efficiency of ceramic cultural relics restoration, present a more complete restoration effect, and provide a substantial digital restoration archive for subsequent data research and utilization. Secondly, a retrieval database for the form of ceramic cultural relics was constructed, and a brief analysis was conducted on the development characteristics of ceramic cultural relics styles in various dynasties. Before restoration, the missing model reconstruction plan can be determined by searching for similar objects, the style of the dynasty, and the geometric features of the damaged area. Firstly, on the premise of protecting cultural relics from damage, three-dimensional laser scanning technology is used to collect data on damaged cultural relics fragments. Finally, 3D printing technology is used to print out the reconstructed model, which is then bonded and fixed with the original fragments. Texture and colour mapping are applied to all 3D fragment models to improve the integrity of the restoration. On this basis, use "Geomagic Control" software to complete the virtual repair of fragments. After obtaining and processing the 3D model data, combined with traditional visual experience comparison and computer algorithm matching, research on fragment alignment and stitching methods [5]. By considering the uncertainty of fluid properties and the characteristics of 3D ceramic printing technology, the CAMD process can identify robust and more reliable molecules in terms of characteristic uncertainty. These samples were subsequently individually evaluated as constraints for CAMD optimization problems to ensure the robustness and reliability of the final designed molecules and processes in real-world environments. These molecules can maintain stable performance during the 3D ceramic printing process (conservative method). At the same time, combining the characteristics of 3D ceramic printing technology, such as printing accuracy, material shrinkage rate, interlayer bonding strength, etc., further expands the scope of uncertainty analysis. From the development trend, with the continuous progress of 3D printing and VR technology, the future ceramic design will be more intelligent and personalized. Designers will be able to show their design ideas more intuitively through VR technology and quickly realize prototyping through 3D printing technology. This will greatly shorten the design cycle of ceramic products, reduce costs and improve market competitiveness.

The ceramic tile industry, as an important component of building materials, is facing unprecedented challenges in the wave of Industrial Revolution 4.0. Among them, the detection and classification of defects on the surface of ceramic tiles has become a key factor restricting the development of the industry due to the complexity of the process and the limitations of current technology. Huynh [6] proposed a convolutional neural network (2DG-CNN) model based on a two-dimensional genetic algorithm, aiming to achieve automatic detection and classification of surface defects on ceramic tiles. In the existing ceramic tile production process, product classification and grading mainly rely on manual labour. Then, two-dimensional chromosomes are used to effectively represent various parameters in the CNN model, such as the size, step size, and filling method of the convolution kernel. Compared with traditional single-point or multi-point crossover, this method can create more diverse and high-quality offspring models, thereby accelerating the evolution and convergence speed of the model. When users plan to customize a unique 3D ceramic artwork, they usually seek help from a 3D printing service provider. In the interview, Liow et al. [7] learned that in addition to directly hiring designers, users also hope to have more choices for designing their own 3D ceramic artworks. They proposed an innovative designer matching platform aimed at accurately matching the most suitable designers based on customer preferences and needs. This online editor allows users to freely create and adjust their 3D ceramic designs through a simple user interface. By combining a designer matching platform and an online design editor, we aim to provide users with a brand new, more flexible, and personalized 3D ceramic art customization experience. However, similar to business card customization, printing service providers usually first require customers to provide their 3D ceramic design files, but many users do not have ready-made design works. At the same time, in order to further enhance user engagement and design flexibility, they also provide users with an online 3D ceramic design editor as an additional option. The purpose of this study is to develop a ceramic CAD design system based on 3D printing and VR technology to promote the innovation and development of ceramic design, realize the digitalization and intelligence of ceramic design, and thus improve the design level and market competitiveness of ceramic products. Its main contents include: developing a ceramic CAD design system with SolidWorks as the carrier and VC++ as the development tool and carrying out simulation experiments on the model. Specific methods include requirements analysis, system design, system implementation, simulation experiments and other steps. This paper will make clear the functional requirements of ceramic CAD design systems through in-depth market research and user demand analysis. Then the system is designed based on SolidWorks and VC++ to realize the functions of creating, editing, previewing and exporting ceramic models. Finally, the feasibility of the system is verified by simulation experiments. Its innovations are as follows:

User-friendly interface: The system provides an intuitive and easy-to-use operation interface, which greatly reduces the learning cost of users and enables designers to use CAD software to design ceramics more efficiently.

Powerful modelling function: The system supports the creation and modification of complex ceramic models, which meet the diverse needs of ceramic design. Designers can preview and modify the design in real-time by using rich pattern design tools and the function of modifying parameters such as colour, shape and texture to realize the personalized design.

3D printing support and preview: This system integrates the functions of 3D printing preview and export, which not only enables designers to check the printing effect of models before actual printing, find and repair potential problems in time, but also ensures the consistency between the quality of printed ceramic products and the preview effect.

VR Display: With the help of VR technology, the system can display design works in a virtual environment, providing a brand-new and immersive design experience for designers and customers.

This paper is divided into seven sections. The first section introduces the research background, significance, content and methods. The second section discusses the relevant research status; The third section summarizes 3D printing and VR technology and their applications in ceramic design. The fourth section expounds on the research and development process of the ceramic CAD design system in detail; The fifth section introduces the functional modules of the system; The sixth section shows the results and analysis of the simulation experiment, and discusses the system performance test and optimization; The seventh section summarizes the research results and puts forward the future research direction.

2 RELATED WORK

NURBS (Non-Uniform Rational B-Spline) functions play a core role in computer-aided design, especially in expressing complex surfaces and fine details, providing strong technical support for the three-dimensional modelling of ceramics. Based on the in-depth discussion of NURBS surface modelling methods, Liu and Li [8] particularly focused on how to apply this technology to the computer-aided design of ceramic shapes. It explores the correspondence between the components of daily ceramics and the sub-object elements in 3D modelling. By introducing computer 3D modelling technology into the modelling and design of daily ceramics, every detail of the shape can be more accurately controlled to meet these requirements. Taking software surface modelling as an example, it provides a detailed explanation of how to establish the relationship between modelling elements in software and basic elements of daily ceramics. The NURBS surface modelling method not only helps designers better express design ideas, but also seamlessly integrates with 3D printing technology, directly transforming designs into physical objects.

The challenge associated with the use of high solid load slurries in 3D lithography-based ceramic additive manufacturing (AM) technology mainly lies in ensuring the printability and shape preservation of ultra-thin layers and complex green structures without direct lower support structures. To overcome these challenges, Liu et al. [9] explored non-contact support strategies to optimize shape retention and printability in additive manufacturing processes. By adjusting the solid load in the slurry, the rheological behaviour of the slurry can be controlled, which in turn affects its printability and the mechanical properties of the final sintered parts. Among them, the sintered samples made from ceramic slurry loaded with 52 vol% solid have the highest bending strength and dense microstructure. The experimental results indicate that the increase in solid load has a significant regulatory effect on the rheological behaviour of ceramic slurry. The application of three-dimensional digital technology has brought innovative changes to the methods and methods of archaeological excavation of cultural relics. Allowing technicians more time and energy to invest in more important cultural relic research has promoted the development of new models of archaeology. With the refinement of the industry and the development of technology, computer vision, 3D laser scanning, artificial intelligence and other technologies can be applied in different stages of archaeological processes [10]. When ceramic cultural relics are unearthed, there are numerous fragments that are difficult to distinguish, and the workload of recording is huge. The traditional single archaeological method makes the entire process very slow and complex. In the process of fragment comparison, the comparison results generated by different comparison methods, such as texture feature comparison results and colour comparison results, are helpful to the subsequent scientific research of cultural relics to a certain extent. Finally, the automatic splicing of fragmented data and the reconstruction of 3D models, as well as the formation of a complete digital model of cultural relics with texture and colour, can create more possibilities for the digital development of cultural relics [11]. Processes such as the digital collection of complex cultural relics, 3D modelling and restoration of immovable cultural relics, scene modelling and display of archaeological sites, and digital restoration of damaged cultural relics can greatly reduce the work pressure of having a small number of people. Furthermore, using more precise scientific instruments to detect cultural relics can obtain more accurate data, which is conducive to scientific research on cultural relics and lays the foundation for better protection of cultural relics. The use of three-dimensional digital technology to assist in the restoration of ceramic cultural relics provides more accurate acquisition of fragmented original data and can generate three-dimensional digital models, providing more original data.

Sun et al. [12] 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. 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 designed resin formula has excellent flowability (machinability viscosity 0.068 Pars), suitable for 3D printing molding, and can achieve ceramics, making it easy to prepare ceramic materials with complex shapes. The printed precursor polymer was cracked under a specific temperature program, and SiOC ceramics were successfully synthesized. The prepared SiOC ceramics were analyzed for their structural composition and physical properties through detection methods such as FT-IR, XRD, Raman spectroscopy, and SEM. The formula does not contain solvents, avoiding ceramic cracking and environmental pollution caused by solvent evaporation. Virtual reality technology is a computer simulation system that can create and experience virtual worlds, generating an environment that simulates reality. By using VR interactive control scripts to interact with player operations, users can have an immersive experience in the scene. During the ceramic VR display process, the UI management script is responsible for switching, hiding, and displaying the entire game UI. At the same time, it integrates multiple types of information and utilizes interactive 3D dynamic visual scenes and physical behaviour system simulations to deceive the eyes and minds of the experience, making them believe it is true and immerse themselves in VR games. The player behaviour script is responsible for controlling the player and managing the interactive sound of scene objects and enemies, as well as playing all sounds in the game. Of course, it is also necessary to establish AI logic scripts to control non-player characters in the game, as well as to interact with scenes and players [13]. Compared with traditional mold casting or cutting methods, this method can more accurately control the shape, size, and distribution of pores, thereby optimizing material performance.

Wang [14] delved into the combination of complexity and ambiguity in ceramic art beauty, not only conducting a systematic study of its aesthetic value. Ceramic art, as a form of art that carries profound cultural connotations, has always been a focus of attention for its unique aesthetics and exquisite craftsmanship. Through image analysis technology, complex patterns and other features in ceramic artworks are extracted, quantified, and recognized, thereby helping non-professionals better understand the essence of ceramic art. Furthermore, they proposed an improved fast offset model aimed at improving the accuracy and efficiency of the model in extracting ceramic features. Through extensive experiments and comparisons, we have found that the improved model exhibits robust changes in extraction quality. It has a strong generalization ability, which can be applied to different types of ceramic artworks. Wang et al. [15] studied the innovative development of traditional ceramic culture in the context of "Internet+" based on the Unity 3D virtual ceramic experience system. By analyzing the difficulties in the inheritance and development of traditional ceramic culture and the necessity of traditional innovation in the information age, the research background of the paper is elaborated. It introduces several methods of ceramic forming and analyzes the main forming method for virtual experience by selecting the most traditional drawing forming. Apply knowledge related to ceramic production and modular design theory to the design and development of Unity 3D virtual ceramic interaction system, design the main functions and interaction processes of the system, and complete the interface design and partial function development of the system. This provides a detailed introduction to its production process, laying the foundation for the design of the virtual pottery experience system in the future. In addition, research on modular design theory is conducted from the perspectives of definition, module division principles, modular design process, and analysis of inter-module correlation, providing a theoretical basis for the functional research and design implementation of virtual ceramic experience systems [16].

This not only helps us to comprehensively evaluate the design effect of ceramic products but also provides targeted optimization suggestions for designers. The powerful feature extraction and recognition capabilities of CNN enable us to identify key features of ceramic products, such as shape, texture, colour, etc., from massive image data. In ceramic design scenarios, the combination of CAD, VR, and CNN modelling methods significantly improves the accuracy and efficiency of modelling. Experimental data shows that our method has improved modelling accuracy by more than 17%, which is particularly crucial in 3D ceramic printing as it directly affects the quality and performance of the final product. Piezoelectric textured ceramics, as a type of material with special physical properties, have received widespread attention from both academia and industry in recent years due to their unique piezoelectric effect and wide application prospects. The introduction of 3D printing technology provides a new approach for the preparation of piezoelectric ceramic textures. This method can not only accurately control the structure and texture of materials at the micro-scale, but also achieve rapid manufacturing of complex shapes and structures at the macro level. Traditional methods for preparing piezoelectric ceramics often struggle to find an ideal balance between production costs and material properties. Based on 3D printing stereo lithography technology, Zheng et al. [17] successfully developed a new method for achieving piezoelectric ceramic texture.

3 DEVELOPMENT OF CERAMIC CAD DESIGN SYSTEM

3.1 Selection and Application of Solidworks Software and Vc++ Development Tools

In the process of developing a ceramic CAD design system, this paper chooses VC++ (Visual C++) as the development tool. VC++ is a powerful programming environment which supports various programming paradigms, including object-oriented programming and procedural programming. Its rich library functions and powerful debugging function greatly improve the development efficiency. We use VC++ to write the core algorithm and interface logic of the ceramic CAD design system. By calling the API interface of SolidWorks, the seamless integration with SolidWorks software is realized. In addition, VC++ also helps us to realize the processing and storage of design data and the interaction with other modules.

3.2 Demand Analysis of CAD Design System

Before developing the ceramic CAD design system, the article made an in-depth demand analysis. Through communication with ceramic designers, manufacturers, and end users, this paper determines the core requirements of the system: friendly user interface, powerful modeling function, 3D printing support, VR display, performance, and stability. See Table 1 for details:

Serial number	*Research and demand analysis content*	*Detailed description*
1	Market research	Through market research, we can understand the current market trend of the ceramic design industry, competitors and the needs and preferences of target customer groups.
2	User group communication	Communicate with ceramic designers, manufacturers and end users in depth to collect their expectations and needs for ceramic CAD design systems.

3	User interface friendliness requirements	Users expect the system to provide an intuitive and easy-to-use operation interface, reduce learning costs and improve operation efficiency.
4	Modelling functional requirements	Designers and manufacturers need system support to create and modify complex ceramic models to meet diverse design requirements, including customization of shape, texture and colour.
5	3D printing support requirements	Users hope that the system can provide 3D printing preview and export functions, so as to directly print the designed model and speed up the product development and production process.
6	VR display demand	In order to enhance the user's design experience, the system should support the display of design works in a VR environment to help users better visualize the design effect.
7	Performance and stability requirements	Users expect the system to have good performance and stability, so as to ensure a smooth experience in the design process and avoid problems such as jamming and collapse.

Table 1: Market research and user demand analysis table of ceramic CAD design system.

Table 1 summarizes the main contents of market research and user demand analysis, defines the functional requirements of the ceramic CAD design system, and provides an important reference for the design and development of the system.

3.3 System Design and Implementation Process

Based on the results of the demand analysis in the previous section, this section designs the overall architecture and functional modules of the ceramic CAD design system and discusses the concrete implementation of the system.

The fundamental purpose of data processing is to extract valuable information from the original data and, after sorting, analyzing, and optimizing, generate data files that can be further used or analyzed. This process is very important to ensure the quality and accuracy of data, especially in engineering, scientific research, product design, and other fields. In modern engineering practice, reverse engineering technology has become an effective means to obtain design data from physical samples. Reverse engineering software can scan and digitize solid objects and convert them into digital models that can be processed by computers. In this paper, geamagic software is selected as the main tool for data processing. This software is powerful and can process the scanned data efficiently. In Geomagic software, the data processing flow is clear and clear, which is mainly divided into three stages:

Point cloud stage: this is the initial stage of data processing. The original data obtained by the 3D scanner exists in the form of points, which are dense and disorderly, forming a so-called "point cloud".

Suppose there is a point cloud P composed of n points, which is expressed as:

$$P = \quad p_1, p_2, p_3, \ldots, p_n \tag{1}$$

Where each point:

$$p_i = \quad x_i, y_i, \quad z_i \tag{2}$$

The input is point cloud P, and the output is preprocessed point cloud P':

$$P' = \text{RemoveNoise} \;\; \text{P} \;\; P' = \text{FillHoles} \;\; \text{P}' \tag{3}$$

Polygon stage: Based on the point cloud data, the software will build a 3D model composed of polygonal meshes. The processing at this stage can remove noise, fill loopholes, and smooth the model so that the model is closer to the shape of the real object.

The input is a preprocessed point cloud P', and the output is a polygonal mesh model M:

$$M = \text{BuildTriangleMesh}\ \text{P'}\ M = \text{OptimizeMesh}\ \text{M}\ M = \text{FillHoles}\ \text{M} \tag{4}$$

Surface stage: The Polygon model is further transformed into a smoother surface model, which is very important for subsequent product design and manufacturing because it provides a more accurate geometric shape description.

Input is polygon mesh model M, and output is surface model S:

$$S = \text{SurfaceFitting}\ \text{M}\ S = \text{OptimizeSurface}\ \text{S}\ S = \text{SimplifyMesh}\ \text{S} \tag{5}$$

Among them, the functions RemoveNoise, FillHoles, BuildTriangleMesh, OptimizeMesh, SurfaceFitting and OptimizeMesh represent the specific algorithms implemented in Geomagic software. Each function contains multiple sub-steps and parameters, which are adjusted according to the specific data types and processing requirements.

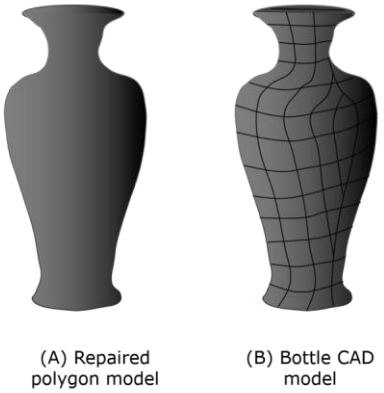

Figure 1: Polygonal model of ceramic art.

Figure 1(A) shows a polygonal model of a ceramic work of art. It can be seen that the scanned data, which may be full of flaws and noises, has been transformed into a clear and regular polygonal grid after being processed by geomagic software. Figure 1(B) is a CAD model of ceramic art after further processing, which can be used for the precise design and manufacture of products. The front and top views of ceramic artworks are shown in Figure 2.

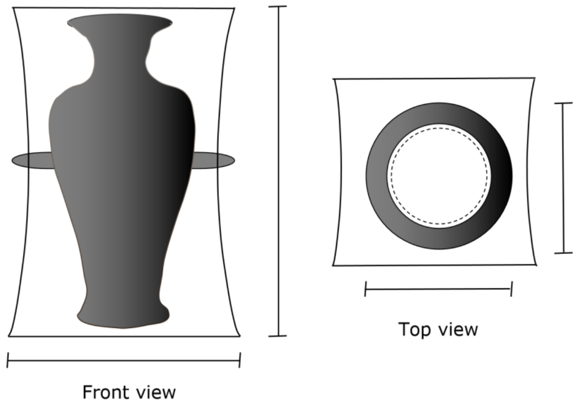

Figure 2: Front view and top view of ceramic artworks.

The mould design of ceramic artworks is a complicated and delicate work. Every work of art has its own unique shape and curve. Even for products with similar dimensions, the main difference in its mould lies in the difference in a curved surface. This difference requires designers and manufacturers to carefully design and adjust according to the characteristics of each artwork. In the traditional design method, designers need to make a brand-new design for each different curved surface, which undoubtedly increases the complexity and time cost of design work. However, with the development of technology, parametric CAD design has brought revolutionary changes to this process. Parametric CAD design allows designers to quickly generate and modify designs by adjusting a series of parameters. For products with similar dimensions, designers can quickly generate new mould designs by replacing some parameters in the original CAD model. This method not only greatly improves the design efficiency, but also avoids a lot of repetitive drawing and modification work.

Let R be the radius of the cylinder, H the height of the cylinder, and θ the rotation angle of the cylinder. The parametric equation of the cylinder can be expressed as:

$$\text{Cylinder R,H,}\theta = x,y,z \left| x = R\cos\theta, y = R\cos\theta, z = H \right. \tag{6}$$

In this equation, x, y and z are the coordinates of any point on the cylinder. By changing the values of these parameters, cylinders with different sizes and inclination angles can be generated. Parametric equation of a circle:

$$\text{Circle R,}\theta = x,y \left| x = R\cos\theta, y = R\cos\theta \right. \tag{7}$$

Where R is the radius of the circle and θ is the angle measured from the positive x axis? Parametric equation of ellipse:

$$\text{Ellipse A,B,}\theta = x,y \left| x = A\cos\theta, y = B\cos\theta \right. \tag{8}$$

Where A and B are the lengths of the semi-major axis and semi-minor axis of the ellipse respectively, and θ is also the measuring angle. Parametric equation of torsion body;

$$\text{Torsion Surface R,}\theta = x,y,z \left| x = R\cos\theta, y = R\sin\theta, z = f\ \text{R} \right. \tag{9}$$

Where: f R is a function about R, which can be used to describe the curvature of the torsion body.

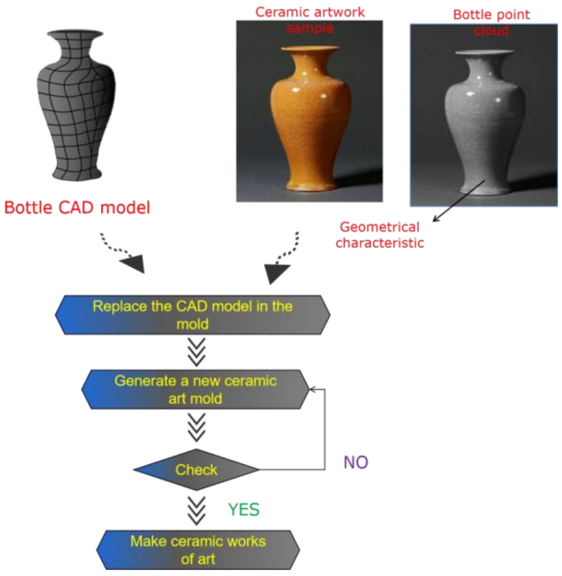

Figure 3: Flow chart of CAD parametric design for ceramic products.

Figure 3 shows the whole process of parametric CAD design of ceramic products in detail. From the initial parameter setting to the automatic generation of the mould to the final design verification, every link is closely linked, forming an efficient and accurate design system. This design method not only improves the design and production efficiency of ceramic artworks but also provides designers with more creative space and flexibility.

In the process of system implementation, this paper follows the following steps:

Interface design: An intuitive and easy-to-use user interface is designed by using VC++ and related graphic libraries to ensure that users can get started easily.

Realization of modelling function: By calling the API interface of SolidWorks, the functions of creating, modifying and saving ceramic models are realized. Users can directly carry out 3D modelling operations in the system.

Preview and export of 3D printing: A special module is developed to deal with 3D printing-related functions. Users can preview the printing effect in the system and export the model to a file format suitable for 3D printing.

VR display: By interfacing with VR equipment, the function of displaying ceramic models in a VR environment is realized. Users can view and interact with the model from the first-person perspective in the virtual environment.

Performance testing and optimization: During the development process, the system is continuously tested and optimized to ensure that it meets the needs of users. By adjusting the algorithm and data structure, the running speed and stability of the system are improved.

4 SIMULATION EXPERIMENT OF CERAMIC CAD DESIGN SYSTEM

The experimental environment in this section includes high-performance computers, 3D printers and VR devices. In the experimental preparation stage, we collected a variety of ceramic design cases and prepared the corresponding test data and assessment indicators. During the experiment, several ceramic models were created and modified by using the ceramic CAD design system. These models cover different shapes, sizes and complexity to comprehensively test the modelling ability and editing function of the system. We recorded the design process and time consumption of each model in detail for subsequent analysis. The response time of the model is shown in Figure 4.

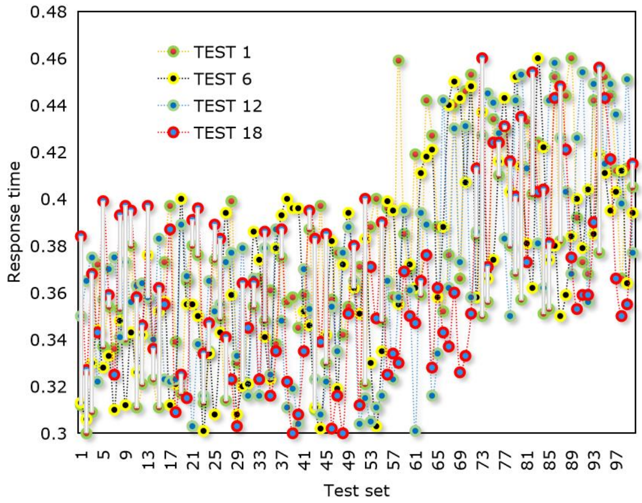

Figure 4: Response time of the model.

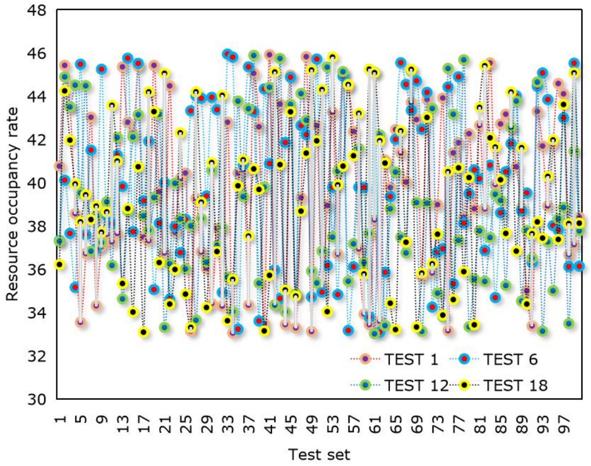

Figure 5: Resource occupancy test of the model.

The resource occupancy test of the model is shown in Figure 5. Follow-up experiments will verify whether the system will crash or its performance will drop significantly under the condition of long-term operation or high load. The experimental results are shown in Figure 6.

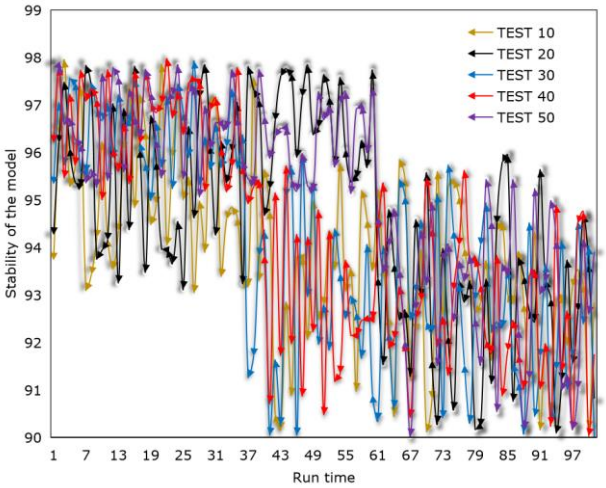

Figure 6: Stability test of the model.

In the process of performance testing, this paper records the data of various performance indicators in detail, including response time, peak response time, average and peak occupancy of CPU and memory, etc. Through the analysis of these data, we find that the response time of the system is slightly longer when dealing with complex models, and the CPU utilization rate increases obviously in high concurrency scenarios. However, the overall performance is excellent, and it can effectively and reliably handle ceramic design tasks.

After the model design is completed, the 3D print preview function is used to check the printing effect of the model. Through the preview, potential printing problems can be found and repaired in time, such as insufficient supporting structure and loss of model details. Subsequently, the model is exported to STL format and printed on a 3D printer. The printing results verify that the model file exported by the system is consistent with the preview effect, and the printing quality is good, as shown in Table 2.

Serial number	*Operating procedure*	*Result Description*	*Assessment*
1	Model design completed	The model has been successfully designed and completed.	-
2	Use the 3D print preview function	Check the model through a 3D print preview.	Preview effect: clear
3	Check for potential printing problems	Inspection of problems such as insufficient supporting structure and loss of model details.	Number of problems found: 2
4	Fix potential printing problems	Fix the problems found.	Number of problems fixed: 2
5	Export model to STL format.	Export the repaired model to STL format.	Export file size: 16 MB
6	Do actual printing on a 3D printer.	Use a 3D printer for actual printing operation.	Printing time: 10 hours
7	Print result verification	Compare the print result with the preview effect and assess the print quality.	Consistency between preview and object: high
8	Print quality assessment	Assess the quality of the printed model.	Print quality rating: 96/100

Table 2: 3D printing effect verification record table.

Finally, this paper assesses the display effect of the ceramic model in a VR environment. Through VR equipment, users can observe the visual effects of the model from all angles and simulate the real display scene. The user rating is shown in Figure 7.

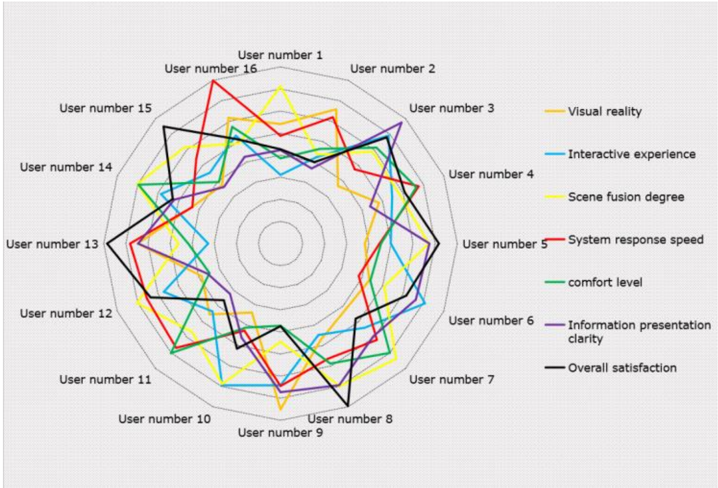

Figure 7: User rating.

The assessment results show that the VR display module can provide users with a highly immersive design experience, which helps users assess the design effect more intuitively. At the same time, this paper also collected some user feedback in order to further optimize the user interface and interactive function of the system.

Through the discussion in this section, it is found that the work efficiency of designers has been significantly improved after using the ceramic CAD design system. In the traditional design process, it takes a lot of time and energy to make and modify clay models, but now these tasks can be completed quickly in the CAD system. In addition, due to the accuracy and visualization effect of the CAD system, the design quality has also been significantly improved. Designers can express their design ideas more accurately, and preview and adjust them in real-time through VR technology, thus ensuring the quality and effect of the final product.

5 CONCLUSIONS

This paper successfully developed a ceramic CAD design system based on 3D printing and VR technology. The system integrates user interface design, ceramic model design, 3D printing preview and export, VR display and other functional modules, providing an efficient and intuitive design tool for ceramic designers. The practicability of the system is verified by simulation experiments and system performance tests. Compared with other ceramic design processes, the system significantly improves the design efficiency and quality and provides strong support for the innovative development of the ceramic industry.

Based on the research in this paper, future research can be carried out from the following aspects: first, in-depth study and optimization of system performance, improve the ability to deal with complex models; The second is to enrich the interactive functions and scene settings of the VR display module and enhance the user experience; The third is to explore the digital management scheme of the whole chain of ceramic industry and realize the seamless connection between design, production and sales. Through these improvement measures, it is expected to further improve the practicability and market competitiveness of ceramic CAD design systems.

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