Academic Journal of Art and Design
ISSN: 3080-9924 (Print), ISSN: 3080-9932 (Online) | Vol. 2, No. 2, 2026

Analysis of Human-Computer Collaborative Creation for Dunhuang Pattern Innovation Empowered by Generative Artificial Intelligence from the Perspective of Parametric Design

Ziwen Xie

Department of Cultural and Creative Arts (CCA), The Education University of Hong Kong, Hong Kong, China

Abstract: The dynamic inheritance of Dunhuang patterns is limited by the practical problems of low-efficiency manual reproduction and high professional demands. Generative artificial intelligence provides the technical conditions for pattern innovation, but the model is based on statistical patterns from training data and cannot grasp the structural logic and symbolic connotations of Dunhuang patterns; therefore, there is a risk of style deviation and semantic dilution. Parametric Design is employed as the analytical framework in this paper to study the operating mode of human-machine collaboration when generative artificial intelligence is used for the innovation of Dunhuang patterns. Parametric Design can be used to set up a controllable rule system for the structure of the Design Object, thus adapting to the natural geometric order of Dunhuang patterns. Under this framework, the digital translation of Dunhuang patterns proceeds along the paths of structural analysis, rule extraction, constrained generation, and multi-dimensional evaluation, and the human-machine relationship evolves iteratively under the constraints of rules. The preservation of cultural authenticity and the determination of copyright ownership are problems to be solved in collaborative creation. This paper proposes a way of thinking that combines technical feasibility with cultural awareness for the digital innovation of Dunhuang patterns.

Keywords: Parametric Design; Generative Artificial Intelligence; Dunhuang Patterns; Human-Machine Collaboration; Cultural Inheritance.

1. Introduction

The decorative patterns of the Mogao Caves in Dunhuang were accumulated from the Northern Liang Dynasty to the Yuan Dynasty and incorporated various visual traditions. Guan Youhui's "Dunhuang Decorative Patterns" studies the system from the Northern Dynasty to the Yuan Dynasty and points out that it was formed by the integration of Central Plains and Western Regions cultures. Geometric patterns of caisson ceilings, scrollwork and clusters of motifs are typical features of the Silk Road civilisation. However, there is a basic contradiction in the inheritance: traditional replication requires prolonged training and manual labour, with a cycle of several weeks; although the "Digital Dunhuang" project has finished the digital collection, static images are not convenient design materials that can be called upon flexibly.

Generative Artificial Intelligence provides new technological conditions for pattern innovation. Stable Diffusion and Midjourney are models that can generate pattern prototypes from text prompts, and the quality of generation depends on the scale and structure of the training data. For patterns with culture and geometry, such as those in Dunhuang, prompt engineering alone will likely lead to a loss of style and structure. The model has learned the "Dunhuang style" based on statistical rules, not from the internal composition logic of the patterns.

Parametric Design values are derived by setting control rules for structural rules. The geometric symmetrical structure of caisson patterns can be analysed by shape grammar, and Liu Yue et al. extracted unit elements and combined deduction rules for design, demonstrating that shape grammar can be applied to analyze the structural features of caisson patterns and generate derivative patterns [1]; the transformation rules of the form of scrollwork patterns also have methods for following, and Zhu Guijun et al. showed that split grammar and shape grammar can achieve digital innovation of Tang Dynasty Dunhuang scrollwork patterns; the composition of motifs in clusters also has quantifiable parameter relationships, and Shen Tianqi et al. used Rhino and Grasshopper to parameterize model the clusters of motifs and the patterns within them, generating variants through shape grammar derivation [2]. Convert the patterns into parameter rules to provide a constrained and interpretable technical interface for the intervention of generative AI. From the perspective of parametric design, we will examine the operating mode, division of responsibilities and cultural boundaries in human-machine cooperation for generative AI-powered innovation of Dunhuang patterns in this paper.

2. From Copying to Parameters: The Technical Logic of Digital Transcription of Dunhuang Patterns

To know why parametric design was developed, we first need to understand the problems with older digital technology. Early digitalisation of Dunhuang patterns used high-precision scanning and vectorisation to move the mural patterns into the computer and create static images. Designers still had to judge, organise and recreate these pictures themselves. The professional threshold was not increased, and design efficiency was still low.

Parametric Design changed the way of thinking by first decomposing the structure, then defining the rules, and finally writing the rules in a programmable parameter system. There are many concentric square wells in the Dunhuang Caisson

Pattern, and each level has a corner and border design. The Scaling Ratio, Rotation Angle and Colour Configuration of the layers meet the relevant rules. Liu Yue and others used shape grammar to analyze the structure and component makeup of the caisson pattern, extracted unit elements, and combined them with deduction rules for design to show that shape grammar can help designers understand the structural characteristics of the caisson pattern and generate patterns that provide data for computer-aided design [1]. Shen Tianqi and others investigated the cluster pattern, and using Rhino and Grasshopper, split the cluster ring and the inner pattern into the smallest units for parametric modelling. Then, using shape grammar, they derived transformations and wrote the derivation rules in parametric language to generate various forms of variations [2].

There are two tiers of value for rule extraction. It can help restrict the generation of generative AI to a specific region in the rule space and prevent random sampling from a black box. Parameter rule extraction is also a problem in culture. Research should move beyond the aesthetic perception of the surface style of a pattern and reach for its logical basis in composition; imitation of surface style is no longer enough [3]. The entire process of digital translation, from high-fidelity acquisition and colour quantization analysis to vector decomposition of patterns, parametric design generation and digital manufacturing, has transformed the intangible experiences in traditional patterns into explicit knowledge that can be passed down and reused.

There are two ways to combine parametric modelling and generative AI. First, treat parametric modelling as a prerequisite constraint for AI; then, use a parameter system to define the structure framework and variation range of the pattern, and convert this framework information into conditions that AI can recognise and input so that the generated results do not deviate from the basic composition logic of Dunhuang patterns [4]. The other way is to do the reverse: have the AI generate a large number of variations first, and then use the parametric evaluation system for quantitative screening of structural similarity and style consistency. Both roads lead to the same place; the creativity of generative AI should be led by a parametric rule system.

3. Dialogue of Rules: Role Reconstruction in Human-AI Collaborative Creation

The rule system restricts the generated results and also changes the roles of people and artificial intelligence [5]. A Parametric Framework introduces new forms for the relationship between people and machines. The designer was in charge before; now, only the software does the work. If AI were still regarded as a "high-level tool" at that time, it would only accelerate the preparation of the draft, and the final selection would still be made by a person. However, the part of AI's capabilities that truly distinguishes it from that of humans, such as pattern recognition and novel combination, was not included here.

More interestingly, the "dialogue of rules" method. People set the cultural goals and boundaries, and then AI creates a large number of variations within those boundaries. According to the above results, people alter the parameters. They go around and around. People no longer say, "I want this"; instead, according to the rules of the parameter, they can say, "This is acceptable" or "This is not acceptable" [6]. Ge Ruixuan and others in their research on the construction of Dunhuang caisson patterns established a three-tier prompt system for cultural semantics, visual structure and colour materials, and reduced the designer's intention to operable parameters. More than 1,200 pictures were taken, and after selection, 36 remained. Norms are cultural rationality and structural conformity in accordance with the rules in the parameters [7].

In short, this is a reorganization of cognitive division. Designers have the authority to interpret culture; thus, the religious connotations, historical background and aesthetic traditions of the patterns must be interpreted by people. The power of artificial intelligence is its ability to explore the space of combinations among many forms that are beyond the grasp of people's understanding in a lifetime. It will be available at that time. At this time, a translation needs to be made: convert the cultural intention into technical parameters that AI can recognize, and then translate the output of AI back into a human-understandable format. Parametric Design is used to achieve the above goals. In the study of the digital translation of the Nine-Colored Deer pattern, a five-dimensional evaluation system was built according to the analytic hierarchy process: cultural authenticity, artistic aesthetics, geometric transformability, material compatibility, and market resonance. Turn the cultural assessment into operating indicators and set up a relative-objective standard to evaluate the results achieved by AI.

It also has new demands for the skills of designers. It is necessary to be skilled in drawing and have an aesthetic sense; at the same time, one needs to be able to "encode" aesthetic judgment by recognising the structural patterns of a design object and then developing clear and flexible parameter rules for expression and modification. If AI is to learn about traditional culture, we must first inform it what that culture is. Parametric Design is to provide a bridge for the irrational idea of beauty to be converted into specific structural information.

4. Constraints and Screening: The Mechanism for Guarding Cultural Authenticity in Collaborative Creation

The enhancement of rule encoding ability is only one feature of collaborative creation. Another problem is how to keep the original culture during the process of AI generation. The preservation of cultural authenticity is a significant problem in human-computer cooperation for creation. Generative AI is used to expand the probability distribution of data. What AI perceives as "Dunhuang patterns" is in fact a product of statistical laws in the training data, always distant from the spiritual essence of Dunhuang culture. The risks are as follows: Although the AI-generated images may be similar to those of Dunhuang, the basic structural logic or symbolic meaning has already been altered [8]. More seriously, there is also the issue of culturally insensitive images; sometimes, AI creates many visually pleasing pictures, but even when they are not suitable for culture, they are kept because they look good. Over time, the cultural connotations gradually fade away and are often lost forever. It is difficult to trace and correct it after being discovered.

Therefore, several links will be added to the cooperative process to address the risk. Parametric Rules are the first tier of defence. Parameterise the structural framework of the pattern and discard generated results that do not meet the

basic structural logic at an early stage. Sun Xufang and others conducted research on the generation design of Dunhuang tile patterns extracted the basic units of the initial pattern and summarized the structural framework. Given the structural constraints, they were developed relatively quickly, maintained diversity, and kept the structural connections with the original pattern. It provided a stable structure for the following innovations.

The second line of defence is Evaluation and Screening. A Good Evaluation System Needs To Set Many Quantitative Standards at All Levels. The AHP method used in the research on the digital translation of the Nine-Colored Deer pattern provided a reference; five dimensions of the evaluation system were established by researchers: cultural authenticity, artistic aesthetics, geometric transformability, material compatibility, and market resonance. They converted the abstract qualitative attribute of cultural authenticity into an operational selection index and provided a basis for each round of selection.

The final defence is carried out by people. In the AI-generated schemes, only those that truly carry on the spiritual essence of Dunhuang patterns and not merely imitate in form will receive approval from professionals with cultural literacy [9]. It should be pointed out that the existence of constraints and screening devices does not reduce the space for innovation. Given the context of Dunhuang patterns, structural constraints can be used to guide the "creativity" of AI towards culturally significant variations and avoid going off track.

5. From Aesthetic Intuition to Rule Encoding: The Transformation of Designers' Cognitive Mode

Based on the above discussion, the foundation of the parametric system is to convert the designer's initial idea of the pattern into concrete and executable structural parameters. This is not a result of technical operation; it is a modification of consciousness.

Traditional Pattern design relies on the sense of sight and touch. After studying the Dunhuang patterns for a long time, designers are likely to have a sense of the rhythm of layers and the graceful feeling of scrolls. It is not to say that one is happy or unhappy. Otherwise, it cannot be turned into commands for the AI to perform. This tacit knowledge is not a problem of manual creation; rather, it is a bottleneck to the quality of AI-generated work in human-computer collaboration. Ge Ruixuan and others have constructed a system of cultural semantic layer prompts to convert tacit knowledge into explicit expressions, and now, designers need to specify the proportional relationship of patterns and what the colour gradient should be, instead of simply saying "it does not look right" [7].

Designers have been inspired to create. According to the joint evaluation of the 35 architecture students, they performed well in the parametric design exercise, and 89% of those reached the high range; however, only 46% of those used AI tools achieved this result. It was not a lack of technical ability; rather, it was difficulty expressing spatial ideas in words [10]. The two modes of cognition are not self-formed; they need to be learned.

An Increase in Cognitive Load is Not Necessarily a Bad Thing. When designers want to present a sense of beauty in structure, they will learn more patterns through this process of learning. Researchers in the parametric design of tortoiseshell patterns have found that by modifying parameters such as radius, number of sides and curvature to create variations, they have effectively changed designers' thinking from "is it beautiful?" to "why is it so?", and thus moved away from copying and began to explore the reason behind the structure. They can now learn to create freely based on what they know.

As the parametric rules are the communication method between people and AI, all the Design choices can be traced back to them and discussed [11]. If the results of the AI generation are not as expected, simply trying again will not suffice; in such cases, one may modify some parameters, for example, change the proportion, correct the rotation angle, or expand the range of colour gradients. The first problem-solving mode for the shift from trial-and-error to conversation in people-AI cooperation is precise problem-finding.

6. Boundaries and Possibilities: Ethical Awareness and Paradigm Outlook in Collaborative Creation

With more evidence of the problems in collaborative creation, people have begun to worry about the ethics of it. Although there is already practical support for the technology of human-machine collaborative creation, ethical discussions have not kept pace. Copyright ownership is the first problem to be addressed. A pattern design scheme is established by a designer; then, AI is employed for generation and optimisation; finally, the results are presented. Currently, the copyright system is based on "human intellectual creations", and whether the pattern recognition and form combination performed by AI fall under "intellectual activities" has not been clarified [12]. Guan Yuying believes that the products resulting from simple prompt words do not constitute a work, and whether a series of modifications to a complex prompt word can be considered a work is still unclear. Wu Handong proposed "layered rights confirmation based on the degree of human intellectual contribution". For public domain heritage, such as Dunhuang patterns, there is no institutional system for training data sources, determination of derivative relationships, and distribution of commercial benefits.

The use boundaries of cultural symbols also deserve attention. Artificial intelligence can quickly replicate the style of Dunhuang patterns; however, has it encroached upon the spiritual rights of cultural symbols? A professor from the Law School of Shandong University indicated that cultural symbols, such as ethnic totems and traditional patterns, are often employed in the training of AI models. If there is no authorisation for the use of the source material or a system of benefit sharing, it may be deemed an infringement of collective cultural rights and thus reduce the distinctiveness of local culture. This judgment also applies to Dunhuang patterns. The layers in a caisson pattern are not only decorative but also connect to the idea of spatial order in Buddhist cosmology. When the AI-generated patterns are taken out of context and applied to commercial products, have their original symbols been lost or modified? Researchers need to be sensitive.

The institution's response is also improving. In September 2025, the Chang Shana Art Center opened in Dunhuang and released the "Digital Copyright Repository of Dunhuang Patterns", which integrated, preserved and provided access to the authorised classic patterns. The "Digital Dunhuang · Open

Resource Library" of the Dunhuang Academy uses blockchain and digital watermarking technology to protect copyrights [13].

The three things that need to be improved in the future are: At the same time, the structure and cultural-semantic constraints of the generated content need to be considered. Institutionally, a copyright recognition and digital resource authorisation mechanism for human-machine collaboration needs to be built. Educationally, design courses to incorporate parametric thinking and cultural research abilities. Parametric Design and generative AI do not offer ready-made tools for the innovation of Dunhuang patterns; instead, they provide a mindset shift: Inheritance is not merely reproduction of the past but creation of new opportunities through understanding the rules.

7. Conclusion

The digital innovation of Dunhuang patterns takes place at a time when both technological conditions and cultural consciousness are changing. Parametric Design makes the structural laws explicit and the generation process parametric, setting bounds for the intervention of generative AI; the efficiency of AI's variant exploration also allows for far-reaching iteration of the parameter rules without manual trial and error. Together, the two forms form a "dialogue of rules" for human-computer cooperation; designers set the cultural goals and demands for authenticity, and then AI conducts exploration and combination innovation within the constraint space. For this model to work, a full chain from structural analysis to parametric generation, evaluation and cultural judgment is needed, and the follow-up of copyright systems and cultural ethical norms is also required.

However, this cooperative model is also imperfect. The extraction of parametric rules is based on designers' understanding of the structural logic of the patterns, and different people have different parametric schemes for the same pattern; there is little standardisation. To date, artificial intelligence has only achieved visual-level processing of cultural semantics, and for deeper problems such as symbolic connotation and religious context, human guidance is still needed in the final decision-making. Copyright ownership and authorisation mechanisms for digital cultural heritage resources have been established but have not kept pace with the development of technology.

The next three things will be promoted. In terms of technology, the structure and culture-semantics of generative models must be addressed simultaneously, and the "cultural awareness" of AI will evolve from visual mimicry to structural logic and symbolic semantics. At the institutional level, new copyright recognition rules and authorisation mechanisms for cultural heritage digital resources in human-machine co-creation need to be established. Add parametric thinking and cultural research abilities to the training content of new courses.

In the end, the digital innovation of Dunhuang patterns is not to replace tradition with technology, but to use new cognitive tools to deepen the understanding of tradition. The purpose of parametric Design here is to make this understanding practical, verifiable and portable.

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