

A Study on the Evolution Laws and Innovative Paths of the Digital Inheritance of Dunhuang Lotus Patterns: An Empirical Analysis Based on Ten Typical Caves

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Abstract. This paper focuses on the lotus patterns of 10 typical Dunhuang caves, using case analysis and comparative research methods to explore the digital inheritance rules and innovation paths of these patterns. The study begins by outlining the evolution of the patterns: the shapes changed from the geometric style of the Northern Qi period (4-6 petals) to the realistic style of the Tang Dynasty (10-14 petals), the colors changed from the simplicity of the Northern Dynasties to the richness of the Tang Dynasty, and the techniques changed from simplicity to sophistication; then it analyzes the existing problems in digital applications, such as insufficient cultural exploration in static applications, poor compatibility of dynamic application scenarios, and low popularity of the database. Finally, it constructs a three-in-one strategy of "digital protection - dissemination - innovation": establish a standard archive database containing quantitative data on shapes and colors, create a dissemination content matrix divided by scenarios and audiences, and employs modular decomposition to integrate traditional patterns with contemporary design, thereby facilitating the dynamic transmission of traditional motifs.

Keywords: Dunhuang lotus patterns, evolution rules, digital inheritance, innovative paths

1. Introduction

Dunhuang murals, a treasure of ancient Chinese art, feature the lotus motif as a core decorative element with profound Buddhist culture and unique aesthetics. Yet in modern design, lotus patterns often suffer from either simplistic copying (lacking cultural depth) or inadequate integration with contemporary concepts (lacking a sense of the times).

The study suggests a set of digital design approaches to solve this problem. Firstly, typical cave samples were selected, and the shapes and colors of the lotus patterns were analyzed morphologically. Secondly, they were traced and converted into a standardized vector graphic resource library using tools such as Adobe Illustrator. Finally, through visual deconstruction and modular design, different style pattern combination templates were created to explore their new visual expressions in modern digital media.

This research aims to organically integrate tradition and modernity through digital means, providing theoretical support and practical examples for the innovative application of Dunhuang

lotus patterns in modern design fields.

2. Research method

Using a combination of comparative research with case analysis, this research conducts research. Case analysis refers to a research method where researchers conduct in-depth, comprehensive and systematic investigation and analysis of specific individuals, groups, organizations, events or phenomena to reveal the essence, laws, problems and causal relationships of things, thereby providing a basis and support for theoretical construction, problem-solving or decision-making. To deeply analyze the morphological characteristics of the Lotus patterns in Dunhuang, this study selects 10 representative Dunhuang grottoes, such as Cave 390, Cave 272 and Cave 407 of Mogao Grottoes, as samples. The selection of grottoes takes into account factors such as the span of dynasties and artistic styles, and selects the ten most distinctive Lotus patterns to ensure the diversity and typicality of the samples. Secondly, cases such as the jewelry design of the Chang Shana team, the dynamic images of the Osaka World Expo, and the digital application of Dunhuang cultural and creative products are selected to analyze the advantages and disadvantages of existing digital practices. At the same time, the differences in the shape, color and techniques of the Lotus patterns in Dunhuang from different dynasties are compared horizontally, and the development process of digital application from static replication to dynamic dissemination is sorted out vertically. By comparing the digital inheritance models of similar traditional patterns at home and abroad, the common laws and individual paths of the digital inheritance of the Lotus patterns in Dunhuang are extracted.

3. Literature review

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3.1. Research on the history and artistic characteristics of the lotus pattern in Dunhuang

Dunhuang patterns, being a significant element of Dunhuang art, embody profound historical and cultural meanings along with remarkable artistic worth. After thousands of years, these patterns have played significant roles in various aspects such as religion, art, and cultural exchange. The kinds of Dunhuang designs have been systematically classified and thoroughly analyzed by many academics. Certain researchers have examined the typology and historical development of lotus patterns in Dunhuang. Scholar Ouyang Lin in works such as "Dunhuang Patterns" and "Miscellaneous Dunhuang Patterns" elaborated on the types of Dunhuang patterns, covering plant patterns (such as lotus and honeysuckle patterns, camellia patterns, and lotus flower patterns), animal patterns (such as auspicious birds and auspicious beasts patterns), geometric patterns, and cloud and gas patterns. The Dunhuang patterns from different periods have their own characteristics. During the Northern Dynasties period, the patterns in the Dunhuang grottoes were simple and distinct, with fewer types, simple images, and not complex combinations, mainly including lotus and honeysuckle patterns, geometric patterns, cloud and gas patterns, auspicious birds and auspicious beasts patterns, etc. Among them, the honeysuckle pattern is simple and plain, free and lively, composed of single-leaf honeysuckle patterns as the basic unit, forming various styles, and under the backdrop of a reddish-brown color, it gives people a simple and plain aesthetic feeling. In the Sui and Tang dynasties, the patterns were rich in content and varied in form, with slender and delicate images. The Sui Dynasty's pavilion patterns were highly innovative, featuring various types such as nested square pavilions, lotus-shaped pavilions, flying celestial beings lotus-shaped pavilions, double dragons lotus-shaped pavilions, and large lotus-shaped pavilions. Each type expressed its own thoughts and had its own charm. The Tang Dynasty's pattern of the lotus flower became the mainstream, with its shape integrating various floral elements, being dignified and elegant, and luxurious. Over the years, the research on Dunhuang patterns has shown a development trend from macro background verification to multi-dimensional and interdisciplinary in-depth analysis. The research perspective has continuously expanded, and the research depth has continuously deepened [1]. Duan Wenjie in "The Ethnic Traditions and Foreign Influences of Early Dunhuang Murals" discussed the ethnic traditions and foreign cultural integration of early Dunhuang murals from a macro perspective, providing a cultural background reference for subsequent pattern research [2]. Li Jun in "The Construction Time of Mogao Cave No. 9 from the Donor Inscriptions" through dating the construction period of the cave, indirectly provided a key basis for the dating research of Dunhuang patterns, helping the academic community clarify the characteristics of patterns in different periods [3]. These two scholars, from the perspective of historical background and dating, to a certain extent, laid the foundation for the research; Yang Xiuying through linguistic analysis of the plural suffix "men" in Dunhuang vows, indirectly revealed the symbolic cognition of the group patterns in the Tang Dynasty society, providing linguistic evidence for the study of the social function of patterns [4]. Liu Jinglin in the supplementary correction work of the Dunhuang document "Food Therapy Herbal", starting from the decorative illustrations of medical literature, analyzed the extension application of Dunhuang patterns in practical objects, combining pattern research with medicine [5]. They broadened the research scope by adopting a cross-disciplinary approach; in addition, Yi Cunkuo "The Aesthetics of Dunhuang Art" systematically analyzed Dunhuang patterns from an aesthetic perspective, explaining their aesthetic characteristics and cultural value, promoting the academic community to re-examine the connotation of patterns from an artistic aesthetic height [6]. Xie Ying "A Comparative Study of caisson Patterns in the Northern and Sui Dynasties of Dunhuang Mogao Caves" focused on this topic, comparing the differences and inheritance of patterns between the two dynasties from the perspectives of shape, color, and

structure, achieving the specialization and refinement of pattern research. The two scholars conducted an art aesthetics and thematic comparison, deepening the research depth [7]. In terms of artistic features, another group of scholars analyzed and studied from the perspectives of shape, color, and composition: Dunhuang patterns have rich and diverse shapes, including concrete and abstract forms. In terms of color, the patterns in the Northern Dynasties grottoes were based on a reddish-brown tone, complemented by green, white, and black colors, appearing simple and solemn; The patterns in the Sui Dynasty were more colorful. The painters used color variations to depict the Buddha's light, creating a mysterious and brilliant effect, and applied this light and color effect in the coffered ceilings and the backgrounds of the flying celestial beings. In terms of composition, the patterns on the coffered ceilings often employed symmetrical and repetitive techniques, reflecting an aesthetic of order. Zhao Shengliang pointed out in "The Melody of Light and Color - A Glimpse into the Decorative Color of Dunhuang Murals from the Sui Dynasty" that during their pursuit of the depiction of Buddha's light, the painters of the Sui Dynasty incorporated elements of foreign Buddhist art and reached an unprecedented level in the use of colors, showcasing Dunhuang's significance as a vital city along the Silk Road [8].

3.2. Dunhuang digitalization and inheritance research of Dunhuang patterns

As digital technology advances, researchers have started to concentrate on the digital preservation of Dunhuang patterns. Chang Shana systematically organized lotus and honeysuckle patterns in "Decorative Patterns of Dunhuang in Different Dynasties of China" and guided the team to apply them in jewelry design, initiating the practice of "static digital transformation" of Dunhuang patterns [9]; Huang Xinran in "Research on the Application of Dunhuang Weaving and Printing Patterns in Ceramic Cultural Products - Taking the Periods of the Wei, Jin, Northern and Southern Dynasties as an Example" discussed the application paths of digital patterns in ceramic cultural products, emphasizing the combination of "form extraction and functional adaptation" [10]. In 2025, the team of Chang Shana presented the dynamic images of Dunhuang patterns at the Osaka World Expo, converting static patterns into dynamic visual language, promoting the investigation of "dynamic digital dissemination" of Dunhuang patterns.

However, the existing research still has obvious deficiencies: Firstly, the research on the evolution rules of lotus patterns mostly focuses on a single period or a single cave, lacking systematic quantitative analysis across different dynasties, which is difficult to support standardized digital inheritance; Secondly, the digital applications mostly remain at the technical level, such as simple vectorization and dynamicization, failing to deeply combine the cultural connotations of patterns with the adaptation requirements of different digital scenarios; Thirdly, there is a lack of comprehensive sorting of the entire digital inheritance chain, and no complete strategy system covering "protection - dissemination - innovation" has been formed. This research is precisely aimed at these deficiencies, through systematic analysis of the evolution rules of patterns, reflection on existing practical problems, and the construction of a scientific digital inheritance path.

4. The artistic characteristics and historical evolution of the lotus patterns in Dunhuang

The artistic features of the lotus patterns in Dunhuang have continuously evolved with the passage of time. In terms of form, color and technique, they have demonstrated a clear evolution process from simplicity and minimalism to maturity and complexity, and from being dominated by religious functions to being equally emphasized on both decoration and aesthetics. This deeply illustrates the cultural context and artistic endeavors of various historical eras.

4.1. Analysis of the characteristics of the lotus pattern in Dunhuang art

The evolution of the design reflects the integration of geometric abstraction and realism with the paradigm. The early Dunhuang lotus patterns were simple and ancient, as shown in Cave 272 of the Mogao Caves during the Northern Qi period, as depicted in Figure 1a. As an early cave of the Mogao Caves, the lotus pattern in this cave was simple and ancient. The number of lotus petals was small (averaging 4-6), and the line nodes were simple (single-petal line nodes were approximately 8-10), with a geometric outline as the main feature, without auxiliary elements; the lines were relatively hard and angular, using simple geometric shapes to outline the basic contour of the lotus, with lotus flowers arranged in layers, reflecting the initial abstract generalization of the lotus shape in the early stage. The lotus pattern in Cave 390 of the Mogao Caves during the late Sui Dynasty showed a tendency towards paradigmization. Figure 1b illustrates an increase in the number of petals arranged in a regular pattern, yielding a full, round shape that radiates outward from the center to the edges. This arrangement, combined with surrounding honeysuckle motifs and geometric designs, creates a complex and orderly structural pattern. It continued the traditional lotus shape while incorporating new elements, presenting diverse characteristics, reflecting the maturity and innovation of artistic creation in terms of structure at that time. At the same time, the "Three Rabbits with Common Ears" lotus pattern in Cave 407 of the Mogao Caves was unique, as shown in Figure 1c. The three rabbits formed a dynamic circular structure through the ingenious design of sharing ears, surrounding the lotus. This unique design broke the convention and added a lively and lively feeling to the traditional lotus pattern, reflecting the bold innovation in the design of Sui Dynasty art, perfectly integrating animal elements with the lotus pattern, creating an imaginative visual effect. From the Northern Qi period to the Sui Dynasty, the lotus patterns shifted from being dominated by religious symbols to being decorative and paradigmatic, reflecting the trend of localization and standardization. The number of petals increased to 8-12, and began to integrate honeysuckle patterns and animal patterns (such as "Three Rabbits with Common Ears"), with an increased complexity of structure (single-petal line nodes reached 15-20); later, the lotus pattern in Cave 217 of the Mogao Caves incorporated realistic elements under the influence of the Tang Dynasty style. The petals were depicted delicately and realistically, with a beautiful and natural shape, showing the full and lively posture of a real lotus. It created a dynamic and vibrant picture, presenting the characteristics of "realism + paradigmization", with the number of petals remaining stable at 10-14, the line nodes being fine (20-30), and forming a fixed structure of "center lotus + peripheral auxiliary patterns". As shown in Figure 1d, it also reflects the open and inclusive, and innovative characteristics of Tang Dynasty art.

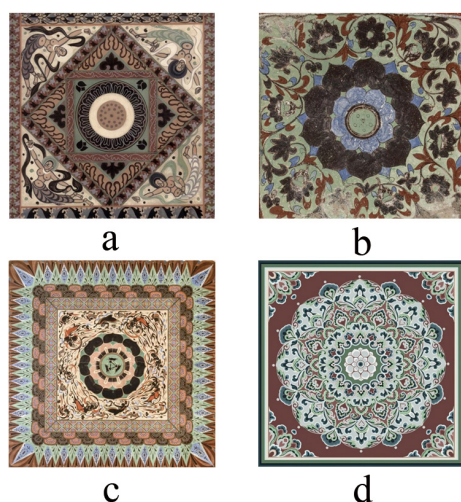


Figure 1. Four different patterns of lotus flowers from different periods.(a)The 272nd cave of the Mogao Caves during the Northern Qi Dynasty;(b)The 390th cave of the Mogao Caves in the late Sui Dynasty;(c)The 407th cave of the Mogao Caves in the Sui Dynasty;(d)Mogao Caves No. 217

In terms of the color system, it showcases visual expressions ranging from religious symbolism to multiculturalism. A basic and serious characteristic was shown in the lotus patterns of the early years. The lotus design in Cave 272 of the Mogao Caves, depicted in Figure 2a, predominantly showcased earth red and stone green, while exhibiting a limited range of colors and an overall simple, serious tone. When it came to the latter, the contrast got somewhat outdated. The earth red established a stable tone, while the colors like stone green served as embellishments, with a strong color contrast, highlighting the sacredness of the lotus, which was in line with the solemn and dignified atmosphere of early Buddhist art. Unlike the simplicity of the early period, the lotus pattern in Cave 329 of the Mogao Caves was during the Tang Dynasty, and the color spectrum was more rich and bright. As shown in Figure 2b, a large number of azure, cinnabar, and stone green colors were used, with high color saturation and a lively and bright tone. During the drawing process, attention was paid to color gradation and transition, making the lotus present a three-dimensional and vivid visual effect, highlighting the splendid style of art during the prosperous Tang Dynasty. Later, the lotus pattern turned into a luxurious and stable color style. The pattern of five lotus clusters and peacock in Cave 61 of the Mogao Caves mainly used orange and yellow as the main colors, supplemented by blue and green. As illustrated in Figure 2c, the orange and yellow hues exude nobility and magnificence, while the green adds balance to the overall palette. This combination showcases a luxurious and refined character, all while creating a stable and grand atmosphere. It emphasizes the multicultural aspect of the fusion between Chinese and foreign cultures, reflecting the legacy and evolution of color usage in the art of the Five Dynasties period, ultimately resulting in a distinctive decorative style.



Figure 2. The color system of the lotus patterns in the Mogao Caves:(a)The lotus pattern in Cave 272 of the Mogao Caves;(b)The lotus pattern in Cave 329 of the Mogao Caves;(c)The lotus pattern in Cave 61 of the Mogao Caves

Traditional techniques reflect the gradual development from simple outlines to sophisticated and diverse skills. In the early period, only simple outlines were used to depict lotus patterns, as shown in Figure 3a. The early lotus pattern drawing technique in Mogao Cave 272 was simple, mainly using uniform thick and thin lines to outline the contours, and then applying flat colors. The lines lacked obvious variations, and the color filling was smooth, focusing on expressing the basic shape of the lotus, reflecting the simple characteristics of the early painting techniques. By the Sui Dynasty, Mogao Cave 390, as shown in Figure 3b, the drawing technique had made significant progress. The lines became more smooth and dynamic, and began to pay attention to the changes in thickness and density of the lines to express the shape and texture of the lotus. In terms of color expression, simple diffusion techniques appeared, enhancing the three-dimensionality of the lotus, reflecting the development process from simplicity to maturity of the techniques, and the painters' higher pursuit of expressing the shape of the object. Later, the lotus patterns in Mogao Cave 217 of the Tang Dynasty reached a highly skilled level. As shown in Figure 3c, fine lines were used to depict the texture and veins of the petals, and the color diffusion was natural and soft, with fine transitions. At the same time, techniques such as powder coating and gold leaf application were adopted, making the lotus patterns more golden and splendid, enhancing the layering and texture of the picture, and reflecting the superb painting skills of the Tang Dynasty and the extreme pursuit of decorative effects. In addition, the lotus patterns in Mogao Cave 311 of the Tang Dynasty had some innovations based on the techniques of the Tang Dynasty. As shown in Figure 3d, in addition to continuing the fine lines and rich color diffusion, the lotus transformed into a child figure in a modular combination form, with unified postures but diverse details, forming a visual rhythm through repetitive arrangement, reflecting the simplification processing of complex images and large-scale production capacity by the artisans of the Sui Dynasty.

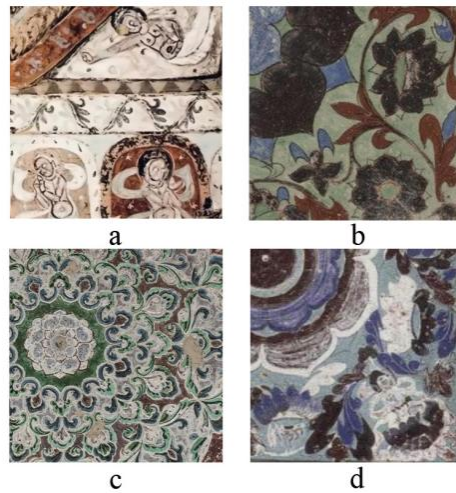


Figure 3. Detail illustrations of lotus patterns in the Mogao Caves at different periods:(a)Mogao Caves No. 272;(b)Mogao Caves No. 390;(c)Mogao Caves No. 217;(d)Mogao Caves No. 311

4.2. Analysis of existing digital applications of Dunhuang lotus patterns

In the era of digitalization, the inheritance and dissemination of the Dunhuang lotus pattern have been facilitated through various digital applications, presenting a new trend of integrating tradition and modernity. However, from the analysis of cases such as the design of Dunhuang floral jewelry by the Chang Shana team, the design of notebook and scarf patterns in Dunhuang cultural products, the dynamic images of Dunhuang patterns at the 2025 Osaka World Expo, the online digital exhibition of the Dunhuang Academy, and the "Digital Dunhuang" database, the current digital applications have certain limitations. Static digital applications mainly focus on the replication and static transformation of the pattern, applying the Dunhuang lotus pattern to modern daily items. The Chang Shana team, with their profound artistic skills, precisely replicated the shape and color of the lotus pattern using vector technology, allowing the ancient Dunhuang lotus pattern to showcase its unique charm in modern jewelry design. For example, a new gold jewelry piece inspired by the canopy pattern from Cave 321 of the Tang Dynasty mural was designed, using 18K gold, enamel, emeralds, and freshwater pearls to restore the color characteristics of the golden and green decorations and the alternating tones of red and brown in the Dunhuang murals, achieving a relatively realistic presentation of the traditional pattern on modern materials. The design of notebooks and scarves in Dunhuang cultural products is the same. Taking the design of the Dunhuang Flying Heaven series of scarves as an example, using high-quality silk fabric, through meticulous printing and embroidery techniques, the flying heaven elements including the lotus pattern are presented on the scarf. To a certain extent, it realizes the combination of traditional patterns and modern daily items.

However, such applications also have obvious shortcomings. In the design process, they mostly "directly appropriate" the lotus pattern. In jewelry design, they do not fully consider the characteristics of different jewelry materials, such as the brilliant cutting of diamonds and the warm texture of jade, on the effect of pattern presentation, as well as the coordination of the pattern with human body dynamics and clothing combinations in the jewelry-wearing scenarios; in textile design, they do not combine the texture and drape of the fabric for innovative design, and do not deeply explore the cultural connotations contained in the lotus pattern, merely using it as a decorative pattern, failing to effectively convey the deep value of Dunhuang culture to consumers.

In addition, dynamic digital dissemination is represented by the dynamic images of Dunhuang patterns at the 2025 Osaka World Expo and the online digital exhibition of the Dunhuang Academy. Using advanced technologies such as animation and 3D modeling, static lotus patterns are transformed into dynamic visual content. In the Chinese Pavilion of the Osaka World Expo, the large-scale multimedia dynamic images led by Chang Shana, featuring the themes of the 24 solar terms, present classic images such as Dunhuang Bodhi Flower and lotus through three-dimensional animation engine technology and real-time rendering technology, and use AI to precisely calculate the fusion of mural lines and 24 solar term images, providing viewers with an immersive viewing experience, greatly enhancing the interest and dissemination of the pattern, attracting the attention of a large number of young people. The online digital exhibition of the Dunhuang Academy uses VR and 3D modeling technologies to allow viewers to break through time and space limitations and enjoy the lotus patterns in the caves, expanding the scope of cultural dissemination.

However, such applications have deficiencies in scene adaptability. The dynamic effects mostly adopt universal designs, without being optimized specifically for the fast-paced and fragmented dissemination characteristics of short-video platforms, as well as the depth and coherence requirements of online exhibitions for content. For example, in short-video platforms, complex and lengthy dynamic displays cannot quickly capture the attention of viewers; in online exhibitions, there is a lack of dynamic connection of logical relationships between different exhibits. At the same time, the modular decomposition of the lotus pattern is not systematic enough. It is difficult to flexibly adjust under different screen sizes (such as mobile phones, tablets, and computers) and different interaction requirements (touch, mouse click, voice control), affecting the user experience. Furthermore, the digital education and research applications are centered around the "Digital Dunhuang" database constructed by the Dunhuang Academy. This database includes high-definition images and basic information of some lotus patterns, providing great convenience for academic research. It enables scholars to break through the limitations of on-site investigations and obtain a large amount of precious research materials, promoting the development of academic research related to the lotus patterns of Dunhuang. However, from a broader perspective of dissemination, this database has certain drawbacks. It focuses on the archival function of cultural relics, but for the general public, it lacks understandable interpretation content, making it difficult to arouse the public's interest in and desire for in-depth understanding of the lotus patterns of Dunhuang. Moreover, the database has not established a standardized pattern data system, and for information such as the shape (such as the number of petals, quantitative indicators) and color (tone, saturation, etc.) of the lotus patterns, it has not presented them quantitatively. This makes it hard to reuse these data in the design field, unable to meet the designers' need for precise data, resulting in their strong professionalism but low popularity, and limiting the dissemination and application of the lotus patterns of Dunhuang in a wider range of fields.

In conclusion, the current digital applications generally have problems such as "overemphasizing technology and neglecting culture", "overemphasizing form and neglecting adaptation", and "overemphasizing a single link and neglecting system construction". There is an urgent need to build a more scientific inheritance strategy based on the evolution rules of patterns.

5. Discussion and discovery

5.1. The evolution rules of Dunhuang lotus patterns and their implications for digital preservation

This study conducted a digital deconstruction and reorganization practice on the Dunhuang lotus patterns of 10 typical caves. The core findings include the following three aspects: Firstly, it identified the quantitative evolution patterns of the lotus patterns from the early period to the Tang Dynasty, clarifying the phased characteristics of the number of petals, element integration, and structural complexity, providing a basis for standardized inheritance; Secondly, it established a quantifiable color digital system, revealing the evolution trajectories of color types, saturation, and matching logic in different periods; it can serve as the core standard for building a digital archive library, ensuring the accuracy of inheritance. Thirdly, cultural connotation is the core of digital innovation: from religious symbolism to decorative function evolution, it indicates that the patterns have always carried the cultural connotations of the times. Digital application should avoid formal replication and should deeply explore and convey its cultural value. The style adjustments of the patterns in different dynasties reflect their adaptation to the aesthetic demands of the times. Digital inheritance needs to combine modern digital scenarios (such as social media, interactive interfaces) and audience preferences to achieve a balance between tradition and modernity.

5.2. Digitalization inheritance strategy system of Dunhuang lotus pattern

In the construction of the digital inheritance strategy system, a closed loop needs to be formed from three dimensions: protection, dissemination, and innovation, to achieve precise preservation, effective transmission, and dynamic transformation of the cultural value of Dunhuang lotus patterns. At the digital protection level, the core is to build a standardized digital archive: based on the quantitative data of 10 typical cave patterns, establish a "pattern information card" for each pattern that includes information such as dynasty, cave number, shape data (number of petals, line nodes, proportion relationship), color data (color values RGB/CMYK, saturation, proportion), technique analysis, cultural symbolism, etc., to ensure the complete preservation of cultural details; the technical storage adopts a multi-format scheme of "AI vector files + high-definition images + 3D models", taking into account the editability and restorability of the patterns, and relying on cloud storage technology to achieve the openness and scalability of the archive, supporting the continuous supplementation of new pattern samples in the future.

At the digital dissemination level, the key is to create a scenario-based content matrix, improving the dissemination efficiency through "scenario design + audience adaptation": in the scenario content design, develop 15-second pattern evolution animations, simplified pattern emojis, etc., for social media such as Douyin and Xiaohongshu, design original environment restoration of cave lotus patterns combined with VR technology for online exhibitions such as virtual exhibition halls, and create micro-lessons on pattern evolution, interactive knowledge quizzes, etc., for educational platforms, for professional researchers to open the complete data access rights of the archive, for the general public to interpret the cultural connotations of the patterns through visual design, and for teenagers to develop interactive games such as pattern coloring and puzzle to enhance interest.

At the digital innovation level, it is necessary to adhere to the core principle of "cultural core + digital form", through theoretical framework construction and method guidance to achieve innovation implementation: on the one hand, from the theoretical level, construct a pattern module disassembly system, break down lotus patterns into "core modules" (such as single petals, flower

buds), "combination modules" (such as lotus + honeysuckle, lotus + three rabbits with common ears), and "decorative modules" (such as borders, background patterns), clearly defining the cultural connotations and applicable scenarios of each module, providing theoretical guidance for innovative design; on the other hand, form cross-scenario adaptation methods, emphasizing the restoration degree of pattern shapes and colors in graphic design such as posters and book bindings, focusing on the dynamic responsiveness of patterns in interactive design such as web pages and APP interfaces, and innovating expression forms for digital media art such as dynamic images and game scenes by combining AI generation and other technical characteristics, allowing traditional patterns to regain vitality in the digital era.

6. Conclusion

The lotus patterns used in Dunhuang ten typical caves were the main subjects of this study. Through methods such as image comparison and style analysis, it explored the historical evolution characteristics of these patterns: in terms of form, they evolved from the early pointed-lipped lotus (with strong religious symbolism) to the middle period when they incorporated Chinese aesthetic elements (with a prominent decorative function), and finally to the late period when they became standardized (combining both aesthetic and practical aspects); in terms of color, it ranged from the simplicity of the Northern Dynasties to the richness of the Tang Dynasty, and then to the elegance of the Song, Yuan, and Qing periods, becoming more diverse with the development of time and technology; in terms of techniques, they progressed from simple line drawing to the use of complex techniques.

Based on the reflection of current digitalization practices, this study points out that there are issues such as technological disconnection from culture, lack of contextual adaptation for the outcomes, and awkward symbol appropriation. Therefore, it constructs a three-in-one strategy of "digital protection - dissemination - innovation": establishing a standardized digital archive, creating a scenario-based dissemination matrix, and prioritizing cultural core in the innovation integration. The innovation in the paper is in the quantitative analysis of the development characteristics of patterns and the creation of an operational digital inheritance strategy. In the future, the sample scope will be expanded, and the practice will be deepened by combining emerging digital technologies to help with the dynamic inheritance of patterns.

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