



Design of Tang Dynasty Bronze Mirror Patterns for Cultural and Creative Products Integrating Extensible Semantics and Shape Grammar

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Abstract. This paper explores the application of traditional Chinese decorative patterns in product design, pointing out that designers often overlook the complex semantics contained in these patterns, which results in a disconnection between products and their original cultural meanings. To address this issue, based on relevant theoretical foundations in semantic analysis and formal design theories, a design method integrating extension semantics and shape grammar is proposed, with the patterns on the bronze mirrors of the Tang Dynasty taken as a case study. Firstly, the pattern primitives of the bronze mirror and their semantics are extracted and selected. After that, the semantics of the bronze mirror patterns are analyzed. Specifically, the characteristic words in the maximum extension semantic interval are identified, and diagrammatic analysis is carried out on them. Based on this, the optimal diagram in the extension interval is selected as a design reference. Subsequently, shape grammar is used to conduct deductions and reconstruction designs on the diagrammatic graphics. Finally, drawing on existing evaluation standards in cultural product design, a design scheme excellence evaluation system covering aspects such as cultural connotations, pattern innovativeness, and visual attractiveness is established to select the best design scheme and create a variety of cultural and creative products. This research aims to explore the cultural semantics of the patterns on the bronze mirrors of the Tang Dynasty, transform them into designs, revitalize cultural heritage, and promote the sustainable development of traditional Chinese culture.

Keywords: Bronze mirror patterns, Pattern primitives, Extensible semantics, Shape grammar, Cultural and creative product design.

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1 INTRODUCTION

The cultural and creative industries, as an emerging sector, have attracted widespread attention in recent years. Statistics show that the global cultural and creative industries have become a significant engine for economic growth in many countries and regions, with the market size continuously

expanding and output value increasing year by year [1,2]. In China, the market size of cultural and creative products has also exhibited steady growth, reaching 16.38 billion USD in 2023, a year-on-year increase of 13.09% [3,4]. As public demand for cultural products and experiences rises, cultural and creative products based on existing cultural resources meet consumers' aesthetic needs and carry the cultural dissemination mission.

Chinese traditional culture has amassed over a millennium, evolving and enriching throughout history. Tang Dynasty bronze mirrors, being an essential component of this cultural heritage, represent another peak after the Han Dynasty. During this period, the integration of ethnic culture and economy led to the diversification of Tang culture, causing changes in the designs of bronze mirrors, which took on new forms [5,6]. Bronze mirrors were not only practical grooming tools in ancient times but also exquisite works of ancient Chinese bronze and metal craftsmanship [7,8]. Their patterns were intricately designed, diverse in form, and rich in meaning. For example, the ribbon attached to the mirror knob symbolizes reunion, harmony, and unity, embodying the essence of traditional Chinese culture and spirit. According to the ancient principle that "images must have meaning, and meaning must be auspicious," the designs on Tang Dynasty bronze mirrors carry rich cultural and symbolic significance. Rooted in the colorful daily life and having a solid mass base, the patterns on bronze mirrors exhibited unique artistic vitality on this fertile ground.

However, due to the diversity in modern society's politics, economy, culture, and art and the richness of people's daily lives, the once vibrant bronze mirrors have been gradually overlooked. The patterns behind these mirrors have not received sufficient attention and are no longer able to meet the aesthetic needs of contemporary society. As a result, Tang Dynasty bronze mirrors and their cultural attributes are facing the risk of losing attention and heritage. Hence, it is crucial to find a way to rejuvenate the cultural significance of Tang Dynasty bronze mirrors.

Currently, significant progress has been made in the academic research on bronze mirrors and their patterns, and the application of traditional Chinese patterns in modern design is gradually maturing. However, in the research of pattern redesign, there are still some deficiencies [9,10]. For instance, many studies have not effectively quantified the cultural connotations or established a comprehensive method for integrating with modern design. In the process of pattern redesign, designers often focus too much on aesthetics, neglecting the in-depth exploration and presentation of the cultural connotations behind these patterns. Most cultural and creative products in the market simply replicate the patterns from cultural relics without fully exploring the relationship between culture and modern society or daily life, resulting in an insufficient understanding of their cultural significance [11]. Designers tend to rely more on subjective experience in their creations, lacking implicit research perspectives and quantifiable research methods. Therefore, this study proposes a design approach for traditional pattern-based creative products that integrates extendable semantics and shape grammar. Through both qualitative and quantitative scientific diagrammatic analysis, it offers a new method applicable for cultural extraction and solution evaluation.

This method extracts representative primitives and feature lexicons from the patterns of bronze mirrors, and combines diagrammatic semantics to make implicit elements explicit. Cultural characteristics are then assessed based on the primitive models, resulting in quantifiable relationships within the extendable range. Additionally, the optimal design solutions are selected through a goodness evaluation method within the extendable innovation framework, ultimately verifying the feasibility of incorporating implicit cultural elements from bronze mirrors into the design of cultural and creative products. Farsani et al. emphasized the significance of cultural identity restoration and protection in cultural sustainability [12]. This aligns with our study's objective of incorporating the implicit cultural elements of Tang Dynasty bronze mirrors into cultural and creative products, thereby promoting the inheritance and sustainable development of traditional culture. This method not only provides practical solutions to issues in cultural product design but also offers a theoretical foundation for the modernization of traditional culture, promoting the diversified development of Tang Dynasty bronze mirror patterns in the cultural and creative product sector. Furthermore, the integration of extensible semantics and shape grammar inherently enhances the aesthetic value of designs. By systematically analyzing and recombining pattern elements, this

method ensures that the derived motifs maintain a harmonious balance between traditional symbolism and modern visual appeal, thereby aligning with contemporary aesthetic preferences while preserving cultural authenticity. As a result, it enhances the quality of cultural products and public satisfaction, achieving the goal of sustainable development.

2 LITERATURE OVERVIEW

2.1 Cultural and Creative Product Design Based on Bronze Mirror Patterns

Currently, research on Tang Dynasty bronze mirror patterns primarily focuses on the theoretical discussion of the decorative features, while studies and practices related to cultural and creative product design are still in the early stages [13-16]. In the past, the main issue with the application of traditional patterns was the tendency to use them directly or with minimal alterations, lacking exploration and re-creation of the deeper meanings and connotations embedded in the patterns. With the advent of the new era, the application of traditional patterns has been profoundly influenced by modern design concepts. The forms of pattern variation have become increasingly diverse, and thinking patterns have become more pluralistic and flexible. Zhao Qin et al. proposed that the transformation and innovation of Tang Dynasty bronze mirror patterns could effectively convey the unique charm of Chinese culture to modern cultural and creative products [17]. Li Zhixuan and Ye Hui emphasized that as cultural symbols, Tang Dynasty bronze mirror patterns not only enhance the artistry of modern packaging designs but also meet consumer demands for cultural depth [18]. Dai Rao explored the application of Tang Dynasty bronze mirror patterns in modern interior design, arguing that combining traditional patterns with modern design languages can add cultural flavor to interior spaces and improve residents' satisfaction with their living experiences [19]. Through innovative design, Tang Dynasty bronze mirror patterns not only preserve their unique artistic characteristics but also integrate organically with modern living environments. Tian Jing studied the innovative application of Tang Dynasty bronze mirror plant patterns in modern jewelry design, highlighting that these patterns possess unique rhythm and grace, aligning with the modern trend of personalized aesthetics [20]. Jing Nan et al. took the Dunhuang cultural and creative product design as an example and proposed three levels of metaphor: representational, operational, and emotional experience metaphors [21]. They clarified the mapping method from the product's source domain to its cultural goals, which was successfully applied to the design of Dunhuang cultural and creative products.

As an important component of Chinese traditional art, Tang Dynasty bronze mirror patterns have gradually transformed from historical relics into a source of inspiration for modern design. These patterns have demonstrated strong vitality and artistic value in packaging design, interior design, and even jewelry design. However, current bronze mirror pattern designs often focus on explicit cultural factors. When expanding and creatively combining pattern elements, designers usually extract, reorganize, and reinterpret the cultural symbols to endow design elements with cultural features. Yet, they often overlook the deeper meanings implied by cultural heritage. This design approach lacks quantifiable scientific research methods such as analysis, illustration, and evaluation, making it difficult to effectively convey the connotations of culture. Moreover, in the process of extracting and representing cultural elements, there exists a certain degree of ambiguity, leading to an insufficient expression of the cultural connotations in the designed products.

2.2 Design Method Based on Extensible Semantics

In 1956, British philosopher Karl Polanyi distinguished tacit knowledge from explicit knowledge, which laid the foundation for understanding and developing the design process. In 1957, American psychologist Charles E. Osgood and his colleagues introduced the Semantic Differential Scales to measure the evaluative intensity and meaning of objects or concepts. Since its introduction, the Semantic Differential Scales have been widely used in various fields such as marketing research and user experience evaluation to quantitatively analyze the perception and attitude of consumers or

users towards specific objects or concepts. Extensible semantics is an innovative design method within the theory of extensible innovation. It explores the extensible elements through quantitative methods and integrates diagrammatic thinking, becoming an important bridge for communication between natural and social sciences [22-24].

Many scholars have made efforts in applying extensible semantics and related methods in diverse design fields. Lee [25] conducted a comparative study on product color and emotional expression using the Semantic Differential Method, achieving the optimization of color and integration with product design. Tong et al. [26] addressed the common issues of ambiguity and uncertainty in product design, introduced the extensible transformation method for innovative design and validated its effectiveness. Duan Jinjuan et al. [27] used the extensible semantics analysis method to extract elements and characteristics from intangible cultural heritage, established an extensible semantic representation model. Although Duan Jinjuan et al.'s method demonstrated feasibility in the specific case of electric vehicle charging station shape design, its generalization to other design scenarios remains to be further explored. Chen Xiang et al. [28] discussed the application of the extensible semantics product design method, transforming cultural features into cultural factors to optimize the shape design of smart products. Li Weili et al. [29] combined extensible semantics with fuzzy comprehensive evaluation to study the exterior design of subway trains. Xu Zejun [30] clarified how to effectively integrate the deep symbols and spiritual connotations of traditional culture into modern cultural products by combining systematic analysis of cultural elements with extensible semantics. Furthermore, scholars have applied extensible theory to optimize design methods in various fields, such as patent product innovation design [31], autonomous vehicle interior design [32], and elderly medical bed design [33], resolving contradictions and complex problems in design, enabling quantitative analysis, greatly enhancing the objectivity and process flow of the design process, and significantly improving design efficiency.

In summary, the extensible semantic theory has shown significant application value in the field of design, and its core is reflected in its ability to systematically solve complex design problems. First, the theory makes implicit knowledge explicit through quantitative analysis tools, effectively resolving the ambiguity and uncertainty that are prevalent in the design process; second, the theory resolves the multi-dimensional contradictions in design through interdisciplinary integration (such as the bridge role of natural sciences and social sciences), which can significantly improve the objectivity and efficiency of the design process and enable complex contradictions to be quantitatively resolved; although the cross-scenario applicability of some cases still needs to be explored, its unique value in knowledge explicitness, cultural translation, process optimization, etc. has become an important theoretical tool to promote design innovation.










2.3 Tang Dynasty Bronze Mirror Patterns and Cultural Connotations

"The ancient Silk Road stretched thousands of miles and endured for millennia, embodying the spirit of peace and cooperation, openness and inclusiveness, mutual learning, and mutual benefit—core values that form the essence of the Silk Road spirit. This is a priceless legacy of human civilization" [34]. The Tang Dynasty, as a critical juncture in the history of the Silk Road, witnessed a period of cultural diversification fostered by the integration of different ethnic groups. Bronze mirrors, which were a representative art form of the Tang Dynasty, vividly reflected the flourishing craftsmanship and cultural splendor of the time. Rooted in the traditional Chinese philosophy of "vessels as carriers of morality," Tang Dynasty bronze mirrors encapsulated profound spiritual values, elevating their pattern design, cultural connotations, and aesthetic expression to unprecedented heights.

In terms of form, Tang dynasty bronze mirrors broke traditional limitations and introduced various new mirror shapes, such as diamond-shaped, square, hexagonal, and octagonal mirrors. These innovative shapes not only showcased craftsmanship advancements but also reflected the diversity of societal aesthetics and culture at the time. Simultaneously, the design of Tang dynasty bronze mirror patterns incorporated more everyday elements, highlighting the prosperity and multicultural nature of Tang society. Regarding craftsmanship, techniques such as mother-of-pearl inlay, gold and silver beating, painted lacquer inlay, and flat repoussé were introduced. These innovations not only enhanced the artistic value of the bronze mirrors but also reflected the economic

prosperity and cultural richness of the era, symbolizing societal affluence and the peaceful lives of the people.

As for the patterns, Tang dynasty bronze mirror motifs covered various aspects of social life, with a greater emphasis on realism. The patterns were diverse, vivid, and dynamic. These designs not only inherited traditional artistic styles but also absorbed foreign artistic influences, creating a distinctive and unique form of artistic expression [35-38]. The main types of patterns include plant patterns, animal patterns, narrative patterns, daily life patterns, and religious patterns, as shown in Table 1.

<i>Category</i>	<i>Subject Matter</i>	<i>Pattern Examples</i>	<i>Cultural Connotations</i>
Animal Patterns	Four Divine Beasts		The Four Divine Beasts are often regarded as protective symbols, symbolizing the harmony of heaven and earth and the balance of the universe. They imply protecting the household, safeguarding the country, warding off evil spirits and ensuring peace.
	Dragon		The dragon is a symbol of good fortune in traditional Chinese culture. It is usually associated with power, nobility, majesty, longevity and good luck. It is closely linked to the stability, prosperity and strength of the country.
	Suanni (a mythical beast resembling a lion)		Suanni is a divine beast similar to a lion. It often appears as a guardian deity in temples and palaces. Its image is usually sitting or lying down while remaining vigilant, conveying a sense of majesty and strength. It symbolizes wisdom, divinity and the protection of the Dharma.
	Mandarin duck		The mandarin duck symbolizes love and fidelity in Chinese culture, representing harmonious marriages and conjugal fidelity. Featured in wedding-related relics, it conveys blessings for enduring love and marital happiness.
	Peacock		The peacock is known as the "King of Birds". It is also an auspicious bird symbolizing wealth, prosperity and peace. The white head of the peacock also symbolizes the deep affection between husband and wife, growing old together and remaining faithful to love.
	Luan and Feng (mythical birds similar to phoenixes)		The luan and feng are legendary divine birds. They are often regarded as symbols of beauty, nobility and kingship. The luan and feng usually represent good fortune, longevity, power and prosperity. They are often used as symbols of kingship and marital happiness.
Plant Patterns	Grape Pattern		The grape motif symbolizes wealth and prosperity through its fertility and abundance, and was used in Tang dynasty court designs to wish for family prosperity and material harmony, reflecting the elite's desire for success and blessings.
	Lotus		The lotus symbolizes purity, wisdom, and transcendence in Chinese culture, reflecting Buddhist enlightenment and untainted character. Its pattern on Tang mirrors embodies spiritual purity and inner wisdom.
	Peony		The peony, the "king of flowers," symbolizes wealth, honor, and prosperity in Chinese culture. Its large, vibrant blossoms represent national flourishing and personal nobility. On Tang dynasty mirrors, the pattern reflects

	Chrysanthemum		aesthetic preferences, signifies social status, and embodies cultural pride, mirroring the era's vibrancy and success. The chrysanthemum symbolizes resilience, longevity, and nobility in Chinese culture, blooming in autumn to embody endurance and virtue. Its pattern on Tang mirrors signifies prayers for health, strength, and integrity, merging natural aesthetics with cultural reverence for vitality and long life.
	Baoxianghua		The Baoxianghua, a Buddhist symbol of enlightenment and universal wisdom, blends lotus, peony, and pomegranate elements, reflecting Tang dynasty's cultural synthesis. Its circular design on mirrors signifies unity, spiritual harmony, and inclusivity of diverse traditions, merging religious reverence with artistic innovation.
Narrative Patterns	Moon Palace Pattern		The Moon Palace Pattern symbolizes cosmic harmony, transcendence, and longevity through lunar myths like Chang'e, embodying purity, cyclical life, and balance. In Tang art, it visually merges spiritual beliefs with aspirations for completeness and familial unity, reflecting cultural reverence for the moon's mysteries.
	High Scholar Mirror		The carefree hermit was a unique cultural symbol in ancient China. The noble character, elegant taste and detached way of life represented by the hermit were an ideal pursuit of intellectuals in the feudal society.
Daily Life Patterns	Playing Polo		Playing polo was a very popular sport in the Tang Dynasty. People from the imperial court to the common folk all loved this sport. The polo pattern conveyed the admiration of Tang Dynasty society for courage, strength and noble demeanor.
	Hunting		Hunting mirrors, like polo mirrors, were favored activities among the people in the Tang Dynasty, especially among the ruling class. In hunting mirrors, four knights are symmetrically arranged around the inner area, and their images are very vivid.
Religious Patterns	Eight Trigrams		In the bronze mirrors of the Tang Dynasty, the pattern of the Eight Trigrams was frequently employed as a symbol for warding off evil spirits and ensuring security. It boasted a strong sense of mystery and philosophical profundity.
	Wan (Swastika) Pattern		The Wan Pattern in Tang mirrors symbolizes Buddhist and Chinese cultural ideals of eternity, harmony, and prosperity. Its repetitive, balanced design conveys auspicious wishes for happiness, wisdom, and spiritual protection, reflecting Tang cultural values and the seamless integration of faith into daily life.

Table 1: Themes and contents of the patterns on bronze mirrors in the tang dynasty.

3 RESEARCH METHODS

3.1 Cultural and Creative Product Design Based on Bronze Mirror Patterns

Extension semantics, based on the matter-element theory of Extenics and combined with graphic thinking, is an innovative method for generating a symbolic expression form to describe the nature of things. Researchers mainly focus on industrial design, emphasizing the in-depth exploration of the semantic features of product modeling, so as to extract and transform them and achieve an effective

combination of qualitative and quantitative aspects [24]. Moreover, currently, this method is gradually being applied in graphic design as well. By leveraging the symbolic nature of culture and interpreting it from both implicit and explicit aspects, it can analyze the implicit connotations of cultural features in a relatively scientific and standardized manner, model complex things, and thus optimize the solution of problems.

Therefore, by applying the innovative method of extension semantics to the redesign of the patterns on bronze mirrors in the Tang Dynasty and proposing the extension design method for bronze mirror patterns, a series of creative patterns with cultural connotations are expected to be generated while protecting traditional Chinese culture. Aesthetic considerations are integrated at each stage of this method. For instance, during the shape grammar deduction phase, principles of contrast, repetition, and unity are applied to ensure that the reconstructed patterns achieve visual coherence and dynamic expression. Additionally, the selection of the optimal diagram in the extension interval prioritizes designs that maximize both semantic relevance and aesthetic impact, as evaluated through criteria like compositional harmony and stylistic innovation. These patterns can then be applied to the design of cultural and creative products to better achieve the inheritance of culture. The flowchart of its design method is shown in Figure 1.

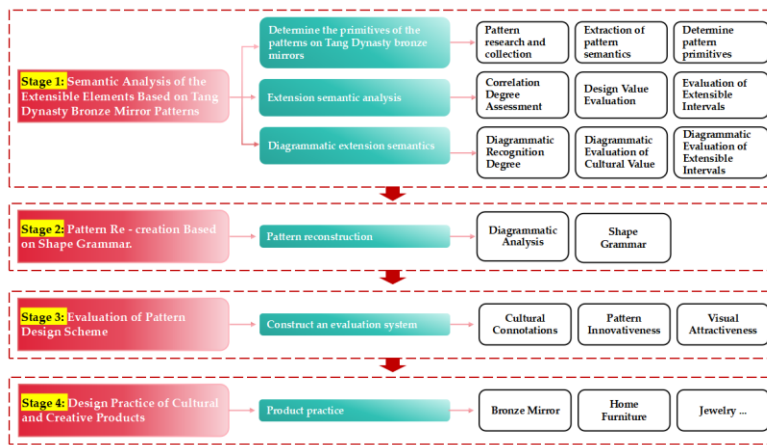


Figure 1: Design process of cultural and creative products with Tang Dynasty bronze mirror patterns integrating extension semantics and shape grammar.

3.2 Cultural and Creative Product Design Based on Bronze Mirror Patterns

3.2.1 Pattern Primitive Selection

In the framework of the extension semantic design method, the selection of pattern primitives holds a pivotal position. Pattern primitives are defined as the fundamental forms and elements constituting a pattern, encompassing lines, shapes, motifs, and symbols. Tang Dynasty bronze mirror patterns are composed of a diverse range of such primitives. For the implementation of design practice, an exhaustive analysis of Tang mirror patterns must be initiated initially to pinpoint their core elements and prevalent structures. The objective of this step is to gain a profound understanding of the basic constituents and recurring patterns within the patterns. Suppose n scholars who are well-versed in the patterns of bronze mirrors in the Tang Dynasty and related historical and cultural knowledge are invited to evaluate pattern primitives. If the evaluation score given by the i -th scholar for the j -th pattern primitive is a_{ij} , then the average score $\overline{O_j}$ of this pattern primitive can be calculated by the following equation [39]:

$$\overline{O_j} = \sum_{i=1}^n a_{ij} / n, i \in [1, n], j \in [1, m] \quad (1)$$

Calculate the evaluation scores of each pattern according to Equation (1), and finally determine the target pattern primitives.

3.2.2 Semantic Analysis of Pattern Primitives

According to the Extension Theory, the connotations of design elements can be defined as specific values and features, which is of practical significance for understanding and analyzing. Taking the design of the Baoxianghua pattern as an example, the quantitative relationship among its cultural connotation P , cultural carrier O , characteristic words C , and extension interval V is constructed as follows:

$$P = [O, C, V] \quad (2)$$

When there are multiple characteristic words for pattern primitives, Equation (2) can be expanded in multiple dimensions, that is:

$$P = [O, C, V] = \begin{bmatrix} O & C_1 & V_1 \\ & C_2 & V_2 \\ & \dots & \dots \\ & C_n & V_n \end{bmatrix} \quad (3)$$

In Equation (3), the semantic extension interval V is decomposed into V_x and V_y . Here, V_x is used to describe the degree of association between the pattern and the semantic characteristic word C , $V_x \in (0, 1]$. The closer the value of V_x is to 1, the stronger the association between the characteristic word and the pattern. Let the score interval for each characteristic word be $[1, \alpha]$, the number of evaluators be β , and the number of evaluators who gave a score of a to a particular characteristic word be d_a . The expression for the mean value of V_x is:

$$\overline{V_x} = \frac{\sum_{a=1}^{\alpha} a d_a}{\beta \cdot \frac{\alpha(\alpha+1)}{2}}, a \in [1, \alpha], d_a \in [1, \beta] \quad (4)$$

V_y represents the cultural semantic connotation of the characteristic word in the product appearance design. The larger its value is, the higher the cultural semantic connotation of the characteristic word in the product appearance design. Suppose the score given by the n -th evaluator for the cultural connotation of the characteristic word is b_n , then the expression for the mean value of V_y is:

$$\overline{V_y} = \frac{\sum_{n=1}^{\varphi} b_n}{\varphi}, b_n \in [1, \theta], n \in [1, \varphi] \quad (5)$$

The extension interval V of the pattern primitives of bronze mirror patterns is:

$$V = \overline{V_x} \cdot \overline{V_y} \quad (6)$$

The larger the value of V in Equation (6), the higher the degree of association between the characteristic word and the cultural semantic connotation, and it should be preferentially selected in design applications.

3.2.3 Semantic Graphic Analysis of Pattern Primitives

Conduct semantic graphic analysis on the characteristic words of bronze mirror patterns, and denote it with h . Suppose the extension interval of the graphic is V_h , and further decompose V_h into V_{h_x} and V_{h_y} , where V_{h_x} represents the recognition degree of the graphic, and V_{h_y} represents the design value of the graphic. Then the expression for V_h is:

$$V_h = \overline{V_{h_x}} \cdot \overline{V_{h_y}} \quad (7)$$

In Equation (7), the larger the value of V_h , the higher the recognition degree of the graphic, and the more its cultural value can be reflected in the design.

3.3 Shape Grammar

Shape Grammar is a design method that employs specific graphical rules for derivation. This approach was first proposed by George Stiny and James Gips, professors at the Massachusetts Institute of Technology. According to the theoretical definition, the equation is given as $SG = (S, L, R, I)$, where SG represents the set of shapes obtained under specific derivation rules, S is the initial set of shapes, I is the finite set of labels, R is the set of derivation rules, and I is the initial shape [40]. This method not only maintains design consistency but also preserves the core concepts and aesthetic characteristics of the design throughout the innovation process.

Common shape rules encompass a series of operations, namely zoom command, mirror command, copy command, rotate command, staggered cut command Bezier curve command and substitution command the process of shape generation, the initial shape is manipulated by applying pre-defined grammatical rules, thereby giving rise to new shapes. During this transformation, different rules can be repeatedly applied to yield a diverse array of design outcomes, fulfilling various design requirements.

Owing to its systematic, flexible, and innovative characteristics, Shape Grammar has emerged as a crucial tool in modern design practice. Through an in-depth understanding and proficient application of Shape Grammar, designers are enabled to produce innovative and aesthetically appealing works while adhering to the fundamental design principles and concepts.

3.4 Superiority Evaluation Method

The superiority evaluation method is adopted in this study. A total of n experts are invited to evaluate m design schemes from three dimensions, namely the depth of cultural connotations S_x , the uniqueness of pattern innovation S_y , and the attractiveness of visual presentation S_z . The score value range is defined as $[1, g]$. Subsequently, the score given by the e -th expert for the f -th design scheme is a_{ef} . Then, under the evaluation dimension reflecting the depth of cultural connotations, the average value of the superiority score S_x can be calculated by the following equation:

$$\overline{S_x} = \sum_{e=1}^n a_{ef} / n, e \in [1, n], f \in [1, g] \quad (8)$$

The calculation methods for \overline{S}_y and \overline{S}_z are identical to that presented in Equation [8]. Subsequently, the final superiority score of the design scheme can be computed using the following equation:










$$S = (\overline{S}_x + \overline{S}_y + \overline{S}_z) / 3 \quad (9)$$

4 DESIGN CASE

4.1 Selection of Pattern Elements for Tang Dynasty Bronze Mirror Designs

The designs of bronze mirrors in the Tang Dynasty boast rich themes and diverse types. Through conducting literature research as well as field surveys, relevant textual and visual materials regarding the existing Tang Dynasty bronze mirrors were thoroughly investigated. Based on the categorization of the themes of bronze mirrors, this paper has organized 17 pattern samples of Tang Dynasty bronze mirrors along with their associated semantics.

Furthermore, in order to enhance the objectivity of the research process, the survey randomly invited 13 designers familiar Tang Dynasty history and experienced in designing Tang Dynasty bronze mirror patterns, as well as 17 professors engaged in Tang Dynasty history and culture research for over 10 years, to rate the degree to which the bronze mirror patterns reflected the cultural connotation. The rating scale was 1 to 5 points, with higher scores indicating stronger reflection of Tang Dynasty historical and cultural connotations. Subsequently, the average score of each bronze mirror pattern element \overline{O}_j was calculated by employing Equation (1). The resultant data are presented in Table 2.

<i>Serial Number</i>	<i>Category</i>	<i>Subject Matter</i>	<i>Pattern Illustration</i>	<i>Characteristic Words</i>	\overline{O}_j
1	Animal Patterns	Four Divine Beasts		Stabilize; Defend; Exorcise; Benediction; Auspicious	2.33
2		Dragon		Sacred; Power; Noble; Majesty; Pray	2.81
3		Suanni		Guardian; Grandeur; Power; Intelligence; Consecrated	2.54
4		Mandarin duck		Love; Loyalty; Harmony; Happiness; Felicity	2.43
5		Peacock		Wealth; Serenity ; Love; Faithfulness; Auspiciousness	3.23
6		Luan and Feng		Beauty; Nobility; Royalty; Auspicious; Power	3.54
7	Plant Patterns	Grape Pattern		Affluence; Prosperity; Harvest; Plentiful; Prolific	2.75
8		Lotus		Holiness; Purity; Wisdom; Nobility; Extraordinary	3.25
9		Peony		Wealthy; Magnificence; Gorgeous; Plump; Elegant	3.63









10		Chrysanthemum		Unworldliness; Graceful; Noble; Integrity; Longevity	2.85
11		Baoxianghua		Integration; Holiness; Auspicious; Nobility; Felicity	3.87
12	Narrative Patterns	Moon Palace Pattern		Mysterious; Extraordinary; Luna; Immortality; Fantasy	2.35
13		High Scholar Mirror		Carefree; Noble; Elegant; Charm; Detached	2.13
14	Daily Life Patterns	Playing Polo		Courage; Strength; Athletics; Vitality; Agile	2.58
15		Hunting		Brave; Strength; Strong; Health; Toughness	3.14
16	Religious Patterns	Eight Trigrams		Auspicious; Pray; Happiness; Wellness; Felicity	2.16
17		Wan (Swastika) Pattern		Exorcise; Mysterious; Philosophy; Prediction; Guard	2.06

Table 2: Selection of pattern primitives for bronze mirror patterns in the tang dynasty.

The evaluation scores \overline{O}_j of the patterns on the bronze mirrors of the Tang Dynasty in Table 2 were sorted. Subsequently, the Baoxianghua pattern, which had the highest evaluation score \overline{O}_j , was selected as the main design object. Meanwhile, the five words, namely "integration", "holiness", "auspicious", "nobility", and "felicity", were taken as the characteristic words of the Baoxianghua pattern on the bronze mirrors of the Tang Dynasty.

4.2 Extension Semantic Analysis of the Pattern Primitives of Bronze Mirror Patterns

In light of the cultural connotations conveyed by the Baoxianghua pattern on bronze mirrors, the representative pattern primitive P of bronze mirrors is constructed. Specifically, the object O that represents the cultural characteristics of the pattern is the Baoxianghua pattern, and the characteristic words used to describe this object are "integration", "holiness", "auspicious", "nobility", and "felicity", that is:

$$P = \begin{bmatrix} \text{Baoxianghua} & \text{Integration} & V_1 \\ & \text{Holiness} & V_2 \\ & \text{Auspicious} & V_3 \\ & \text{Nobility} & V_4 \\ & \text{Felicity} & V_5 \end{bmatrix} \quad (10)$$

In an attempt to evaluate the cultural connotation value of the characteristic words of the Baoxianghua pattern in the Tang Dynasty, 15 scholars, who had carried out specific research on both the history of the Tang Dynasty and the semantics of bronze mirror patterns, were invited to

participate in the scoring task. The scoring was conducted based on the degree of correlation between the characteristic words and the cultural connotations of the Baoxianghua pattern in the Tang Dynasty. The scoring range was set from 1 point, indicating the weakest correlation, to 5 points, representing the strongest correlation. Subsequently, the degree of correlation \bar{V}_x between the pattern primitives and the characteristic words was calculated by employing Equation (4), and the results are presented in Table 3.

Characteristic Words	Score					\bar{V}_x
	5 points	4 points	3 points	2 points	1 point	
Integration	8	6	5	7	4	0.22
Holiness	10	7	7	5	1	0.24
Auspicious	8	6	3	8	5	0.21
Nobility	5	4	6	8	7	0.18
Felicity	6	8	8	4	4	0.22

Table 3: The degree of correlation of the cultural connotations of the characteristic words of the Baoxianghua patterns in the Tang Dynasty.

In order to evaluate the cultural value of these characteristic words more comprehensively, another five scholars engaged in the historical and cultural studies of the Tang Dynasty were invited to score and evaluate these characteristic words respectively. The score range was set from 1 to 10 points, with 10 points representing the highest recognition degree of the cultural value of the characteristic word by the scholars. Meanwhile, according to the scoring situation of each characteristic word by Scholar b_i ($i = 1, 2, 3, 4, 5$), Equation (5) was used to calculate the mean cultural value \bar{V}_y of each characteristic word in the Baoxianghua on the bronze mirrors of the Tang Dynasty, as shown in Table 4.

In an endeavor to evaluate the cultural value of these characteristic words in a more comprehensive manner, an additional five scholars who were engaged in the historical and cultural studies of the Tang Dynasty were invited to conduct scoring and evaluation for these characteristic words individually. The scoring range was defined as ranging from 1 to 10 points, where 10 points denoted the highest level of recognition by the scholars regarding the cultural value of the characteristic word.

Simultaneously, in accordance with the scoring situation of each characteristic word by scholar b_i ($i = 1, 2, 3, 4, 5$), equation (5) was utilized to calculate the mean cultural value \bar{V}_y of each characteristic word in the Baoxianghua pattern on the bronze mirrors of the Tang Dynasty. The results are presented in Table 4.

Characteristic Words	Score					\bar{V}_y
	b_1	b_2	b_3	b_4	b_5	
Integration	7	5	6	8	6	6.4

Holiness	9	8	5	7	6	7.0
Auspicious	7	7	6	5	7	6.4
Nobility	6	4	2	3	4	3.8
Felicity	7	5	4	6	5	5.4

Table 4: The mean value of the cultural value evaluation of the characteristic words of the Baoxianghua patterns in the Tang Dynasty.

In light of the calculation results presented in Table 3 and Table 4, the extension design interval values of the characteristic words of the Baoxianghua patterns on the bronze mirrors of the Tang Dynasty were computed by employing Equation (6). The outcomes are shown in Table 5.

<i>Extension Interval</i>	<i>Characteristic Words</i>				
	<i>Integration</i>	<i>Holiness</i>	<i>Auspicious</i>	<i>Nobility</i>	<i>Felicity</i>
\overline{V}_x	0.22	0.24	0.21	0.18	0.22
\overline{V}_y	6.4	7.0	6.4	3.8	5.4
V	1.38	1.71	1.34	0.69	1.18

Table 5: Extension interval of the characteristic words of the Baoxianghua patterns in the Tang Dynasty.

In accordance with the extension interval values of the characteristic words of the Baoxianghua patterns in the Tang Dynasty obtained from Table 5, the characteristic words "holiness", "integration", and "auspiciousness", which possess relatively larger extension intervals, were selected as the main semantic directions to be taken into account in the appearance design of this cultural and creative product.

4.3 Evaluate the Diagrammatic Semantics of the Characteristic Words

Utilized diagrammatic thinking to decompose the Baoxianghua patterns on the bronze mirrors of the Tang Dynasty into individual graphics. Subsequently, for each characteristic word, 10 representative associated pictures were selected. Thereafter, 10 volunteers, who were well-versed in the culture of the Tang Dynasty and engaged in design research work, were invited to participate in the voting process. For each characteristic word, the top 3 pictures with the highest voting rates were chosen, and the diagrammatic semantics of the characteristic words were presented in Table 6.

<i>Characteristic Words</i>	<i>Diagrammatic Semantics</i>		
	h_1	h_2	h_3















Integration			
Holiness			
Auspicious			
Nobility			
Felicity			

Table 6: The diagrammatic semantics of the characteristic words of the Baoxianghua patterns in the Tang Dynasty.

Three volunteers, who were engaged in design research work, were invited to conduct an evaluation of two aspects: the distinguishability of the diagrammatic semantics of the characteristic words presented in Table 6, with its value ranging from 0 to 1; and their corresponding cultural values, scored within the range of 1 to 5. The evaluation results regarding the distinguishability are shown in Table 7, and those for the cultural values are presented in Table 8.

<i>Volunteer ID</i>	<i>Diagrammatic Semantics</i>	<i>Integration</i>	<i>Holiness</i>	<i>Auspicious</i>	<i>Nobility</i>	<i>Felicity</i>
D_1	h_1	0.8	0.6	0.8	0.6	0.4
	h_2	0.5	0.5	0.5	0.3	0.5
	h_3	0.2	0.4	0.3	0.3	0.2
D_2	h_1	0.3	0.6	0.6	0.4	0.4
	h_2	0.4	0.6	0.5	0.2	0.3
	h_3	0.1	0.2	0.3	0.1	0.2
D_3	h_1	0.2	0.6	0.5	0.4	0.5
	h_2	0.7	0.2	0.4	0.3	0.3
	h_3	0.1	0.3	0.1	0.1	0.1

Table 7: Evaluation results of the distinguishability of the diagrammatic semantics of the characteristic words.

<i>Volunteer ID</i>	<i>Diagrammatic Semantics</i>	<i>Integration</i>	<i>Holiness</i>	<i>Auspicious</i>	<i>Nobility</i>	<i>Felicity</i>
D_1	h_1	4	3	3	4	3
	h_2	4	4	3	3	3
	h_3	2	1	2	3	2
D_2	h_1	5	4	4	2	4
	h_2	4	4	3	2	3
	h_3	2	3	2	1	2
D_3	h_1	5	4	3	3	4
	h_2	4	5	5	2	3
	h_3	1	2	2	2	3

Table 8: Evaluation results of the cultural value of the diagrammatic semantics.

Through conducting mean processing and in-depth analysis on the above-mentioned evaluation results, the mean value $\overline{V_{h_x}}$ of the distinguishability corresponding to each diagrammatic semantics and the mean value $\overline{V_{h_y}}$ of the cultural value associated with the diagrammatic semantics were derived. The specific values are presented in Table 9.

<i>Diagram Number</i>	<i>Mean Values</i>	<i>Integration</i>	<i>Holiness</i>	<i>Auspicious</i>	<i>Nobility</i>	<i>Felicity</i>
h_1	$\overline{V_{h_x}}$	0.43	0.60	0.63	0.47	0.43
	$\overline{V_{h_y}}$	4.67	3.67	3.33	3.00	3.67
h_2	$\overline{V_{h_x}}$	0.53	0.43	0.47	0.27	0.37
	$\overline{V_{h_y}}$	4.00	4.33	3.67	2.33	3.00
h_3	$\overline{V_{h_x}}$	0.13	0.30	0.23	0.17	0.17
	$\overline{V_{h_y}}$	1.67	2.00	2.00	2.00	2.33

Table 9: The evaluation of mean values of the diagrammatic semantics of each characteristic word.

According to Equation (7), the extension semantic interval V_h of each diagram were calculated, as shown in Table 10.

<i>Diagram Number</i>	<i>Integration</i>	<i>Holiness</i>	<i>Auspicious</i>	<i>Nobility</i>	<i>Felicity</i>
h_1	2.02	2.20	2.11	1.40	1.59
h_2	2.13	1.88	1.71	0.62	1.10
h_3	0.22	0.60	0.47	0.33	0.39

Table 10: The evaluation of mean values of the diagrammatic semantics of each characteristic word.

As can be seen from Table 10, in the diagrammatic semantics of "holiness" h_1 , "integration" h_2 and "auspicious" h_1 have a relatively large extension interval. These elements have certain

representative values for the cultural connotations of the Baoxianghua patterns and can be used as reference elements for design to conduct re-creation.

4.4 The Re-creation of Bronze Mirror Patterns Based on Shape Grammar

In accordance with the theory of shape grammar, this study selected the Baoxianghua pattern and incorporated three graphics that are in line with the semantic characteristics of the Baoxianghua pattern on the bronze mirrors of the Tang Dynasty, which were presented in the previous section, as design elements. Initially, these design elements were decomposed into multiple initial shapes. Subsequently, the shapes obtained after decomposition are organized and summarized. The details are presented in Figure 2.

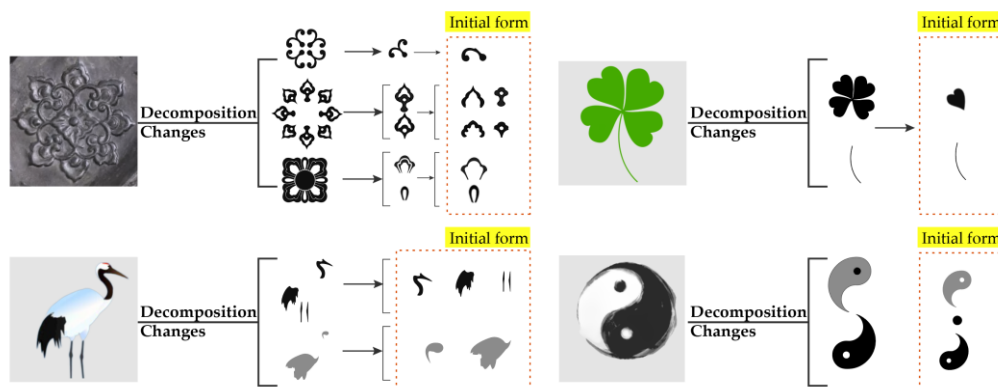


Figure 2: Reconstruction and Initial shapes of the pattern primitives of the Baoxianghua patterns on the bronze mirrors of the Tang Dynasty.

Subsequently, by employing the generation rules within the framework of shape grammar, which include but are not limited to zoom command, mirror command, copy command, rotate command, staggered cut command, Bezier curve command, and substitution command, multiple initial shapes were subjected to these commands. Eventually, several basic graphic units were generated.

Moreover, in conjunction with the composition forms of the bronze mirror patterns, further evolutions and combinations were carried out. Typically, the basic structure of the bronze mirror patterns takes the central point as a reference and exhibits diverse layout patterns, such as the square pattern, radial pattern, symmetrical pattern, rotational pattern, concentric circle pattern, or the “米” character structure. This reflects the significance attached to balance and symmetry in traditional Chinese culture, as documented in reference [41].

Ultimately, based on this compositional concept and modeling outline, and taking into account the overall visual effect, appropriate adjustments were made to the thickness of the lines as well as the original proportions. Consequently, three creative patterns were formed, and the details are presented in Figure 3.

As depicted in Figure 3, Pattern 1 employs a multi-level concentric circle layout. The outer layer is encircled by petal-shaped graphics, while the rotating geometric pattern positioned at the center forms an echo with the symmetrical layout of the peripheral petals. This design scheme serves to not only augment the visual impact but also accentuate the repetitiveness and layering of the pattern. Consequently, the overall design exhibits a pronounced three-dimensional effect.

4.5 Evaluation of Pattern Design Scheme

In an attempt to precisely select the design schemes that can both adequately reflect the connotations of the Baoxianghua patterns and satisfy modern aesthetic needs, a comprehensive excellence evaluation was conducted on the candidate schemes.

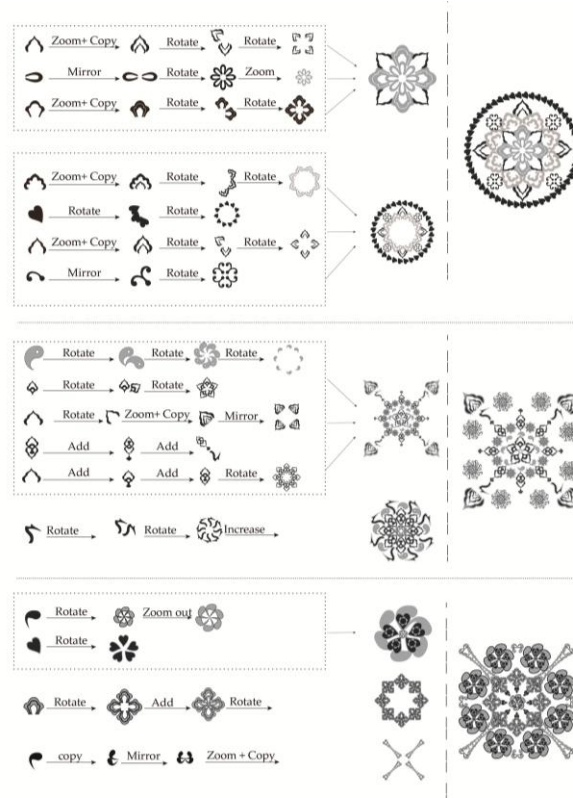


Figure 3. Reconstruction and transformation process of pattern primitives.

The evaluation system comprised three dimensions, namely, cultural connotations S_x , pattern innovativeness S_y , and visual attractiveness S_z . For each dimension, a scoring standard ranging from 1 to 5 points was adopted for quantification purposes.

Specifically, fifty volunteers were deliberately invited to take part in this online scoring activity. These volunteers consisted of 28 seasoned design professionals and 22 experts in the field of pattern research. Based on the collected scoring data, the excellence evaluation values S of each design scheme were computed using Equations (7) and (8). Subsequently, the results were sorted out and presented in Table 11.

Pattern Design Number	$\overline{S_z}$	$\overline{S_y}$	$\overline{S_x}$	S
Pattern 1	4.76	4.32	4.62	4.57
Pattern 2	4.15	4.18	4.43	4.25
Pattern 3	3.54	4.52	4.54	4.20

Table 11: Evaluation of the quality of different reconstructed patterns.

As presented in Table 11, Pattern 1 has garnered extensive recognition from experts and design professionals with regard to cultural connotation, pattern innovation, and visual appeal. This indicates that the Tang Dynasty bronze mirror pattern design method, which is predicated on the extension semantics and shape grammar principles, proves to be effective in achieving a balance between the profound meaning of patterns and their visual expression within the cultural and creative product design process.

Consequently, Pattern 1 was ultimately chosen as the primary direction for cultural and creative design. Subsequently, the main pattern along with its derived patterns were applied to four product categories, namely, fashion accessories, bronze mirror series, home furniture, and jewelry, as depicted in Figure 4.

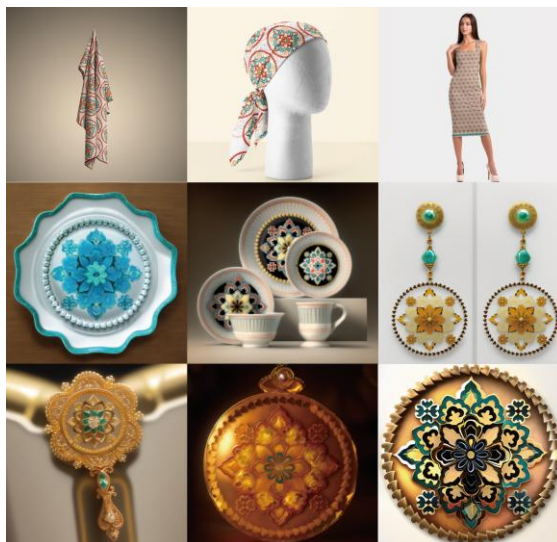


Figure 4: Cultural and creative product design renderings.

5 CONCLUSIONS

In the realm of historical and cultural creative product design, achieving innovation in the product's appearance while simultaneously retaining its cultural connotation constitutes a crucial aspect. This has perpetually posed a significant challenge within the domain of cultural and creative product design.

This research endeavor introduces extension semantics and shape grammar into the arena of cultural product design. By conducting a comprehensive analysis of the design elements inherent in Tang Dynasty bronze mirror patterns, extracting characteristic words, performing semantic analysis, and undertaking graphical interpretation, this study integrates shape grammar to facilitate innovative design. The overarching objective is to objectively and rationally externalize the implicit cultural elements of intangible cultural heritage, thereby making substantial contributions to the inheritance and dissemination of traditional Chinese culture.

The design methodology put forward in this paper enriches the theoretical framework of modern cultural product design and furnishes novel perspectives for prospective applications in the realm of cultural and creative product design. Critically, the method's emphasis on aesthetic value ensures that cultural products transcend mere symbolic representation to become objects of visual and emotional engagement. By embedding quantifiable aesthetic metrics within the extensible semantic framework, this approach bridges the gap between cultural heritage and modern design trends, ultimately enhancing the market competitiveness and cross-cultural appeal of Tang Dynasty-inspired cultural products.

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