Innovating Yinxu Bronze Patterns Through Cultural Semantics and Shape Grammar

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Abstract. This study proposes a hybrid methodology combining semantic extension and shape grammar to innovate Yinxu bronze patterns. It addresses symbolic complexity and form repetition by extracting cultural features and applying rule-based generative design. A fuzzy evaluation model assesses the schemes by innovation, expressiveness, and aesthetics. Results show that the generated motifs retain traditional symbolism while adapting to modern aesthetics. Furthermore, the study reflects on the constraints of current motif innovation, revealing the structural inertia within traditional pattern production and suggesting pathways for its reactivation. This interdisciplinary approach offers theoretical and practical insights into the digital reinterpretation of cultural heritage motifs.

Keywords: Shang Dynasty bronzes, cultural semantics, semantic extension, shape grammar, innovative design

1 Introduction

Yinxu bronze ware, a hallmark of late Shang Dynasty culture, embodies the metallurgical artistry and symbolic aesthetics of early Chinese civilization. Motifs such as *taotie*, *Kui* dragons, and cloud-and-thunder patterns reflect deep cultural beliefs, social hierarchy, and reverence for the natural and spiritual world[1]. Contemporary reinterpretations of traditional culture face challenges—many modern designs lack symbolic clarity and cohesion, leading to meaning loss. Repetitive visual structures hinder innovation and fail to meet diverse design needs. In today's global visual culture, bronze motifs must balance cultural depth with modern aesthetics[2]. Recent studies have explored cultural semantics and digital preservation of motifs[3]. Approaches such as extension theory and shape grammar have been applied to other cultural patterns[4]. However, most focus on vessel forms or broad themes, often neglecting the semantic and morphological detail of decorative elements[5]. In addition, existing generative methods are limited by simplistic rules and lack systematic evaluation mechanisms[6].

To address these gaps, this study focuses on decorative motifs from Yinxu bronze ware and proposes a hybrid methodology that integrates semantic extension with shape grammar[7]. Cultural keywords are extracted and visualized through semantic mapping; shape grammar rules generate design variants, evaluated via a fuzzy model in

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terms of innovation, cultural relevance, and aesthetics. This structured framework offers a scientifically grounded path for modernizing traditional cultural symbols.

2 Methodological Foundations for the Innovative Design of Yinxu Bronze Patterns

2.1 Cultural Semantics of Yinxu Bronze Patterns

Yinxu bronze ware, emblematic of late Shang culture, features symbolic motifs such as *taotie* and *Yunlei*, reflecting ancient beliefs, social hierarchy, and divine reverence. Symmetrical in form, these patterns symbolize authority, protection, and exorcism. Their layered meanings—e.g., *taotie* embodies mystical power and spiritual emotion—necessitate semantic analysis to inform culturally grounded contemporary design.

2.2 Semantic Extension Theory

Semantic extension is a feature-based analytical method aimed at revealing the multi-dimensional attributes of complex objects through logical modeling. At its core, the extension theory is based on the construction of a basic element called a "matter-element," defined as a triad:

$$M = (C, V, U) \tag{1}$$

In semantic extension theory, C is the object, V the attribute, and U the value. This model quantifies cultural features for design. For example, “majestic” and “protective” guide *taotie* motif innovation (Fig. 1).

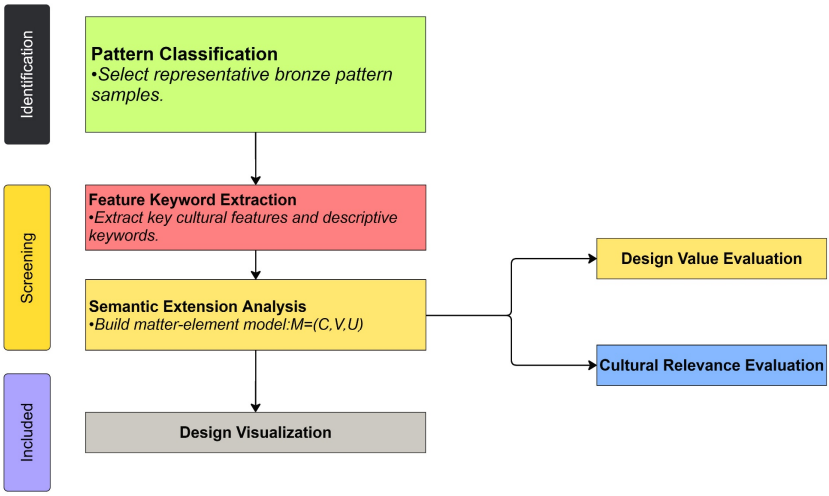

Fig. 1. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified. The macro button chooses the correct format automatically.

2.3 Shape Grammar Theory

Shape grammar, introduced by Stiny and others, is a rule-based design system that governs the generation and transformation of shapes through a defined set of operations. It encompasses generative rules (such as translation, mirroring, and rotation) and derivative rules (such as scaling, shearing, and deformation), and has found broad application in fields like architectural design and ornamental pattern development.

In the context of bronze motif design, shape grammar offers a systematic framework for morphological innovation while ensuring the continuity of traditional cultural semantics. Through the decomposition, recombination, and transformation of fundamental taotie motif elements, a repertoire of structurally varied patterns can be generated. These new motifs preserve core symbolic meanings while adapting to contemporary design aesthetics and functional contexts.

The following Table 1 presents a classification of shape grammar rules into generative and derivative categories:

Table 1. Classification of Shape Grammar Generation and Derivation Rules

Rule Type	Rule Name	Operation Description
Generation Rules	Translation	Move the pattern in a certain direction
	Horizontal Reflection	Create left-right symmetrical replication
	Vertical Reflection	Create top-bottom symmetrical replica Rotate the pattern around a central axis
	Rotation	Rotate the pattern around a central axis
Derivation Rules	Scaling	Enlarge or shrink the pattern proportionally
	Oblique Reflection	Generate an oblique pattern at a specific angle
	Deformation	Apply freeform transformations to the shape of the pattern

3 Research Methodology

3.1 Sample Collection

A dataset of representative decorative motifs from Yinxu bronze ware was compiled through literature review, field investigations in museums, and digital database searches. Based on historical prominence and semantic clarity, three canonical motif types were selected for focused analysis: taotie (beast mask), kui dragon, and yunlei (cloud-and-thunder) patterns. From these, motifs exhibiting consistent morphological structures and well-established cultural semantics were identified as the core subjects for subsequent semantic analysis and generative design (Table 2).

Table 2. Semantic Features of Typical Yinxu Bronze Patterns

Rule Type	Visual Characteristics	Cultural Semantics	Representative Sample
Taotie (Beast Mask)	Symmetrical form, complex curves	Move the pattern in a certain direction	Beast mask on the belly of a bronze *ding* vessel
Yun lei (Cloud-and-Thunder)	Regular, continuous spiral cloud motifs	Create left-right symmetrical replication	Cloud pattern on the foot of a bronze vessel
Kui Dragon	Elongated form, simplified animal motif	Apply freeform transformations to the shape of the pattern	Kui dragon pattern on a bronze *zun* vessel

3.2 Semantic Evaluation Based on Feature–Semantic Association

Based on semantic extension theory, a feature–semantic association model was built to quantify the cultural meanings of Yinxu bronze motifs. The evaluation included four steps: extracting feature keywords, scoring cultural relevance, assessing design value, and conducting a comprehensive semantic analysis. A panel of bronze experts and designers evaluated selected motifs to identify high-frequency descriptive terms, which formed the core semantic feature set. Cultural relevance for each keyword was then quantified using the semantic extension model.

$$U_x = \frac{\sum_{i=1}^{n} S_i}{n} \tag{2}$$

where S_i is the semantic score assigned by the *i*-th evaluator, and *n* is the number of evaluators. Design value was calculated in a similar fashion:

$$U_y = \frac{\sum_{i=1}^{n} D_i}{n} \tag{3}$$

where D_i represents the design relevance score provided by each expert. Finally, a comprehensive semantic-extension value was computed by multiplying the two dimensions:

$$U = U_x \times U_y \tag{4}$$

This unified score reflects both the cultural significance and design potential of each feature keyword, serving as a robust indicator for guiding subsequent pattern generation and evaluation processes.

3.3 Generative Design Using Shape Grammar

Based on the selected high-value semantic keywords, shape grammar rules were applied to guide the generative design of innovative bronze motifs. The process involved the structured decomposition and transformation of traditional patterns through a set of formalized operations.

First, representative motifs were decomposed into their fundamental and auxiliary shape components, forming the basis for subsequent geometric manipulation. Generative rules—such as translation, mirroring, and rotation—were then applied to produce foundational geometric configurations. Building upon these base forms, derivative operations including scaling, deformation, and recombination were used to generate diverse design variants. This rule-based approach enables a balance between preserving cultural semantics and introducing morphological innovation, facilitating the development of patterns that are both historically grounded and visually novel[8]. The shape grammar operations were categorized according to their visual functions (see Table 3).

Table 3. Classification of Shape Grammar Rules and Their Design Effects

Rule Type	Rule Description	Design Effect
Generation Rules	Replicates base elements along a specific direction	Extends the overall pattern
Mirroring Rule	Generates symmetrical patterns along horizontal or vertical axes	Enhances visual symmetry and balance
Rotation Rule	Rotates the pattern around a central axis	Increases dynamic visual perception
Scaling Rule	Enlarges or reduces pattern elements proportionally	Enhances visual hierarchy and depth

3.4 Fuzzy Comprehensive Evaluation Model

To scientifically evaluate the performance of the design schemes, a fuzzy comprehensive evaluation model was employed. This method integrates multiple evaluation dimensions and expert judgments into a weighted decision-making framework. The procedure is as follows: First, three evaluation criteria were selected: design innovation (d_1), cultural semantic relevance (d_2), and aesthetic appeal (d_3). A weight vector was assigned based on expert consensus. To ensure the scientific validity of the evaluation criteria, this study adopted a combined Delphi–AHP approach. Ten experts in bronze motifs, traditional art, and visual aesthetics participated in two rounds of anonymous Delphi surveys, rating the importance of three dimensions: design innovation, cultural semantic relevance, and aesthetic appeal. Based on the results, a pairwise comparison matrix was formed, and AHP was applied to compute the normalized weight vector:

$$K = [0.3, 0.5, 0.2] \tag{5}$$

The calculated consistency ratio (CR) was 0.06, which is below the generally accepted threshold of 0.1, indicating good agreement among expert judgments. This process ensures that the weight distribution in the evaluation model is both expert-informed and mathematically sound, enhancing the credibility and scientific rigor of the fuzzy comprehensive evaluation. Next, a fuzzy relation matrix was constructed by collecting expert scores for each criterion across different design schemes:

$$W = \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{bmatrix} \tag{6}$$

The fuzzy evaluation vector H was then computed by performing a weighted synthesis of the criteria:

$$H = K \cdot W \tag{7}$$

Finally, a satisfaction score vector was defined as: P = [1,0.5, 0]

$$V = P \cdot H \tag{8}$$

This quantitative model enables multi-dimensional and objective comparison of design schemes, integrating both subjective expert assessments and defined evaluation weights. It ensures a balanced consideration of innovation, cultural depth, and visual quality in the design process.

4 Design Practice

4.1 Feature Analysis of Motif Samples

Table 4. Semantic Features of Typical Yinxu Bronze Patterns

Rule Type	Historical Vessel	Form Characteristics	Cultural Semantics
Taotie (Beast Mask)	Shang Dynasty ritual tripod	Symmetrical abstract animal faces; rhythmic and ordered curved line	Exorcism, majesty, protection
Yun lei (Cloud-and-Thunder)	Shang Dynasty *fang zun*	Ordered spiral and cloud-like lines symbolizing continuity and cyclical patterns	Dynamism, vitality, eternal generation
Kui Dragon	Shang Dynasty *gong*	Simplified serpentine or dragon-like shapes with strong visual force	Reverence, mystery, life extension

At the initial stage of the study, representative decorative motifs were collected and analyzed from Yinxu bronze ware. Among them, three motifs—*taotie* (beast mask),

Yun lei (cloud-and-thunder), and *Kui long* (dragon)—were identified as the most representative due to their frequent appearance and complex cultural connotations. These motifs not only recur widely in Shang Dynasty bronzeware but also embody rich symbolic meanings, making them ideal subjects for semantic and morphological exploration in subsequent design practices. Table 4 summarizes the core morphological and cultural characteristics of the three representative Yinxu motifs selected for analysis

4.2 Semantic Extension Analysis

Based on semantic extension theory, the selected motifs underwent multi-dimensional analysis to extract culturally significant keywords. These were quantified by their cultural relevance and design value. A panel of ten bronze ware experts evaluated each motif by scoring predefined keywords reflecting cultural symbolism and aesthetic applicability. These scores were used to compute composite semantic-extension values as the basis for generative design. As shown in Table 5, the *taotie* motif achieved the highest score (0.782), indicating strong cultural relevance and design potential. *Kuilong* and *Yunlei* followed with scores of 0.695 and 0.655, respectively.

Table 5. Semantic Evaluation Scores of Representative Motifs

Motif Type	Feature Keywords	Cultural Relevance	Design Value	Composite Score
Taotie	Exorcism, Majesty, Protection	0.85	0.92	0.782
Yunlei	Dynamism, Vitality, Continuity	0.77	0.85	0.655
Kuilong	Mystery, Reverence, Power	0.79	0.88	0.695

5 Model Construction and Innovative Design

5.1 Shape Grammar Modeling

Based on the semantic extension results for the *taotie* motif, shape grammar rules were applied to generate diverse design schemes. These operations were guided by cultural keywords and the structural logic of the original motif. The grammar rules were categorized by visual or semantic function. As summarized in Table 6, translation, mirroring, and rotation rules produced pattern variants, each contributing effects such as spatial expansion and dynamic enhancement.

Table 6. Shape Grammar Rules and Their Design Effects

Rule Type	Design Operation	Resulting Effect
Translation Rule	Translate motif elements horizontally	Extends the overall pattern
Mirroring Rule	Duplicate elements via horizontal/vertical mirroring	Enhances visual symmetry and balance
Rotation Rule	Rotate elements around the central axis	Enhances visual hierarchy and depth

Based on semantic extension analysis and shape grammar rules, the *taotie* motif was reinterpreted through three distinct design schemes—F1, F2, and F3—each addressing different contemporary aesthetic and cultural needs.

- Scheme F1: Traditionalist Reconstruction: This scheme preserves the original geometry and symbolism of the *taotie* motif with minimal changes. Basic operations like horizontal/vertical translation and mirroring maintain structural integrity. Emphasizing symmetry, ritual formality, and authenticity, it suits museum exhibitions and scholarly reconstructions.
- Scheme F2: Minimalist Modernism: This approach simplifies the motif into abstract geometric forms using scaling, oblique reflection, and proportional compression. It balances traditional symbolism with modern aesthetics, making it suitable for product design, branding, and digital visual systems.
- Scheme F3: Expressive Dynamism: This design employs structural transformation and layering to enhance expressive power. Using rotation, nonlinear deformation, and element recombination, it achieves spatial depth and rhythmic energy. Visually striking, it suits creative fields such as fashion, immersive installations, and multimedia experiences.

5.2 Comprehensive Evaluation

The proposed design schemes were evaluated using the fuzzy comprehensive evaluation model introduced in Section 3.4. The model considered three weighted criteria—design innovation, cultural semantic relevance, and aesthetic appeal—to generate a composite score for each scheme. The evaluation results are presented in Table 7.

Table 7. Fuzzy Evaluation Scores for Design Schemes

Evaluation Criteria	F1	F2	F3
Innovation(d_1)	0.75	0.85	0.90
Cultural Semantic Relevance(d_2)	0.80	0.78	0.83
Aesthetic Appeal(d_3)	0.82	0.84	0.87
Composite Score(V)	0.79	0.82	0.86

Scheme F3 achieved the highest composite score, reflecting its superior performance in design innovation and cultural semantic expression. It was thus chosen as the optimal direction for further refinement.

6 Results

The integration of semantic extension and shape grammar enhanced both the innovation and cultural relevance of bronze motif design. Semantic extension extracted and quantified key cultural features, making implicit meanings explicit—for instance, *taotie* scored highly in “exorcism,” “majesty,” and “protection” (U = 0.782), revealing strong

design potential. While expert judgment introduces subjectivity, future work could employ machine learning for greater objectivity. Shape grammar supported morphological innovation via translation, mirroring, and rotation, producing three schemes (F1–F3); F3 performed best (score: 0.86), confirming the method's adaptability. However, limitations remain: semantic interpretations vary across contexts, and current rules oversimplify complex motifs. Additionally, visual dimensions such as color, texture, and material were not considered. In conclusion, this interdisciplinary framework provides a structured approach to culturally rooted design innovation. Future research should explore AI-driven semantics, dynamic grammar, and richer visual elements to broaden its scope across diverse cultural contexts.

7 Conclusion

This paper presents a hybrid method combining semantic extension and shape grammar to modernize Yinxu bronze patterns. By extracting cultural features and applying rule-based design operations, the approach ensures both symbolic continuity and visual innovation. A fuzzy evaluation model provided objective assessment across three dimensions: innovation, cultural relevance, and aesthetics. Three design schemes were developed, with F3 showing the highest overall score due to its dynamic form and expressive strength. The study offers a practical framework for cultural motif innovation and suggests future integration of AI and visual elements like color and texture to enhance design richness.

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