ART AND DESIGN
Journal homepage: https://art-design.com.ua/en
8(2), 2025

Received 03.02.2025 Revised 19.05.2025 Accepted 25.06.2025

UDC 7.05:685.31
DOI: 10.30857/2617-0272.2025.2.2

Research on casual shoe pattern design based on shape grammar

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Abstract. This research investigated the integration of cultural elements from the Zhujiajiao bridges in Shanghai into casual shoe pattern design, employing shape grammar and the fuzzy evaluation method. The study focused on four iconic bridges – Release, Huimin, Chenghuangmiao, and Yong'an – extracting and redesigning their distinctive patterns to create a collection of decorative elements. These patterns were enhanced by a colour scheme inspired by the Jiangnan water town landscape. The research process comprised three steps: extracting bridge elements using design software, redesigning these elements based on shape grammar rules to generate pattern collections, and evaluating the patterns and colours using a fuzzy evaluation method with input from teachers and students. Shape grammar, defined as SG = (S, L, R, I), was utilised to evolve initial bridge elements through various rules, resulting in three pattern sets (SG_1, SG_2, and SG_3). The colour scheme, characterised by neutral tones and contrasting hues, was developed by extracting colours from significant buildings in Zhujiajiao. Two colour schemes (C_1 and C_2) were created and matched with the pattern sets. Using the fuzzy evaluation method, these combinations were evaluated according to criteria such as usability, design characteristics and template attractiveness. The results revealed that the combination of patterns SG_1 and SG_3 with colour scheme C_2 was the most preferred. These redesigned patterns and colours were successfully applied to casual shoe designs, resulting in visually appealing and culturally significant footwear. The study demonstrated the practicality of shape grammar in automating design processes for culturally creative products, enriching casual shoe designs with traditional bridge patterns while fostering appreciation of cultural heritage in contemporary fashion

Keywords: Zhujiajiao bridge cultural elements; traditional pattern integration; cultural inheritance; Chinese culture; modern footwear; fashion; graphic design

INTRODUCTION

As of 2025, there has been a heightened focus on integrating traditional cultural elements into contemporary designs, particularly in the field of fashion. This study is especially timely and relevant as it explores the incorporation of cultural motifs from the iconic Zhujiajiao bridges in Shanghai into casual shoe pattern designs, utilising shape grammar and fuzzy evaluation methods to enrich modern footwear with traditional aesthetics and to foster an appreciation of cultural heritage. Previous research on pattern design and shape grammar has primarily focused on four key areas. According to L. Bu *et al.* (2023), reflecting the local characteristics of ancient towns in order to achieve differentiated competitiveness has become a significant issue in the

Suggested Citation:
Qiang, W., & Pashkevych, K. (2025). Research on casual shoe pattern design based on shape grammar. *Art and Design*, 8(2), 20-32. doi: 10.30857/2617-0272.2025.2.2.

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development of culturally and creatively themed ancient towns. Earlier studies related to pattern design and shape grammar fall into the following categories: The first concerns the application of shape grammar in pattern reuse and optimisation. Shape grammar, as a powerful design tool, has demonstrated considerable potential in this area. A. Caetano *et al*. (2020) discussed computational design (CD) and proposed an improved and robust classification method based on traditional shape grammars for key CD concepts, including parametric design. D. Chen & P. Cheng (2024) used first-order quantitative theory to establish a correlation model between shape grammar transformation rules in clothing pattern design and young people's image perceptions. Their research illustrated the mapping relationship and degree of influence on consumer preference through graphical methods. The second area was the exploration of computational design within architectural design. With the rapid advancement of digital technology, computational design has seen increasingly widespread application in this field. N. Ding *et al.* (2020) defined and applied concepts of parameterisation, generation, and algorithmic design in architecture, offering a theoretical foundation for the digital and intelligent transformation of pattern design. This trend was driving architectural practice towards greater efficiency, flexibility, and personalisation.

The third category involved the innovative application of traditional patterns in modern design. As an essential component of cultural heritage, traditional patterns have received increasing attention regarding their adaptation and innovation within contemporary design contexts. A series of studies have focused on the use of traditional patterns in modern design across different cultural contexts. N. Ding *et al.* (2020) extracted and analysed traditional furniture patterns, applying the shape grammar theory to derive core elements for new decorative patterns through evolutionary reconstruction, thereby enabling the morphological transformation and cultural continuity of traditional furniture designs. M. Kulińska *et al*. (2022) explore how body measurements are widely used and implemented in the digital design of traditional garments. Y. Xu & F. Xia (2024) employed shape grammar to extract and deduce the basic elements of Miao embroidery patterns in Wenshan, resulting in the creation of innovative designs. W. Huang (2023) selected typical Ruyuan Yao embroidery patterns for compositional analysis, deconstructs them into fundamental elements, and reconstructs these to form innovative base patterns. By applying shape grammar, these base patterns are developed into a series of unit innovations that are subsequently integrated into product design.

The fourth area concerns the application of shape grammar in automated and intelligent design. L. Zhang & Y.R. Xiao (2024) analysed the perceptual differences between residents and tourists regarding the characteristics of ancient towns, examining the emotional responses these evoke and identifying influencing factors. E. Yılmaz *et al.* (2023), following the arrangement of intelligent microcapsules, utilise shape grammar to determine the pattern structure and design of a new sports bra, enhancing its aesthetic appeal. L. Gao & X. Li (2025) introduced topological geometry into product shape design, conducting hierarchical feature analysis of a target product prototype and identifying its form-defining characteristics based on topological weights. Primary features are constrained by topological properties, while secondary features are derived through shape grammar rules, ultimately generating an innovative product design scheme.

Ultimately, this study aimed to contribute to the revitalisation of traditional cultures through modern design practices, while also offering valuable insights into the application of shape grammar in pattern redesign.

MATERIALS AND METHODS

The research process involved several key steps. First, four representative bridges in Zhujiajiao were selected as the subjects for pattern extraction. These bridges – namely, the Release Bridge, Huimin Bridge, Chenghuangmiao Bridge, and Yong'an Bridge – were chosen for their distinctive styles and historical significance. Through meticulous abstraction and line drawing, the basic elements of each bridge were extracted and subsequently reorganised into a cohesive pattern design. Next, the extracted patterns were further refined and transformed using shape grammar rules. It is worth noting that Adobe Photoshop was used in the study. This process involved applying various generative and modifying rules to the initial patterns, producing a range of variations that preserved the core characteristics of the original bridges while incorporating modern design elements. The refined patterns were then evaluated through a fuzzy evaluation method, which assessed their aesthetic appeal, cultural authenticity, and adaptability for footwear design. In order to illustrated the redesign of bridge culture, design software was employed to optimise the derived patterns through adjustments such as mask transparency, pattern layer overlays, and transparency locking. While retaining the original patterns and colours, this process enabled a more harmonious integration of bridge elements characteristic of the Jiangnan water town. In addition, a combination of product design techniques was applied to create patterns embodying the features of the water village. These culturally rich patterns were then incorporated into the design of casual footwear.

The pattern extraction and redesign process for Zhujiajiao was divided into three main stages. Firstly, four ancient bridges with distinctive stylistic features were selected as the basis for element extraction. Their line drawings were abstracted to obtain the defining features of water town bridge architecture. Based on shape grammar, the extracted elements were arranged and integrated according to design principles to generate more complex, orderly, and decorative monolithic design elements. Subsequently, constraints and transformation rules were applied using graphic design software. The primary features of the original bridges were analysed in terms of points, lines, and surfaces. At the same time, unnecessary design elements were harmonised or removed to form a comprehensive pattern set. Colour schemes were also developed based on real-life scenes. Finally, the fuzzy evaluation method was employed to refine the basic elements of the water town bridges, compare data, evaluate the pattern and colour collections, and determine the optimal combination for application in casual shoe design. The process is illustrated in Figure 1.

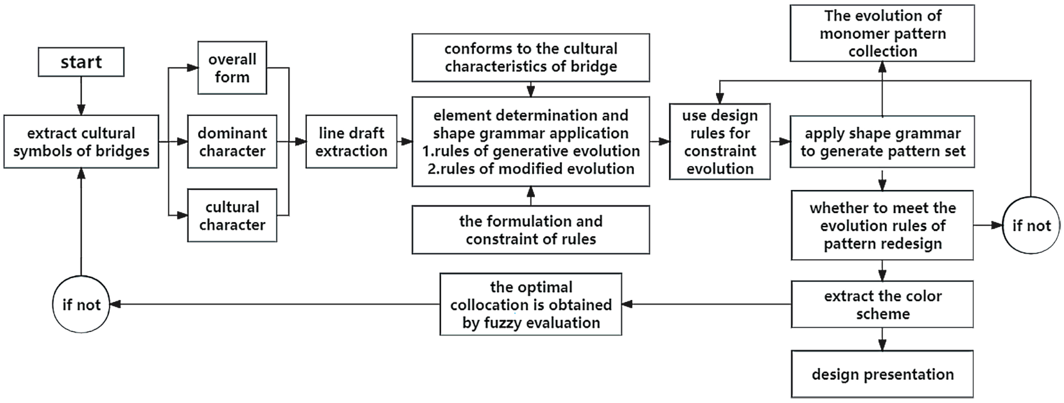


Figure 1. Flow chart of the study

Source: developed by the authors

The pattern system functioned as a design language integrating generative and modifying rules. Shape grammars served as modern computational tools that, once transformation rules were established, enabled the combination of basic forms, evolutionary commands, and novel, style-specific design outputs. The evolutionary rules of generative design allowed for creative development through the sequential application of multiple rule sets, resulting in a coherent and innovative design language.

According to the definition of shape grammar by G. Stiny & J. Gips (1971), it can be expressed as SG = (S, L, R, I), where SG denoted the finite set of shapes resulting from the application of evolution rules; S represented the set of shapes derived through operations such as proportional transformation, rotation, mirroring, etc.; L referred to the finite set of markers; R was the finite set of inference rules for evolution; and I was the initial shape from which the inference process begins. In practical product shape inference, the initial shape corresponded to the target morphological curve. Evolutionary inference can be applied to part or all of these curves, with the optional use of shape markers. Affine transformations allow for arbitrary angular tilting and longitudinal scaling while maintaining co-linearity, co-pointing, and mutual parallelism. The corresponding operations include translation, scaling, rotation, and miscutting. Bézier curve transformation refers to stretching a curve through four control points while preserving affine and geometric properties. This study primarily applied evolutionary rule constraints, with modifying rules serving as the primary mechanism and generative rules as a supplement. The aim was to ensure that the elements extracted from the target scenery retained the defining cultural characteristics of the bridges after undergoing transformation through the evolutionary reasoning process, as illustrated in Figure 2.

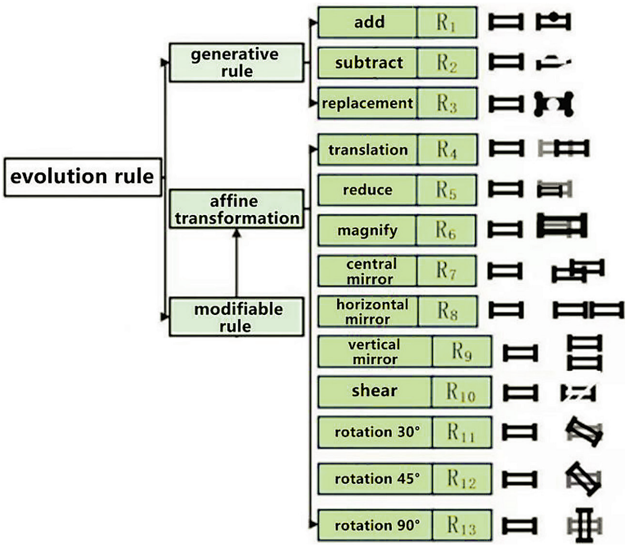


Figure 2. Evolution rule description

Source: developed by the authors

Evolutionary rules encompass design operations such as addition, subtraction, division, modification, replacement, deletion, scaling, mirroring, copying, rotation, and miscutting. As shown in Figure 3, a design language can be derived from these fundamental operations and then applied to design objects. These rules demonstrated that shape grammar functions as a design methodology governed by the principles of arithmetic logic.

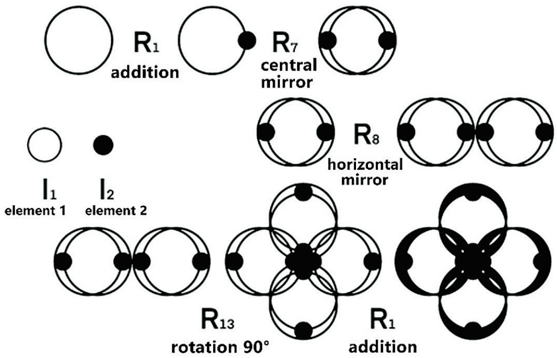


Figure 3. Scheme of rule instructions
Source: developed by the authors

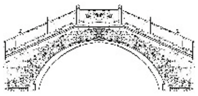
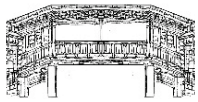
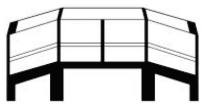
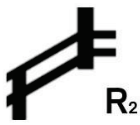
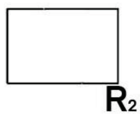
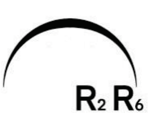
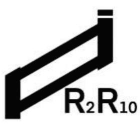
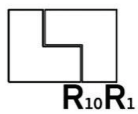
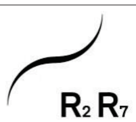
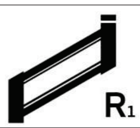
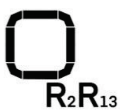
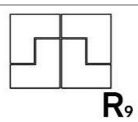
To begin with, based on the principles of modelling and composition of basic elements, the initial shape of the pattern was extracted with careful attention to the monolithic modelling structure and the continuity of the subsequent design. The distinct elements required for the design were extracted using Photoshop 2024 and Procreate 5.3.4. These four basic elements were imported into Procreate, where, using a single-line brush, they were manipulated according to shape grammar: the first step involved retaining the original form of each initial element while incorporating new design features; the second step filtered and removed overly complex components to highlight each element's distinctive characteristics; the third step applied modification instructions while preserving the structural skeleton of the original form, thereby generating alternative stylistic variations. The architectural outlines of the four historic bridges in Zhujiajiao were abstracted and simplified into line drawings, yielding four groups of basic elements: I_1, I_2, I_3, and I_4. While maintaining the distinctive features of the bridges, a degree of deformation was introduced using affine transformations and generative rules. These served as secondary evolutionary tools. The generative evolution rules enabled the preservation and enhancement of the bridges' most distinctive design features.

RESULTS AND DISCUSSION

Characterisation of Zhujiajiao bridge elements

The extraction process of the bridge elements is presented in Table 1. Firstly, real-life images of the bridges were processed to extract features, and line drawings were generated using Adobe Photoshop.

Table 1. Characterisation and extraction of Zhujiajiao bridge elements

Feature refinement	Fangsheng Bridge – I_1	Yong'an Bridge – I_2	Chenghuangmiao Bridge – I_3	Huimin Bridge – I_4
Picture				
Line draft extraction				
Line abstraction				
Evolution of element 1				
Evolution of element 2				
Evolution of element 3				
Extraction result	New element – T_1	New element – T_2	New element – T_3	New element – T_4

Source: developed by the authors

As observed across the four groups of elements, the abstracted forms exhibit not only structural stability but also distinct stylistic features characteristic of Jiangnan water town architecture. The compositions primarily consist of quadrilateral and smooth, circular surface elements. Subsequently, generative evolutionary rule R_2 was applied to amplify key features by selectively deleting components from the four structural groups (I_1, I_2, I_3, and I_4), without compromising their skeletal morphology. These elements were then further refined and amplified, retaining their defining characteristics and adhering to rule-based constraints. During the feature refinement process, it was essential to apply modifiability rules to deepen shape derivation and produce more nuanced characteristic elements. To ensure alignment between the derived forms and the target design intentions, a combination of evolution rules – add (R_1), enlarge (R_6), vertical mirror (R_9), and miscut (R_{10}) – were applied alongside R_2. These helped optimise feature modelling under positional constraints. Finally, additional rules, such as central mirror (R_7), vertical mirror (R_9), and 90-degree rotation (R_{13}), were employed to further evolve the forms, resulting in the final new elements: ($T_1 = R_2 + R_2 + R_6 + R_2 + R_7$), ($T_2 = R_2 + R_2 + R_{10} + R_1$), ($T_3 = R_2 + R_9 + R_2 + R_{13}$), and ($T_4 = R_2 + R_{10} + R_1 + R_9$). These four evolved groups of elements successfully retain the modelling characteristics of the original bridges while also expressing a more structured and coherent formal style, contributing to the understanding of morphological principles and the preservation of visual rhythm.

Evolution and redesign of foundation elements

Building upon the refined elements described above, four sets of foundational forms were derived. These forms employed affine transformations under the modifiability rules, enabling arbitrary angular tilting, telescopic scaling, and rotational transformations while preserving co-linearity, common points, and parallelism. This approach facilitated the directional control and precision required in the subsequent redesign phase, as shown in Table 2.

Table 2. Transformation rules applied to foundational element evolution

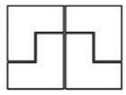
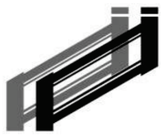
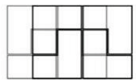
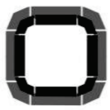
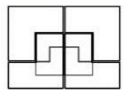
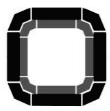
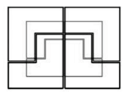
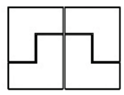
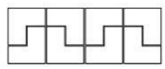
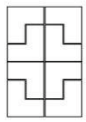
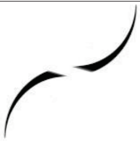
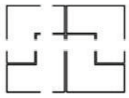
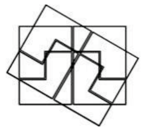
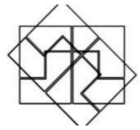
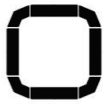
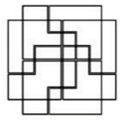
Element rule / Transformation rule	T_1	T_2	T_3	T_4
				
$R_1/R_2/R_3$	Unused	Unused	Unused	Unused
R_4				
R_5				
R_6				
R_7				
R_8				
R_9				

Table 2. Continued

Element rule / Transformation rule	T_1	T_2	T_3	T_4
R_{10}				
R_{11}				
R_{12}				
R_{13}				

Source: developed by the authors

According to the formal characteristics of the Jiangnan water town bridges, and following the refinement and evolution of the geometric elements, select forms from the base set in Table 2 were used to generate reconfigured designs under defined constraints, as illustrated in Figure 4. Subsequently, the final pattern design was executed, and three sets of pattern results – SG_1, SG_2, and SG_3 – were generated, as shown in Table 3.

The refined base elements provided a structured foundation for precise and directionally consistent pattern redesign, inspired by the architectural characteristics of bridges in the Jiangnan water town region.

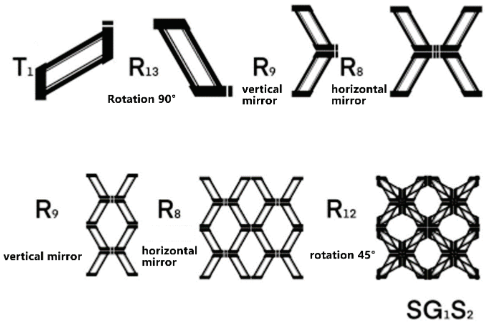


Figure 4. Schematic diagram of element evolution
Source: developed by the authors

Table 3. Matrix of final cultural and creative pattern designs

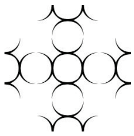
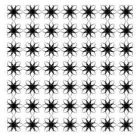
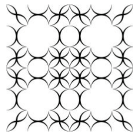
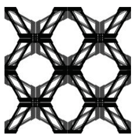
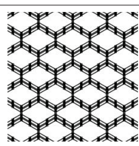
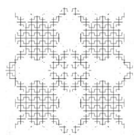
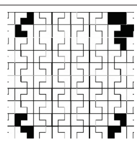
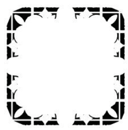
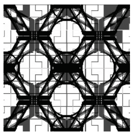
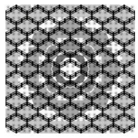
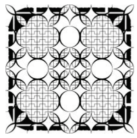
Element rule	SG_1 $T_1R_9R_8R_{13}R_3R_{13}$ $T_2R_{13}R_9R_8R_8R_{13}$ $T_4R_9R_8R_9R_1$	SG_2 $T_1R_{13}R_{13}R_8R_9$ $T_2R_7R_4R_{13}R_4R_8R_9$ $T_3R_{13}R_5R_6R_6$	SG_3 $T_1R_9R_8R_4T_1R_9R_4$ $T_4R_9R_8R_9R_{10}$ $T_3R_6R_{10}$
S_1			
S_2			
S_3			

Table 3. Continued

Element rule	**SG_1** $T_1R_9R_8R_{13}R_3R_{13}$ $T_2R_{13}R_9R_8R_8R_{13}$ $T_4R_9R_8R_9R_1$	**SG_2** $T_1R_{13}R_{13}R_8R_9$ $T_2R_7R_4R_{13}R_4R_8R_9$ $T_3R_{13}R_5R_6R_6$	**SG_3** $T_1R_9R_8R_4T_1R_9R_4$ $T_4R_9R_8R_9R_{10}$ $T_3R_6R_{10}$
SG set			
Extraction result	Pattern design – SG_1	Pattern design – SG_2	Pattern design – SG_3

Source: developed by the authors

Colour extraction, pattern evaluation and screening
The predominant colour palette of Zhujiajiao Ancient Town comprises neutral tones such as green, white, and grey, with a balanced contrast between warm and cool hues. The buildings display a marked contrast in brightness, with harmonised transitions between walls and roofs, creating an overall natural and refined visual impression. The low-saturation colour system defines the core chromatic perception of the town. Representative buildings emblematic of Jiangnan culture were selected for their significant architectural and cultural value. The primary colours include black, white, grey, ochre, lake blue, indigo, universal blue, dark grey, and deep red, complemented by secondary tones such as light green, vermilion, emerald green, dark green, light yellow, and gold. Two sets of colour schemes – C_1 and C_2 – were designed by extracting hues from photographs using Adobe Photoshop, and these colour groupings were applied in the subsequent redesign process. The schemes are illustrated in Figure 5. To effectively evaluate and optimise the visual characteristics of the redesigned patterns and to preserve their cultural associations with bridge architecture, this study employed a fuzzy comprehensive evaluation method. This addressed the limitations of shape grammar-based evolution, pattern redesign, and colour matching. Three pattern sets and two-colour schemes were assessed using this method. Evaluation criteria and weighted indicators were established to quantify the performance of each design scheme. These indicators enabled a preference-based synthesis of design attributes under environmental constraints, laying a strong foundation for the application and innovation of the design elements, as presented in Table 4.

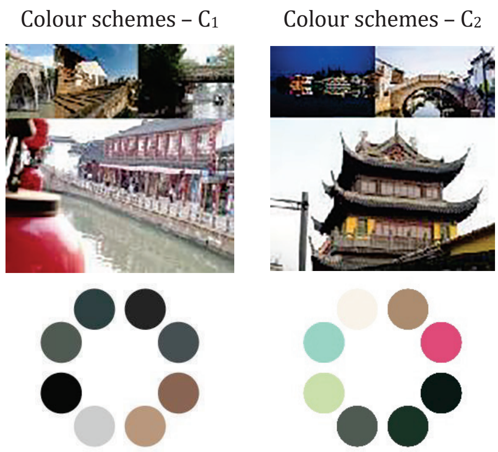


Figure 5. Colour scheme collection table
Source: developed by the authors

Table 4. SG_1 advantage indicator table

K_A	Description of indicators	Weighting/%
K_1 – utilisation capability	Excellent formal sensibility and broad applicability in creative contexts	0.51
K_2 – design features	Clear representation of Jiangnan water town architectural elements	0.36
K_3 – pattern advantage	High continuity, replicability, and strong potential for reinterpretation	0.13

Source: compiled by the authors

After the morphological evolution process, three groups of pattern collections were generated, producing a wide range of pattern elements suitable for design combinations. Based on the aforementioned deductions, three pattern collections – SG_1, SG_2, and SG_3 – were established. In order to identify the optimal combination of pattern and colour scheme, the fuzzy evaluation method was employed to determine the preferred evaluation outcomes for the pattern and colour schemes used in this design. The dominant indices were defined as follows: K_A, the pattern ensemble index, and KB, the colour scheme index, as illustrated in Figure 6. In conjunction with the reference to corridor bridge structures and their historical origins, the five sets of dominant indices for the design – K_A and K_B – are presented in Tables 4 and 5.

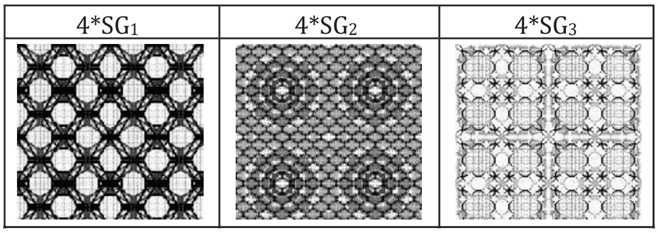


Figure 6. Example of K_3 pattern advantages
Source: developed by the authors

Table 5. C_1 advantage indicator table

K_B	Description of indicators	Weighting/%
K_1 – utilisation capability	Design value after integrating pattern elements	0.64
K_2 – colour attributes	Reflects the Jiangnan water town cultural style	0.36

Source: compiled by the authors

To enhance clarity in both demonstration and evaluation, a schematic table illustrating the advantages of the K_AK_3 pattern was produced (Fig. 6), along with a schematic table demonstrating the K_BK_1 utilisation capability, as shown in Figure 7.

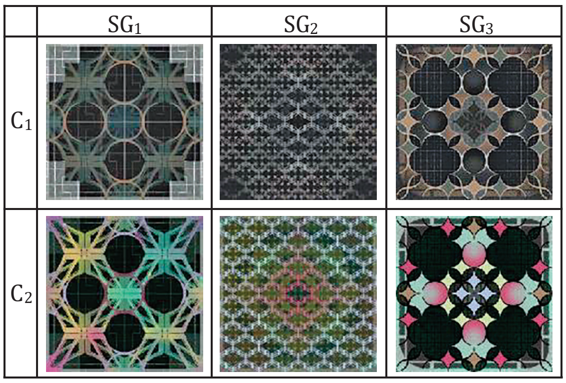


Figure 7. Example of K_BK_1 pattern advantages
Source: developed by the authors

Ten lecturers and 35 visual communication design students from the teaching and research department participated in evaluating the dominant indices of the pattern and colour collections. They contributed to determining the weighting percentages of each dominant index in the bridge design, thereby constructing a comprehensive weighting system for pattern design evaluation.

Evaluation and optimisation of culturally-inspired design solutions

Taking into account the requirements of both pattern design and colour schemes, a five-point rating scale was used: very good, excellent, fair, not very suitable, and unsuitable. The scoring vector was assigned as α = (90 80 70 60 50) X. The 45 aforementioned participants evaluated each aspect of the styling and decorative design independently. This is summarised in Table 4. A fuzzy comprehensive evaluation matrix was then constructed, and the calculation method along with the results are presented in Tables 6 and 7, using pattern SG_1 and colour scheme C_1 as examples.

Table 6. SG_1 final assessment score calculator

Evaluation matrix				Weighting			Scores						
P_{SG1}	0.56	0.24	0.13	0.07	0.00	K_A	0.51	P*k	0.286	0.122	0.066	0.036	0
	0.32	0.27	0.37	0.04	0.00		0.36		0.115	0.097	0.133	0.014	0
	0.24	0.37	0.23	0.16	0.00		0.13		0.031	0.048	0.023	0.021	0
/							Total		0.432	0.220	0.222	0.071	0
							α		90	80	70	60	50
							Total*α		38.88	17.57	15.57	4.25	0
							Score		76.27				

Source: compiled by the authors

Table 7. C_1 final rating score calculator

Evaluation matrix				Weighting			Scores						
P_{C1}	0.37	0.39	0.13	0.04	0.00	K_B	0.64	P*k	0.237	0.250	0.083	0.026	0
	0.40	0.13	0.28	0.19	0.00		0.36		0.144	0.047	0.1008	0.068	0

Table 7. Continued

Evaluation matrix	Weighting	Scores					
/		Total	0.381	0.296	0.184	0.094	0
		α	90	80	70	60	50
		Total*α	34.27	23.71	12.88	5.64	0
		Score	76.50				

Source: compiled by the authors

From the above, the evaluation weight vectors $H_{SG1} = P_{SG1}{*}K_A$, $H_{C1} = P_{C1}{*}K_B$ for pattern SG_1 and Colour C_1, together $H_{SG1} = (0.4320, 0.2169, 0.2224, 0.0709, 0)$, $H_{C1} = (0.3808, 0.2964, 0.1840, 0.094, 0)$. Finally, multiplying by the scoring vector $\alpha = (90\ 80\ 70\ 60\ 50)X$, the final scores for pattern H_{SG1} and colour H_{C1} were 76.27 and 76.50, respectively. The evaluation also produced the following scores for pattern SG_2 – 74.33, pattern SG_3 – 76.27, and colour C_2 – 79.34. As pattern SG_1 and SG_3 achieved equal scores, and colour scheme C_2 outperformed C_1, the final design presentation incorporates pattern SG_1, pattern SG_3, and colour scheme C_2.

In order to more effectively present the redesigned bridge culture concept, design software was employed to refine and optimise the output. Building upon patterns SG_1 and SG_2, mask transparency adjustments in Procreate 5.3.4, along with the stacking and interweaving of pattern layers and alpha-locked overlays, were utilised to enhance the texture of the colour scheme without altering the original patterns or palette. This process helped to ensure that the pattern design, based on the architectural features of bridges in the Jiangnan water town, appeared more cohesive and harmonious. Additionally, modifications and enhancements were made to the design according to the characteristics of the patterns, integrating elements consistent with Jiangnan bridge culture. These refinements were intended to align with the aesthetic preferences of tourists, thereby facilitating the seamless integration of the designs into both footwear and broader cultural and creative applications.

Innovative design of Zhujiajiao bridge pattern casual shoes

Following the redesign of the bridge patterns, a cross-disciplinary approach combining product design principles was applied to create pattern motifs that convey both a strong design language and the unique character of water towns. This initiative not only presents a novel pathway for the preservation and innovation of Zhujiajiao's bridge culture but also provides inspiration for the development of cultural and creative products – particularly the design of Zhujiajiao-themed casual footwear, as illustrated in Figure 8.

Using graphic design software, these culturally rich motifs were skilfully embedded into casual shoe designs, creating a bridge between tradition and modernity, and between cultural heritage and contemporary fashion (Fig. 9).

Figure 8. Casual shoe pattern – design presentation 1
Source: authors' material

Figure 9. Casual shoe pattern – design presentation 2
Source: authors' material

Locally representative casual footwear products were selected and combined with refined pattern designs. A minimalist approach was adopted, with the patterns arranged in a continuous and layered composition. Design elements primarily included patterns SG_3 and SG_1, while the colour palette was dominated by the cool tones of scheme C_2. The final visual outcomes are shown in Figures 8, 9, and 10.

Figure 10. Casual shoe pattern – design presentation 3
Source: authors' material

The impact of technology on modern society is both profound and multifaceted, influencing nearly every aspect of daily life. This transformation is especially visible in the field of design. Through parametric modelling, generative techniques, and algorithm-driven design, researchers have advanced the automation and optimisation of design processes, enhancing both efficiency and creative capability. In the area of ethnic pattern design, for instance, shape grammar enables the creation of intricate, culturally significant motifs with a level of precision and repeatability that is challenging to achieve manually. Similarly, in architecture, computational design tools have enabled the exploration of complex geometries and structures, pushing the boundaries of design and construction possibilities. Furniture design has also benefited greatly from these advancements, enabling designers to create bespoke pieces that fit seamlessly within a given space and meet specific functional requirements. Three-dimensional shape generation, cultural heritage conservation, and textile and fashion design are further fields in which shape grammar and computational design have made notable contributions. In each of these disciplines, the ability to define and manipulate forms using algorithmic rules has led to more efficient and innovative design processes.

C. Cui & N. Shaari (2023) enhanced shape grammar to enable the efficient reuse and innovative development of national patterns, offering a new approach to intelligent and automated pattern design. A. Chantamool *et al.* (2024) improved shape grammar by incorporating a national narrative research method, focusing on a hand-woven silk group selected through purposeful sampling. Data were gathered via in-depth, face-to-face interviews, and analysed using interpretive thematic analysis. F. Zhang *et al.* (2023) applied shape grammar to interpret the characteristics of box-type furniture in detail, highlighting its importance within Korean traditional furniture. The study proposed ideas for the organic integration of traditional and contemporary Korean furniture design. Y. Li *et al*. (2024) used innovative derivative patterns in the design of modern leather goods, ensuring that the products aligned with contemporary aesthetic sensibilities while retaining national characteristics and cultural depth. Y.L. Wang *et al*. (2024) combined grounded theory principles, shape grammar, and sustainable design methodologies to reinterpret and innovate the aesthetic design of Ming-style furniture. A. Wutte & J.P. Duarte (2021) proposed a parametric shape grammar for ancient Egyptian funerary monuments, which could be used to reconstruct incomplete tombs, extend existing ones, or generate new designs. Y.G. Ying & F.T. Jin (2024) inferred that shape grammar facilitates the effective transformation of designers' knowledge, providing technical support for the intelligent application of shape grammar in design and manufacturing processes. Research into the automatic generation of rule-based logo designs further illustrates the significant potential of shape grammar in automated design systems. This line of inquiry not only enhances design efficiency but also establishes a solid foundation for the future of intelligent design development.

B.L. Qi *et al*. (2023) analysed and extracted shape feature lines at various levels of train head forms, creating abstract design elements by applying shape grammar. An interactive genetic algorithm was then used to encode these design features. F. Zhang *et al.* (2024) conducted research on gene extraction and intelligent assisted design in the context of Nanjing Republic architecture, highlighting the characteristics of inheritance, selection, replication, and variation in architectural gene expression. This work achieved a creative transformation and innovative development of architectural heritage, demonstrated the potential for intelligent, assisted cultural and creative design, and enhanced the cultural depth of such products. However, in the field of footwear creative design, there remains a lack of research on the application of shape grammar. Footwear design is a complex discipline that integrates both art and technology. Its cultural and creative aspects require not only aesthetic appeal and uniqueness but also account for comfort and functionality. Shape grammar, with its strong capabilities in shape transformation and rule-based reasoning, offers a distinct opportunity for innovation in footwear design. By defining shape rules and transformation logic, a wide variety of shoe designs can be automatically generated while maintaining coherence and design unity. This approach would not only streamline the design process but also create new possibilities for creativity and innovation. Designers could more easily experiment with diverse shapes, patterns, and materials, thereby expanding their range of design options. In addition, shape grammar can support designers in capturing and transforming traditional footwear elements, enabling the modern expression of cultural heritage and its innovative transmission. This is particularly valuable in the context of cultural heritage conservation, where the preservation of traditional footwear design holds significant importance. P. Gerchanivska (2021) conceptualised cultural identity as a resource for social development, revealing its structural integrity through correlations with cultural codes and transformation models.

This study explores casual shoe pattern design using shape grammar, through the extraction and redesign of elements from the ancient town bridges of Zhujiajiao. Other related studies – such as N. Ding *et al*. (2022), on the reuse and optimisation of patterns in furniture design using shape grammar; Y. Li *et al.* (2024), on the automatic generation of logo designs; and Y. Xu & F. Xia (2024), on the integration of shape grammar and the analytic hierarchy process in redesigning Miao embroidery patterns – all demonstrate the broad applicability of shape grammar across design field. These studies share a common approach with the present article in their application of shape grammar rules for innovative and optimised design. However, this study differs in its design subject, objectives, and evaluation methodology. Moreover, the fuzzy evaluation method employed here offers a novel perspective on design assessment, which is less frequently seen in related research.

CONCLUSIONS

This study provides a detailed account of the process of redesigning cultural design elements from bridges in Jiangnan water towns, through the extraction and reinterpretation of features from the Zhujiajiao bridge. The coherence of this redesign is closely aligned with the conceptual framework of footwear design. In the final design outcome, a colour scheme was applied that not only integrated the distinctive colours of the water town but also effectively combined regional hues with modern commercial appeal. At the same time, the authors curated a series of patterns that reflect the elements of the Zhujiajiao bridge, which not only enrich the visual layering of the design but also express the harmonious integration of tradition and modernity. The design outcomes not only demonstrate the unique charm of Shanghai Zhujiajiao's traditional culture but also thoroughly explore its generative logic and visual expression in a modern design context. Using the fuzzy evaluation method, the combination of SG_1 and SG_3 patterns, along with the C_2 colour scheme, was identified as the most popular.

Through this practical exploration, methodological guidance has been provided for the modern reinterpretation and innovative design of traditional Chinese culture. It is also hoped that this design practice will inspire greater interest in, and respect for, traditional culture among designers, thereby supporting the ongoing inheritance and creative evolution of Chinese cultural heritage. It is anticipated that the application of this design concept will continue to broaden, with more elements of traditional Chinese culture being successfully integrated into modern design.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

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Дослідження проектування моделей повсякденного взуття на основі граматики форми

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Анотація. Дослідження було спрямоване на інтеграцію культурних елементів мостів Чжуцзяцзяо в Шанхаї у дизайн моделей повсякденного взуття з використанням граматики форми та методу нечіткого оцінювання. Дослідження було зосереджено на чотирьох знакових мостах – Release, Huimin, Chenghuangmiao та Yong'an – з яких було виокремлено та перероблено характерні візерунки для створення колекції декоративних елементів. Ці візерунки були доповнені кольоровою гамою, натхненною ландшафтом водного міста Цзяньньань. Процес дослідження складався з трьох етапів: вилучення елементів мостів за допомогою дизайнерського програмного забезпечення, редизайн цих елементів на основі правил граматики форми для створення колекції візерунків, а також оцінка візерунків і кольорів за допомогою методу нечіткого оцінювання із залученням викладачів і студентів. Граматика форми, визначена як SG = (S, L, R, I), була використана для еволюції початкових елементів мостів за різними правилами, в результаті чого було створено три набори візерунків (SG_1, SG_2 і SG_3). Кольорова гама, що характеризувалася нейтральними тонами та контрастними відтінками, була розроблена шляхом вилучення кольорів з визначних будівель у Чжуцзяцзяо. Було створено дві колірні схеми (C_1 і C_2), які були зіставлені з наборами зразків. За допомогою методу нечіткого оцінювання ці комбінації було оцінено за такими критеріями, як зручність використання, дизайнерські характеристики та привабливість патернів. Результати показали, що комбінація візерунків SG_1 і SG_3 з колірною гамою C_2 була найкращою. Ці оновлені візерунки та кольори були успішно застосовані в дизайні повсякденного взуття, що призвело до створення візуально привабливого та культурно значущого взуття. Дослідження продемонструвало практичність граматики форми в автоматизації процесів проектування культурно-креативних продуктів, збагачуючи дизайн повсякденного взуття традиційними візерунками мостів і водночас сприяючи поціновуванню культурної спадщини в сучасній моді

Ключові слова: культурні елементи моста Чжуцзяцзяо; інтеграція традиційних візерунків; культурна спадщина; китайська культура; сучасне взуття; мода; графічний дизайн