New Interactive-Generative Design System: Hybrid of Shape Grammar and Evolutionary Design - An Application of Jewelry Design

Somlak Wannarumon Kielarova[1(✉)], Prapasson Pradujphongphet[1], and Erik L.J. Bohez[2]

[1] Faculty of Engineering, Naresuan University, Phitsanulok, Thailand
somlakw@nu.ac.th, prapassonp@gmail.com
[2] School of Engineering and Technology, Asian Institute of Technology, Pathumthani, Thailand
bohez@ait.ac.th

Abstract. This paper proposes a new methodology for developing a computer-based design system. It places designers at the centre of design process to perform their tasks collaboratively with the design system. The proposed system is developed based on interactive shape grammar and evolutionary design algorithm, which is able to increase the creativity and productivity of design activity. Designers can utilize the generated designs to initialize their conceptual design process more easily and rapidly. The source of form diversity is derived from genetic operators. Subjective user preference is used for design evaluation. The system can be integrated with computer-controlled model-making machines to automatically build physical artifacts. As a result, designers can easily start their conceptual design process through obtaining the desired designs and the resulting physical artifacts in line. The human-computer synergy is illustrated for the design of jewelry, but it is applicable to other industrial product design problems.

Keywords: Evolutionary design · Evolutionary strategy · Shape grammar · Generative design · Parametric design · Jewelry design

1 Introduction

In conceptual design stage, designers generally carry out activities such as generating design ideas, recording them, and making decisions whether to continue to generate more ideas or instead to explore more possibilities of the preferred existing ones [1]. Therefore, at this stage designers generate a number of various alternatives [2].

Currently, there are various computer-aided design (CAD) packages available in the market. Nevertheless the available computer-aided design packages are mostly used in detailed design stage rather than in conceptual design, because most of CAD systems are not able to suitably support designers in conceptual design activities.

Generative design (GD) system is a computer-based design system that can support designers in divergent thinking throughout design exploration and design generation.

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It enables designers to explore a large design space, which provides a larger range of design possibilities than manual design process [3]. Furthermore, a generative design system can also generate designs that might have not been predicted by designers themselves [4]. Despite design exploration and design generation being crucial in conceptual design stage, most of available CAD systems cannot properly support designers in this stage. The proposed design system was therefore developed to address these issues.

This paper aims to bring the benefits of computer-based design systems into the early stage of design process, which is important for creative design. This paper proposes a generative evolutionary design system, which combines shape grammar and evolutionary strategy algorithm for achieving the above purposes. The system is an interactive design system, which is used for jewelry design application. It is able to increase creativity and productivity of design activity. Designers can apply the generated designs to initialize their conceptual designs more easily and rapidly through obtaining the desired designs and the resulting physical artifacts in line.

The paper is organized in five main sections. The related theories and research papers focusing on topics such as generative design, shape grammar and evolutionary strategy are presented in Section 2. The development of hybrid shape grammar and evolutionary strategy is introduced in Section 3. The experimental results are discussed in Section 4. Finally, the research work is concluded in Section 5.

2 Related Research

2.1 Generative Design

Generative design (GD) is a process that employs computational capabilities to support designers working in design process and/or automate some parts of the design process [5]. GD is expected to help designers in divergent thinking. Singh and Gu had investigated five commonly used GD techniques in architecture [5]. Those techniques are cellular automata, shape grammars, L-systems, genetic algorithms, and swarm intelligence. Their review of the existing literature indicates that most of the available GD systems are developed based on one of the above GD techniques.

Several researchers have studied various issues of GD. One of the most important issues in developing a GD system is user-system interaction. There are different models of user-system interaction depending on the objectives of the uses of GD systems. Chase [4] summarized the user-system interaction paradigms in the following ways: minimal user interaction using optimization techniques; tight control over rule application; and computer generation with user selection. He also explained the possible interaction scenarios, which are categorized into full control, partial control, and no control. Prats et al. [6] recommended that an effective design system should provide a communication channel between designer and the system. An generative design tool that applies partial control interaction model to guide conceptual design process was developed by Orbay and Kara [7]. Tapia [8] developed a shape grammar-based design system, which allows user to define and select rules. Additionally, this system also offers user the selection of control mode such as user control and system control.

There are only a few publications on generative design systems in jewelry applications. The GD system developed by Kumar *et al.* [9] is a geometrical modeling method to generate 3D patterns for traditional Indian Kundan jewelry. Another system was developed by Sharma *et al.* [10]. In this case the relevant CAD system for ornament design industry in India was studied and a GD system named Estampa was implemented. The system can generate ornamental patterns by transforming primitive motifs. A generative design system for jewelry design application was also developed by Wannarumon S. *et al.* [11]. The first iteration of this system was based on evolutionary algorithm. Later on, Shape grammar method was used to create a shape generation mechanism to generate jewelry ring design without considerations of gemstone setting [12].

It can be seen, based on the literature examples discussed above, that shape grammar integrated into generative design systems have a good potential to support design applications in art and design domains.

2.2 Shape Grammar

Shape grammars (SG) were first introduced by Stiny and Gips in 1972 [13]. Four basic components of an SG are defined by Stiny [14]:

- an initial shape
- set of shapes
- set of shape rules
- set of symbols

To generate a design, shape grammar needs sets of shape rules and to perform calculations with shapes in the following order: recognition of a given shape and its possible replacements; compiling rules; and exploring the shape grammar [8, 13]. Shape grammars generate designs by formalizing the spatial relations between their elements [6]. Shape transformations can be explicitly described and used for systematic generation of design alternatives using shape grammars. Alternating the sequence of shape rules can generate different designs. A new type of rule named 'piecewise line-rule' used in conjunction with the decomposition rule to describe and transform curved outlines was presented by Prat [15]. His technique can be used to systematically generate design alternatives.

In this paper, we are interested in the shape grammar technique rather than other techniques, because SG is specifically suitable for form and style generation [5]. Furthermore it can be easily modified to create new design languages with small changes in grammar rules [16]. Several researchers have developed shape grammar-based GD systems for different applications. Stiny and Gips [13] had developed shape grammars for generating paintings and sculptures. In architecture applications, Stiny and Mitchell [17] proposed parametric shape grammar for generating the ground plan of Palladio's villas as Palladian style. The parametric shape grammar that generates the compositional forms and identifies the function zones of Frank Lloyd Wright's prairie-style houses was developed by Koning and Eizenberg [18]. Shape grammars were also implemented in engineering design problems such as roof truss design by Shea and Cagan [19]. Shape grammars were applied in industrial design

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3.1 Shape Gramn

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applications and are illustrated in the following examples. Agarwal and Cagan [20] developed a function-based grammar to design coffee makers. Partial control protocol was applied to set up the interaction between designer and the system by allowing user to select design rules. Pugliese and Cagan [21] proposed a two-dimensional Harley-Davidson motorcycle shape grammar for capturing brand identity. Two-level shape grammars based on shape decomposition method were proposed for Zhuang ethnic embroidery design exploration by Cui and Tang [22]. Kielarova et al. [12] developed a shape grammar-based design system for jewelry design applications. The authors have studied shape transformations in jewelry ring design process to identify transformations of shapes from one state to another, and to develop shape grammar and shape rules.

2.3 Evolutionary Strategy

Schwefel was the first to investigate the evolutionary strategy (ES) and develop the (1+1)-ES system. Later on the scope of ES was expanded by Rechenberg [23]. ES was developed based on the concept of natural evolution. ES was initially applied for parameter optimization. Instead of binary strings real values are used in ES to code parameters. Contrary to genetic algorithm that includes both crossover and mutation, ES uses only mutation. The basic implementation of ES was a two member (1+1)-ES system, where one parent generates one offspring using mutation and the better of the two is selected, while the other is eliminated. In ES, each individual is represented by its genotype and strategy parameters that are both evolved. In order to improve the algorithm for parallel processing with respect to local optima, two general forms $(\mu+\lambda)$-ES and (μ,λ)-ES were suggested [24]. We are interested in ES's abilities to increase diversity of design alternatives.

3 Development of Interactive-Generative Design System: Hybrid of Shape Grammar and Evolutionary Design

We propose an interactive-generative design system based on a hybrid of shape grammar and evolutionary strategy. This research work is extension from the previous research [12], which has studied shape transformations in jewelry design and developed shape rules to be applied in shape grammar to generate new design alternatives. The previously published system was limited in its shape generating capabilities. Therefore a new system is proposed herein. This new system was developed by integrating ES into the shape grammar-based generative design system to generate more preferred alternatives. The outline of this system is shown in Fig.1.

3.1 Shape Grammar for Jewelry Design

The major issue for developing shape grammar systems for jewelry application is the variety of shapes of jewelry items. It is, therefore, necessary to define scope and limitations of the shape grammar to be developed. In this paper, we demonstrate the development of shape grammars, which can generate design elements for designing earrings. Gemstone earrings, shown in Fig. 2, were studied in terms of their characters and shapes for developing shape grammar. The color of the gemstone was not considered. After the analysis, the features of the earrings were abstracted as follows:

- The earrings are set with main gemstones and decorated with minor ones on the top as shown in Fig. 3. This constitutes a strong spatial relationship.
- Choosing different gemstone cuts, as shown in Fig. 4, can vary shapes of earrings.
- Design parameters are size of earring, size of gemstones, gemstone cuts, and shapes of decorative items.

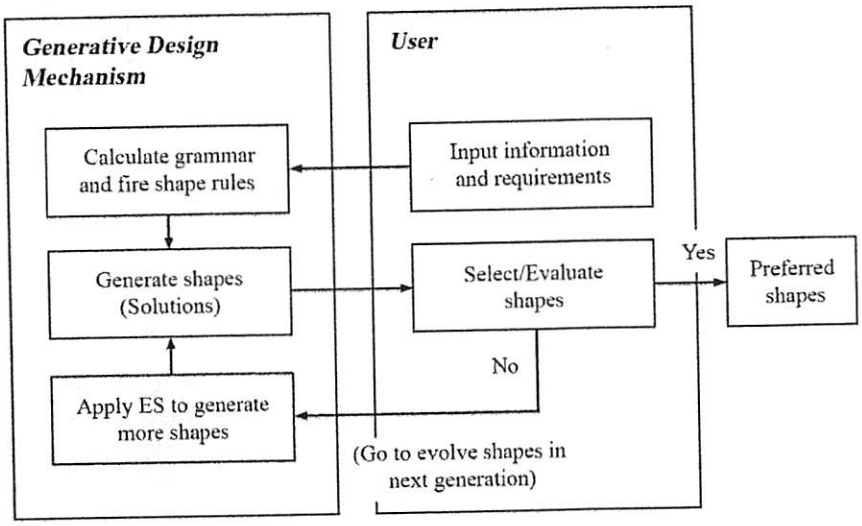

Fig. 1. Workflow of the proposed generative design system

The features described above indicate that it is possible to apply shape grammar rules to represent the gemstone earring design process.

The earring shape grammar consists of sets as follows:

- Shape grammar (SG) = {S_m, S_l, S_d, S_c, R, L, I}
- Set of main gemstone cuts (S_m) = {Round, Oval, Pear, Square, Heart Shape, etc.}
- Set of minor gemstone cuts (S_l) = {Round, Oval, Pear, Square, Heart Shape, etc.}
- Set of shapes of decorative elements (S_d) = {circle, oval, rectangle, square, triangle, other freeform items}
- Set of shapes of connectors (S_c) = {circle, oval, rectangle, square, triangle, other geometric shapes}
- Set of shape rule (R) = {Initial Rules, Shape Transformation Rules, Termination Rules}
- Set of symbol or label (L) = {•1, •2, •3, … }
- Initial shape (I) shown in Fig 3. (b)

The initial shape consists of three main elements: main gemstone; minor gemstone; and connector. The shapes of main and minor gemstones can be varied within the set

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of standard gemstone cuts, i.e. round, oval, pear, square, etc. Transforming a set of geometric shapes and other freeform shapes can vary the shapes of decorative element items. Shape of the connector is limited in geometric shapes such as circle, square, etc. Shape grammar rules consist of initial rules, shape transformation rules, and termination rules. The initial rules are used in the starting step of the generative design process to generate a main gemstone, a minor gemstone or decorative item, and a connector. Furthermore, initial rules also establish their positions.

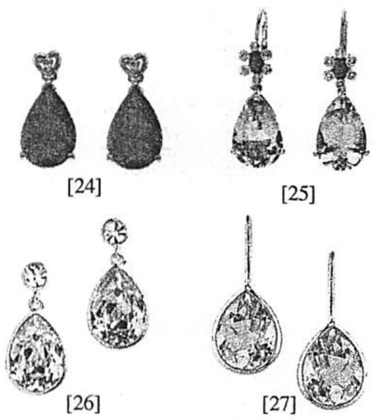

Fig. 2. Examples of earrings [25-28] used for studying their shape grammars

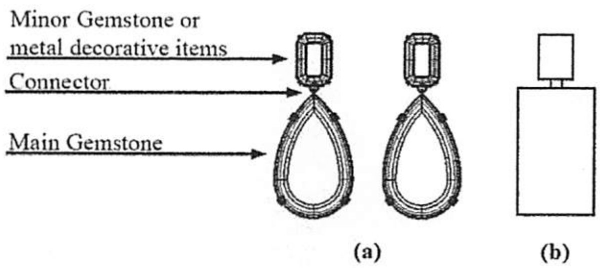

Fig. 3. (a) schematic outline of studied earrings; (b) initial shape

Shape transformation rules were obtained from [12], and are used for adaptation and transition of design elements. Termination rules are used to create and to position gemstone, decorative items, and connectors, when all tasks are finished. After the application of these rules the shape grammar process will stop. Label set is represented by dots in sequence, to signify shape-manipulating sequences along with spatial relationship.

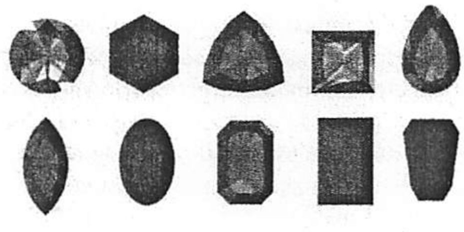

Fig. 4. Examples of gemstone cuts

3.2 Modified Evolutionary Strategy

The concept of evolutionary strategy (μ+λ)-ES is employed to create an evolutionary design algorithm. The process begins by taking the generated shapes (solutions) from the shape grammar process as a set of initial parents. A new evolutionary design algorithm is then implemented in the following order:

1. Choose generated design items as μ parents that contain m design parameters

$$X = (x_1, x_2, x_3, \ldots, x_m) \quad (1)$$

2. Create λ new offspring by mutation.

$$X' = (x_1', x_2', x_3', \ldots, x_m') \quad (2)$$

Applying a random vector of size X with normal distribution performs the mutation

$$X' = X + N(0, s) \quad (3)$$

3. Select μ individuals for next generation from (μ+λ) population of all parents and offspring by user.
4. Repeat steps 2 and 3 until satisfactory solution is found or the defined computation time is reached.
   In the algorithm, no recombination is applied. An example of chromosome used in this process is shown in Fig. 5.

4 Experimental Results and Discussions

The prototype system was developed using Visual Basic script in Rhinoceros 5.0 software [29]. Using the hybrid shape grammar and evolutionary design algorithm method, the proposed generative design system can generate a large number of earring designs within the defined shape grammar depending on the process parameter setting. The generative design system works as shown in Fig.6.

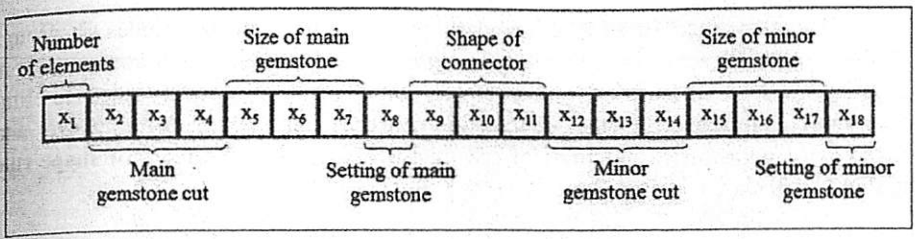

Fig. 5. Example of chromosome used in the evolutionary process

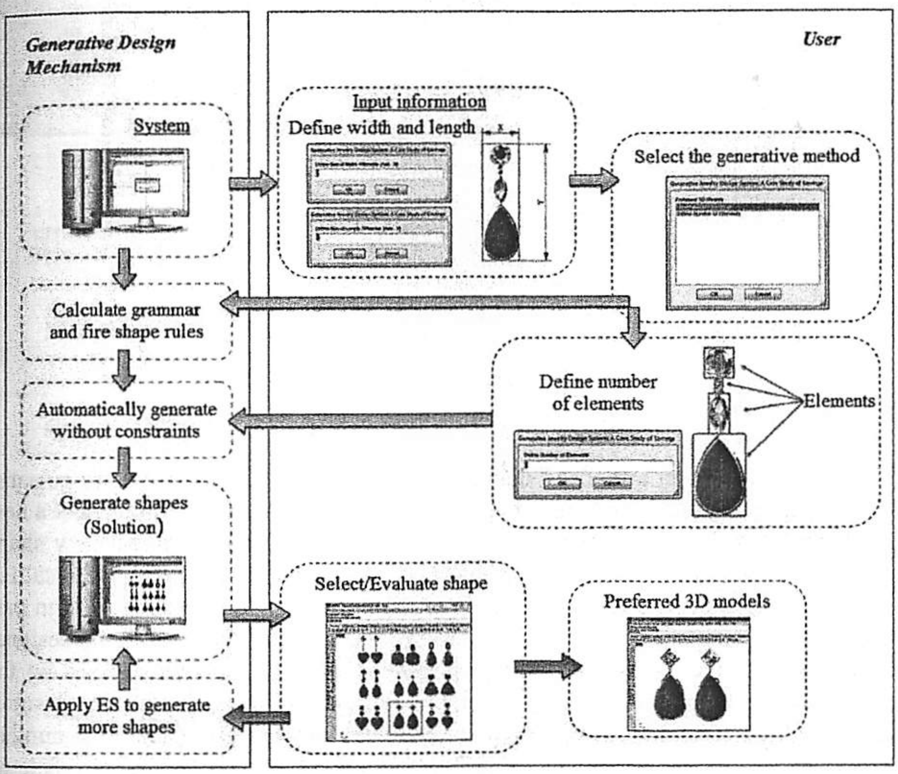

Fig. 6. Demonstration of the system flow

In the experiment, the process parameters set consists of the number of elements, number of gemstone cuts, types of setting, number of connector's shapes, number of outline transformation rules, and number of structural transformation rules. Consequently, the number of all possibilities of earring designs is 1,180,096. Designers can control direction of design generation through the input parameters that are size of earrings, number and size of gemstones, gemstone cuts, and shapes of connectors. The generative design system then will generate initial shapes. The system calculates shape transformations for all possibilities in the design space, calculating from the input parameters. The system applies the rules to the shapes and then generates a set of possible shapes according to the predefined shape rules, which includes six groups of rules: outline transformation rules (straighten, bend convex, bend concave, etc.); structure transformation rules (mirror, rotate, add element, etc.); safety rules (to eliminate sharp edges/corners); rules of selecting gemstone cut; rules of defining sizes and positions of gemstones; and rules of creating connectors. An example of shape rule application is shown in Fig. 7.

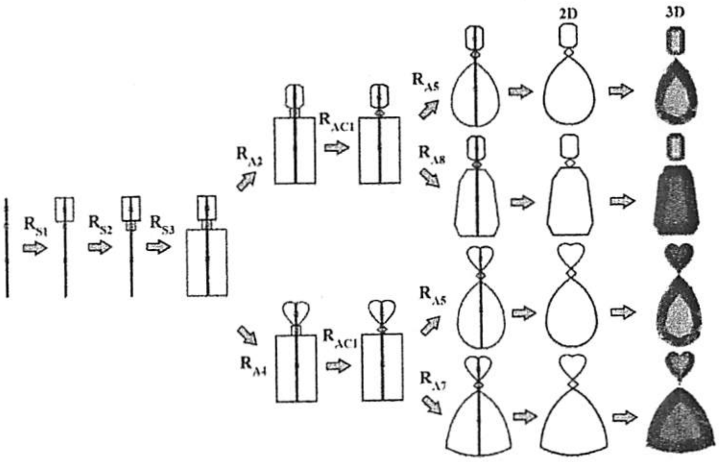

Fig. 7. Example of shape rule application used in earring design

Designers can select a favorite shape to continue the process. If there are no satisfactory shapes, they can track back to create/select a new initial shape or select a new rule from thirty-five shape rules, or define a new position/condition for new shape generation. After calculating the parameter data, and applying the rules, the resulting designs will be shown to user to select from them the ones to be used as design parents in the evolutionary design process. The process runs iteratively until the designer terminates it. In the evolutionary process, more designs are generated based on the selected ones. Thus, the designer can obtain a family containing the favorite designs. The number of generated designs from evolutionary process depends on the number of parents. The system allows choosing 20 generated designs as parents to create 60 new offspring by mutation. After that the system selects 20 individuals for next generation. In this evolutionary process, the designer works as the fitness function. Therefore different user can generate different set of designs. In other words, the system can generate designs according to user's style. The generative design system can work as an external working memory for imaginary process, which can solve overload of visuospatial working memory of human designers. The system can also be integrated with computer-controlled model-making machines to automatically build physical artifacts. As a result, designers can easily start their conceptual designs through obtaining the desired designs and the resulting physical artifacts in line.

Figure 8 (on the left) shows some of the resulting designs generated by the system in an example where a designer defines the input parameter of main gemstone as pear cut. On the other hand designs obtained when no inputs were defined, and the system ran automatically, are shown in Fig. 8 (on the right).

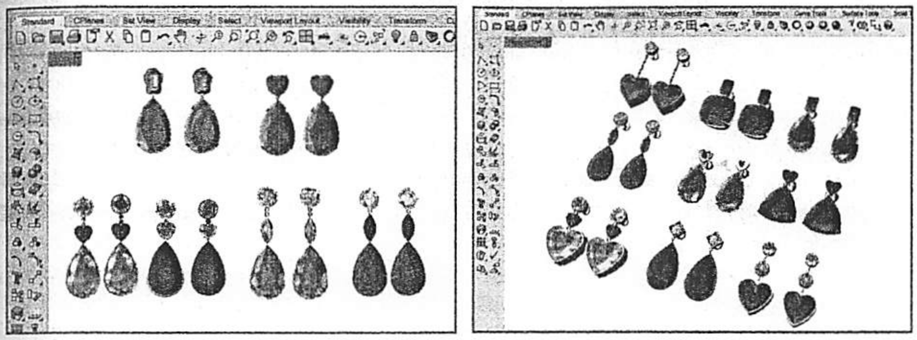

Fig. 8. Example of the resulting earring designs generated by the system

Furthermore, the design elements generated by the system can be used for designing a set of earrings and pendant as shown in Fig. 9.

Fig. 9. Example of a set of earrings and pendant generated by the system

A workshop was organized for five participants who were given the task of designing jewelry earrings using the generative design system. All participants were satisfied with the performance of the system. They remarked that the system is easy and intuitive to use. However, they required a short amount of time to become familiar with the system.

5 Conclusions

This paper presents an interactive-generative design system, which is a hybrid of shape grammar and evolutionary strategy. The system is designed to allow user to work with it semi-interactively in both shape grammar process and evolutionary design process.

The generative design system can support designers to automatically generate gemstone earring shapes based on input parameters such as earring size, gemstone size, gemstone cut, and shapes of connectors. With the integration of evolutionary strategy algorithm, the proposed design system can increase the number of generated earring designs. This system thus can operate as an external working memory for imaginary process, which can solve the overload of visuospatial working memory of human designers. The system can generate emergent shapes that play a part in solving idea saturation during conceptual design. As a result, the proposed system can support designers in a creative and productive manner. The system can be integrated with rapid prototyping and computer numerical controlled machines to automatically build physical artifacts in line.

In further works, the system could be extended for evaluating the aesthetic scores and presenting to customers through web-based design system.

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References

1. Kolli, R., Pasman, G.J., Hennessey, J.M.: Some considerations for designing a user environment for creative ideation. In: Interface 1993, pp. 72–77. Human Factors and Ergonomics Society (1993)
2. French, M.J.: Conceptual Design for Engineers. Design Council, London (1985)
3. Krish, S.: A Practical Generative Design Method. Computer-Aided Design **43**, 88–100 (2011)
4. Chase, S.C.: A Model for User Interaction in Grammar-based Design Systems. Automation in Construction **11**, 161–172 (2002)
5. Singh, V., Gu, N.: Towards an Integrated Generative Design Framework. Design Studies **33**, 185–207 (2012)
6. Prats, M., Lim, S., Jowers, I., Garner, S.W., Chase, S.: Transforming Shape in Design: Observations from Studies of Sketching. Design Studies **30**, 503–520 (2009)
7. Orbay, G., Kara, L.B.: Learning geometric design knowledge from conceptual sketches and its utilization in shape creation and optimization. In: ASME Conference, pp. 683–691 (2009)
8. Tapia, M.: A Visual Implementation of a Shape Grammar System. Environment and Planning B: Planning and Design **26**, 59–73 (1999)
9. Kumar, G.V., Garg, T.K., Puneet, T.: Geometrical Modeling of 3D Patterns for Traditional Indian Kundan Jewelry. Int. J. of Engineering Science and Technology **3**, 5666–5670 (2011)
10. Sharma, S., Singh, Y., Virk, G.S.: Study on Designing and Development of Ornamental Products with Special Reference to the Role of CAD in it. Int. J. of Current Engineering and Technology **2**, 443–447 (2012)

11. Wannarumon, S., Bohez, E.L.J., tal-based User-centered Jewelry
12. Kielarova, S.W., Pradujphongph System: Jewelry Design Applica
13. Stiny, G., Gips, J.: Shape gramm ture. In: Information Processing
14. Stiny, G.: Introduction to Shap Design **7**, 343–351 (1980)
15. Prats, M.: Shape Exploration in ton Keynes, UK (2007)
16. Alcaide-Marzal, J., Diego-Más, ratory Study on the Use of Digit **34**, 264–284 (2013)
17. Stiny, G., Mitchell, W.J.: The p and Design **5**, 5–18 (1978)
18. Koning, H., Eizenberg, J.: Th Houses. Environment and Plann
19. Shea, K., Cagan, J.: The Desig the Ability of a Computational sign Intent. Design Studies **20**,
20. Agarwal, M., Cagan, J.: A Ble vironment and Planning B: Pla
21. Pugliese, M.J., Cagan, J.: Capt a Motorcycle Shape Grammar.
22. Cui, J., Tang, M.-X.: Integrati Ethnic Embroidery Design Ex
23. Beyer, H.-G., Schwefel, H.-P.:
24. Dianati, M., Song, I., Treiber, Strategies. Technical Report. U
25. Right Honghua Development
26. Goldies Jewelry Inc. http://ww
27. Charles Jewelry Inc. http://cha
28. C Jewelry Fashion Inc. http://
29. Rhinoceros Software. http://w