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Folding Agent: Parameter Visualization in 2D-to-3D Pattern Transformation

Chiung-Hui Chen

Asia University, 7451616@gmail.com

Abstract. An important research field of artificial intelligence at present is the intelligent agent. The emergence of the software agent provides students in the field of design with conceptual skills, such as parametric design and derivative design, which makes the exploration of complicated shapes possible through computing. Therefore, in the field of visual design, it is very important for students to learn the application of parameters and train their thinking in parametric design. In this study, through the discussion of the characteristics of folding, the visualization simulation system of folding parameters was introduced into the course of three-dimensional constitution design to improve the ability of students in the field of visual design to transform 2D patterns into 3D folding patterns.

Keywords: Visualization; simulation; folding; pattern.
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1 INTRODUCTION

The intelligent agent is a branch developed from artificial intelligence, which helps humans solve problems by simulating human thinking and problem solving. According to the definition of Webster's New World Dictionary, an agent has two characteristics, that is, an agent can execute things and represent others. In terms of hardware, the robot is a kind of agent; in terms of software, the agent is a computer system in the environment, which can present certain behaviors in a flexible and automatic manner to accomplish the tasks assigned to it. Since the beginning of the 1990s, when agent had a complete architecture, theory, and language, the software agent was gradually put into practice. Since the middle of the 1990s, due to the emergence of a large number of open distributed computing modes and the environment Internet, as well as the knowledge representation tools of computing and an information communication mechanism, multi-agent systems have gained more attention [27].

The emergence of software agents makes the fields of architecture, industrial design, and visual design jump from traditional drawing and model presentation. With the concepts and skills of parametric design and derivative design, the exploration of complicated shapes becomes possible through computing. The digital model, as developed in the design process, can also solve efficiency problems through software, such as structure and cost analysis, and assist with computer-aided manufacturing, From the development of the concept to the generation of digitalization, and finally, the continuous digital process of digital manufacturing, the design process has undergone comprehensive innovation.

Therefore, the introduction of parametric intelligent software for design teaching is a topic worthy of discussion. A characteristic of the parametric design method is that it can form a continuously changing appearance by adjusting the parameter values under the existing logic architecture of the calculation, and thus, achieve real-time adjustment, analysis, and evaluation of the design scheme to make the design process a feedback mechanism. With the development of artificial intelligence, in the course of three-dimensional composition design, it is very important to make students in the field of graphic design study the application of parameters and train their thinking in parametric design. "Folding", which is a technique of design operation and helps students to learn the construction of basic shapes, is often used as a training method in the initial stage of three-dimensional design. This study constructed folding design teaching that introduces parametric design thinking based on the characteristics of folding, and then, validated the folding operation by practical teaching.

In order to improve the ability of students in the field of visual design to transform 2D patterns into 3D folding patterns, this study introduced the folding parameter visualization simulation system Origami Simulator, as jointly developed by the Center for Bits and Atoms, Massachusetts Institute of Technology and the Artificial Intelligence Laboratory [1][2][7]. This system has the function of "intelligent automatic folding", which takes the fold texture as the program base and digitizes the fold through the simulation system. Different from the procedural steps of traditional folding, automatic folding is a way of synchronously folding different graphics on the same plane; therefore, intelligent automatic folding can omit excessive folding steps, and take different graphics as the fold texture to generate the folding patterns, in order to produce the desired results.

2 RESEARCH PURPOSE

Based on the above, this study discusses how to introduce parameterized intelligent software into folding design teaching, in order to reduce the technical threshold for students' learning of parametric design in the field of graphic design, integrate traditional and parameterized applications, and improve students' ability in both traditional and digital design thinking. The research framework is shown in Figure 1, including the application of the intelligent agent in three aspects of folding design teaching. The research purposes include:(1)summarize the folding texture and folding patterns through literature review, and discuss the functions of folding, the calculation rules of folding texture, and the appropriate teaching practices;(2)integrate parametric design thinking into the three-dimensional folding design course through the experimental teaching method;(3)summarize a mutual application thinking mode for 2D combined with 3D parameter visualization for the folding design teaching course.

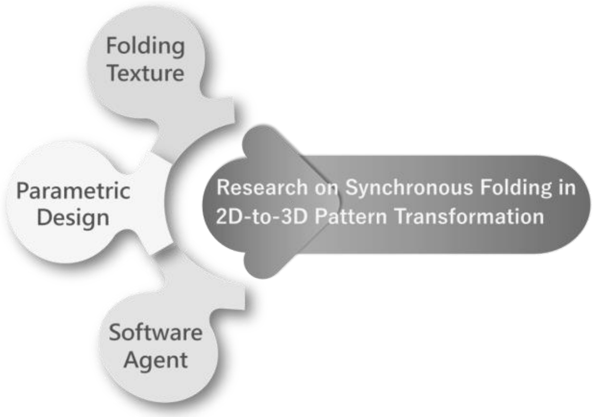


Figure 1: Software agent in the three aspects of 2D texture with 3D parameter visualization.

3 LITERATURE REVIEW

According to the needs of the research purpose, the important references collected at present are further elaborated according to different topics, as follows:

3.1 Folding and Application

Folding has the abilities of dimension transformation and shape transformation, and thus, has become one of the design methods that designers like to use. Kostas Terzidis [24] mentioned in *Expressive form* that "folding" is a complex process, which has the ability to transform the dimensions of the objects; for example, a two-dimensional thin plate can be transformed into a three-dimensional object through the folding method, and due to this characteristic, folding is widely used in daily life. Many professional disciplines also take folding as the research theme, ranging from protein folding to space engineering. In addition to changing the appearance of objects, the process of the change across dimensions is an interesting topic for exploration [5]. However, the folding technique is an invention of human beings. The most common folding phenomenon in nature is the blooming process of flowers. There is a dynamic relationship between folding and unfolding, which is achieved through symmetry, synchronicity, and sequence [24].

Folding is widely favored by all walks of life due to its unique geometric beauty, thus, it is often used as the research object in the fields of fashion, science, machinery, and architecture. The concept of expandable and scalable folding is widely used by engineering and design fields in products with dynamic folding design, including the extended solar panel for the International Space Station [28], the telescopic operating table shield used in sterilized operating rooms [8], deformable remote control vehicles for search and rescue [17], and dynamic exterior walls for adjusting the indoor physical environments of buildings [25].

The increasingly mature digital tools can simulate the dynamic appearance in the process of folding, and designers can choose the form of folding by setting different parameters, determine the movable free angle of a completed work, and even combine digital manufacturing tools to realize the simulation object in the real world; however, there are many different challenges in this process [26]. Jackson [12] developed multiple folding textures, including the single fold texture, parallel line texture, radial line texture, V-shape texture, X-shape texture, and complicated-shape texture, thus, providing a method for designers to apply the concept of folding to design. Jackson held that we should start with the most basic folding technique, i.e., folding in half, and then, develop more complex folding textures in the process of actual folding, in order to explore the various possibilities. The parallel-line folding unit and radial folding unit can be developed by continuous folding in half, as translation, reflection, rotation, and glide reflection can be repeated through the texture patterns of small units.

3.2 Characteristics of Parametric Design

Parametric design is the mainstream of design research and creation in recent years, as it is very helpful for design thinking because it can create complex 3D patterns and continuously give feedback to designers in the process, and the generated data can be extracted in various ways to link and derive new geometric forms and relationships [3]. The thinking of parametric design is different from the previous ways of thinking, as designers can obtain various design possibilities through various parameters and variables in the operation [24]. Moreover, some unexpected results of shapes may be presented during parameter adjustment, arousing surprising design stimuli to the designers.

The advantages of parametric design lie in the various parameters, which would form a dynamic but firm structure in the design process according to certain rules, and through the real-time processing of massive data computing by a computer, the design process becomes a dynamic feedback mechanism and is transformed into a visual presentation, which is totally different from the traditional designers' logic of directly determining the design form based on intuition and experience [24]. As the operation process of parametric design involves logic and program, in order to make it easier for designers to understand and operate, some parametric graphics software would simplify the complex program principles into relationship icons for operation. Every step input by the designer would be stored in the computer memory, that is to say, the computer would record all steps and input variables, and if there is a causal relationship between the input actions of the designer, it can go back to any step in the design process at any time. After the change is completed, the computer will automatically recalculate the original follow-up steps, thus, saving time lost due to repeated actions.

3.3 Artificial Intelligence and Software Agent

The intelligent agent is one of the important research fields of artificial intelligence. From the end of 1970s to the beginning of 1990, researchers focused on the theory of software agents. Hewitt first proposed a software module with independent organization, interaction, and parallel processing, called Actor, which became the original concept of the software agent [11], followed by DVMT [18], MICE [6], etc. Gasser [10] put forward the concept of a macro agent, which focuses on the characteristics of the agent's social ability, that is, it would communicate and share information with other agents through its social mechanism to jointly complete common tasks.

Since agents have complete architecture, theory, and language since the 1990s, the software agent has gradually been put into practice. Wooldridge believed that the concept of an agent community began to appear in the 1980s, while the multi-agent system, as a knowledge representation tool of computing and an information communication mechanism, has been paid more attention since the middle of the 1990s due to the emergence of a large number of open distributed computing modes and the environment Internet [27].

In other words, the behavior of an agent has autonomous characteristics, just like the operational mode of human society. The agent system divides the tasks to be executed into many sub tasks according to the complexity of the problem, which will then be performed by specific program modules. The sub tasks can be further subdivided into smaller sub tasks, which will be completed through the work division and cooperation among the sub modules divided under the modules. In this way, the whole system is composed of different agents according to the specific subordinate, parallel, or independent relationships between the function and the task, thus, forming a multi-agent environment.

3.4 Analysis and Comparison of Folding Systems

This section describes the analysis and comparison of the folding visualization simulation systems. The case systems include six representative systems, namely, Tree Maker, Pepakura Designer, Oripa, Origamizer, Reference Finder, and Origami Simulator. The purpose is to understand the limitations and characteristics of each system.

- Tree Maker

Lang [13] conducted in-depth research on base graphics and developed the origami algorithm of circles and rivers to calculate the square origami graphics of natural objects according to the characteristics of their shapes. The software developed with this method was named Tree Maker, which allows users to define the limb structure characteristics of the origami shape, calculate and produce the corresponding origami graphics through the circles and rivers algorithm [4][14][19] and finally, the origami works would be completed by the designer by hand.

- Pepakura Designer

Pepakura Designer [23] can make an exterior expansion graph based on the imported 3D object model, and automatically produce or allow the user to define the segmentation field and expansion mode. After the user outputs the origami graphics, they can collage a paper model similar to the original 3D object.

- Oripa

Oripa is an origami texture editor with visualized operation [9][20]. Users can edit the origami graphics according to the type of lines pre-defined in the software, and then, process the simulation. Oripa presents the folded state in the form of a perspective drawing.

- Origamizer

Tucking is the most widely used technique to hide the redundant parts of paper folding. Tachi [21][22] introduced this technique into a digital system and further developed the software Origamizer, which can analyze the surface of origami works into hundreds or thousands of small folds, and divide Tucks into “Vertex Tuck” and “Edge Tuck” by using the characteristics of the paper, in order to calculate the origami graphics inside the origami works. With this algorithm, Origamizer can flatten any origami work into a seamless origami graphic.

- Reference Finder

Lang [16] established a set of computer-based line positioning system for the “open” and “close” behaviors of origami, as based on the binary system, and named it the Reference Finder. The Reference Finder [15] is a database system, which indexes several solutions according to the x y coordinates of the fold line position required by the user, in order to fold it closest to the position required by the user with as few steps as possible.

- Origami Simulator

This system is an online system jointly developed by the Center for Bits and Atoms, Massachusetts Institute of Technology and Artificial Intelligence Laboratory [1][2][7] and is quite different from the above five software systems. The Origami Simulator does not perform the folding behavior under a series of program actions; an iterative algorithm conducts the synchronous folding of several folds to produce the minimum displacement on the planar geometric shapes. The user can set the equal-view-angle 3D view (view Iso) to observe the changes in the transformation simulation from a 2D texture into a 3D texture. It also allows the user to write programs, which will then visualized by the system through arithmetical data.

Through the above evaluation and analysis, we can see that there are some differences in the functions and characteristics of these six systems. This study believes that an appropriate teaching simulation system must be able to assist students in the field of graphic design to improve their ability in design thinking for transforming from 2D to 3D folding. In particular, both Pepakura Designer and Origamizer have the limitation that users must be able to construct 3D files before operating the system, which is very difficult for students in the field of graphic design, and thus, will reduce their learning motivation. Therefore, this study introduces the Origami Simulator system into teaching, which can integrate with other 2D vector graphics software. Table 1 shows the characteristics and differences of these six representative systems.

Name of the folding system	*Characteristics*	*Input Condition*	*Visualization*
Tree Maker	Construction of folding appearance by 2D texture with geometrical relationship.	Functions defined in the system.	Assist the user to define the structural features of the origami shape.
Pepakura Designer	Expand the object to generate 2D folding texture through a 3D object by means of planar analysis.	3D object file.	Export expansion views of the 2D folding texture.
Oripa	After completing the 2D folding texture with the line editor, simulate the 3D appearance after folding.	Functions defined in the system.	Assist the user to draw folding texture and generate perspective drawing.

Origamizer	Expand the object to generate 2D folding texture through a 3D object by means of planar analysis.	3D object file.	Assist the user to draw folding texture.
Reference Finder	Fold closest to the position required by the user and begin with as few steps as possible.	Enter the X and Y coordinates of the fold point with the fold line positioning system.	Assist users to construct the program diagram of the 2D folding texture.
Origami Simulator	Automatic folding Synchronous expansion and closing.	Imported SVG (scalable vector file) Description data (programmable) 3D object file.	Transform the 2D texture into 3D folding in real time to produce digital texture forms, and then, parametrically derive a variety of folding shapes with varying angles.

Table 1: Comparison analysis of folding systems.

4 RESEARCH CONTENT

This study derives a set of intelligent folding patterns from the observations of folding in the process of a teaching experiment, and discusses the relationship between the folding texture and the shape by combining the automatic folding simulation system (Origami Simulator). This research content mainly consists of three parts: folding textures, the logical rules of folding textures, and the variability of folding

In this study, the basic design course "three-dimensional composition design", as offered by the Department of Visual Communication Design of Asia University, Taiwan, was taken as the experimental course, which is a 3-credit practical course. The main reason for choosing this basic design course is that it is offered by the university where the author works as a lecturer, thus, it is easier to obtain the complete records of the data. In addition, this basic design course for students at lower grades aims to train their basic aesthetic ability and media operation, which is commonly applied in different design fields. In view of the above factors, this course is suitable for the research content of this study.

a) In the first stage, the author conducted the research mainly through literature review and practice, in order to construct the digital textbook of folding texture. Through literature review, six kinds of basic folding textures and folding patterns were summarized: single fold texture, parallel line texture, radial line texture, V-shape texture, X-shape texture, and complicated-shape texture, as shown in Figure 2.

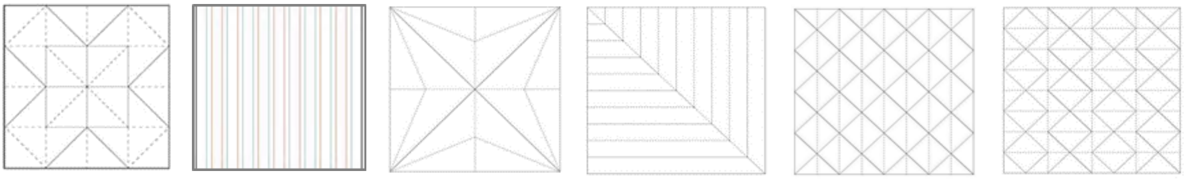


Figure 2: Six types of folding textures: (a) Single fold texture, (b) Parallel line texture, (c) Radial line texture, (d) V-shape texture, (e) X-shape texture and, (f) Complicated-shape texture.

b) Analyze the above six kinds of folding textures to determine the rules of folding textures, and then, construct the 2D digital textures. Figure 3 shows the change of folding shapes during the transformation from 2D to 3D folding, and then, the six kinds of digital textures are applied to the practice of digital textbooks. The variability of different folding textures can be derived from various actions, such as the translation, dislocation, reflection, and repetition of digital textures.

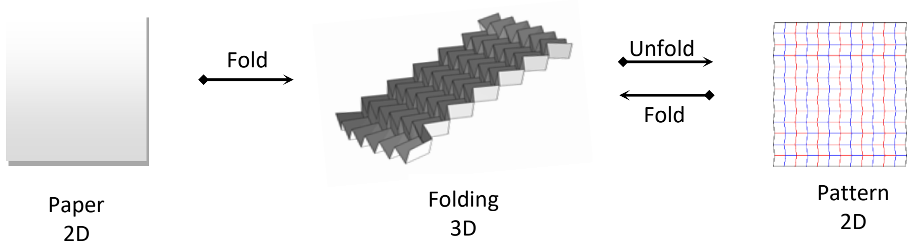


Figure 3. Change of folding shapes during transformation from 2D to 3D folding.

c) Data-oriented operation of folding textures: the data-oriented operation of drawing numerical rules with computer geometry is to establish students' integrated thinking ability in the transformation from 2D texture to 3D folding parameters. The operation procedure of folding texture is shown in Figure 4, in which six kinds of folding graphs are developed into six kinds of digital folding textures in sequence, which is also the logical rule for students to operate. This study refers to 6 kinds of folding patterns: single fold pattern, parallel line pattern, radial line pattern, V-shape pattern, X-shape pattern, and self-organized unit pattern, which are imported into the simulation system, meaning the Origami Simulator, to carry out 3D transformation for the six kinds of folding patterns.

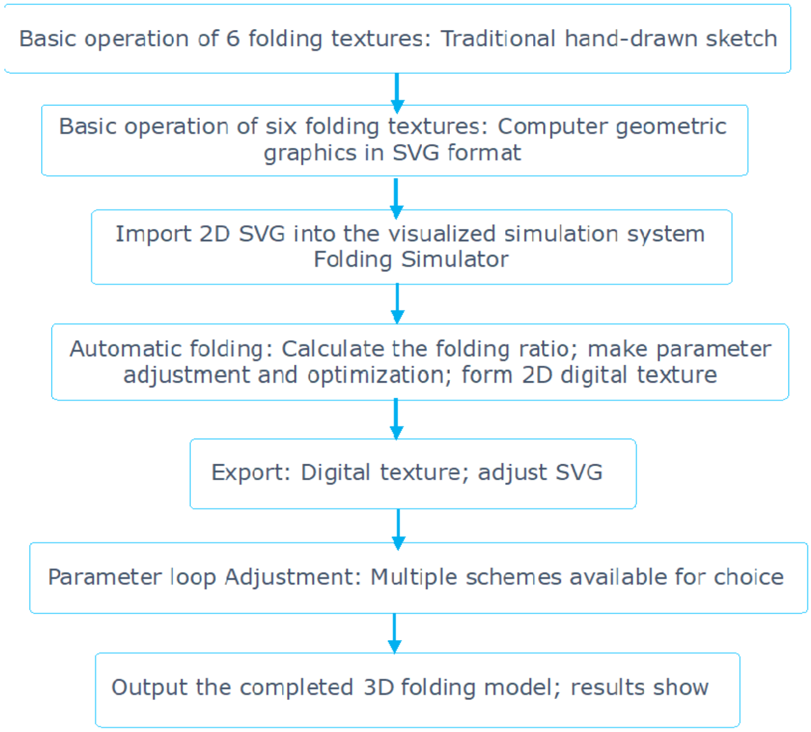


Figure 4: Procedure of data-oriented operation.

d) Taking the application unit of a spring storybook manual as an example to carry out automatic folding. First, establish an X-shape texture, use the replication function, and rotate 45 degrees, and then, conduct left translation until reaching the overlapping state. The included angle of the texture is 45 degrees, and the folding ratio parameters of the visualized parameters imported to simulate the synchronic folding are 20%, 40%, 60%, 80%, and 90%, respectively. Students can change SVG parameters repeatedly during operation, observe their changes in real time, and select the most suitable scheme to output the physical work, as shown in Figure 5.

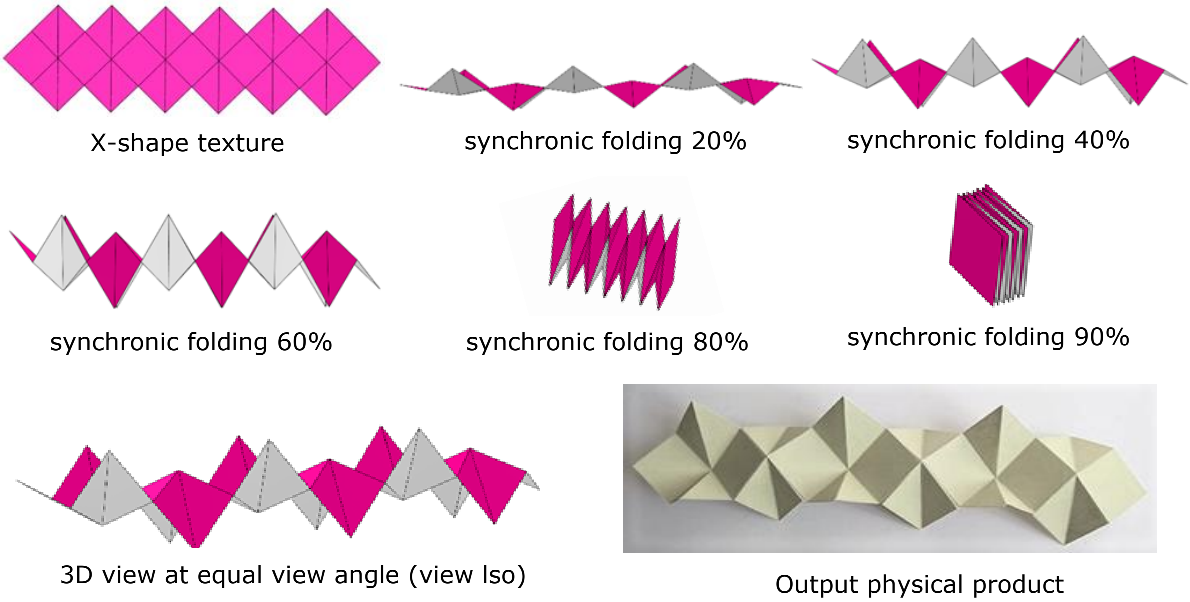
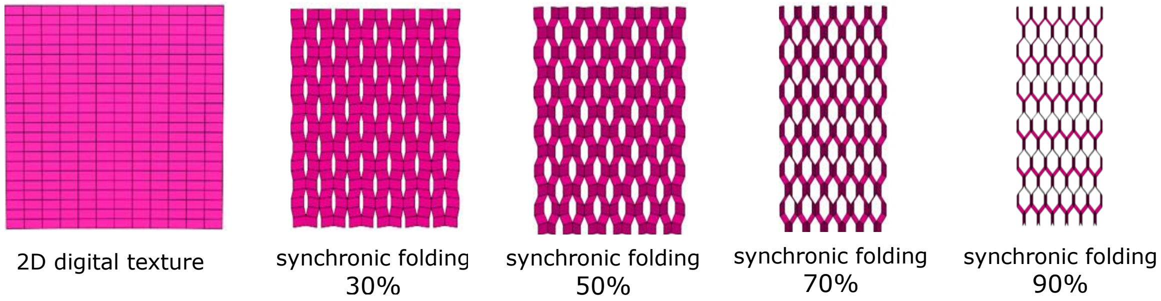


Figure 5. X-shape texture: The included angle of the texture is 45 degrees, and the folding ratio parameters of the visualized parameters imported to simulate the synchronic folding are 20%, 40%, 60%, 80%, and 90%.

e) Creative application of folding skills: goal-oriented operation aimed at the application in design (see Figure 6), where the purpose is to train students to transform design problems into analysis logic and obtain results combining the application of software simulation, in order to improve their ability of applying folding in design through practice.



3D view at equal view angle (view Iso) | Observe the change of 3D | Output physical product

Figure 6. A kirigami honeycomb pattern in different stages of evolution.

5 CONCLUSIONS AND FUTURE STUDIES

Through the discussion of the characteristics of folding, this study constructed a folding design pattern that introduces parametric thinking, which intends to improve the ability of students in the visual design field to transform 2D patterns into 3D folding shapes, and to verify the feasibility of synchronic folding operations with practical teaching. The preliminary research results show that a software agent enables students in the visual design field to use parametric design skills, thus, freeing them from the traditional ways of graphics and model presentation. By exploring the change of 3D shapes, as derived in the folding process under the influence of angles, and with the application of the fold ratio, we could solve the problems of material waste and efficiency.

In the follow-up research, we will introduce the folding technique into the application of creative design from the market point of view, which is mainly guided by the practical goal of design, training students to transform design problems through the logic of analysis, and simulating the best scheme with the application of a parameter system, in order to improve their abilities in applying folding to creative design through practice. An evaluation questionnaire can be designed to compare and analyze students' design drawings produced by these three media (hand drawing, 2D computer graphics, and the folding visualization simulation system) and the works created with the application of folding.

Chiung-Hui Chen, https://orcid.org/0000-0002-2917-1888

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