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TIME-BASED FORM TRANSFORMATION IN FOLDING SPACE

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Abstract. *Design activity could be treated as state transition computationally. In stepwise processing, in-between form-states are hardly to be observed. However in this research time-based concept is introduced and applied in order to bridge the gap. In architecture, folding is one method of form manipulations and architects also want to search for alternatives by this operation. Besides, folding operation has to be defined and parameterized before time factor is involved as a variable of folding. As a result, time-based transformation provides sequential form states and redirects design activity.*

1 INTRODUCTION

Design activity is one process of doing design. So does architect manipulates target forms. Generally, form wouldn't pop up suddenly and jumps to the architects' desk. Instead, it needs certain time to develop/grow and even interact with designers by outer shapes. Hence, in this research, we extent form transformation with time and apply on folding method which is relative to time issue on development of architecture history.

1.1 Time-based media

In terms of human thinking, design activity happens according to solution and its design process as well as has the natural feature – "continuity". As time involved, time-based media is more appropriate than traditional one to describe spatial experience or relationship by representing design features dynamically[2]. On the other hand, design state is static itself, but sequential design statues would compose one dynamic design process[10], that is what time-based media contribute to.

1.2 Form transformation

For a long time, form has been an essential topic for architecture to involve in and devote to their intelligence. Basically, form is one of main outer features of physical architecture to represent designers' concepts and express itself to people. Transformation is applied generally to anything that undergoes a process of change[4]. It not only indicates that architecture has evolved through as orderly, step-by-step process but also suggests rationality and a narrative in what has been done. There many methods of transformation such as shear, compression, distortion and etc.

1.3 Folding spaces in architecture

Among these diverse methods, "folding" manipulation is considered as one of key directions in current form exploration experiments. Folding in architecture was first brought up in Peter Eisenman's work – "Rebstock Master Plan" (Figure 1).

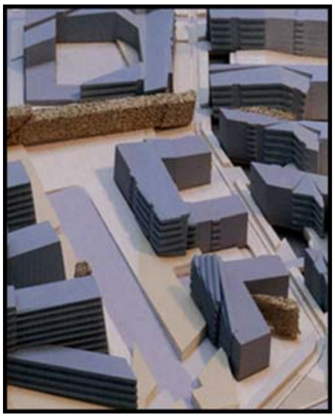

Figure 1: Site model of Rebstock Master Plan (1990~1991)

Certainly, Eisenman is not the only architect to adopt folding to frame design ideas. The book called "Folding in Architecture"[8] edited by Greg Lynn shows some inspiration on how folding might affect design and design process. From their work, we could observe the final result and outcome.

1.4 Summary

Since enlarging the folding manipulation by time-based computational tool is our objective, there are two main issues for us to study, one is the **computational mechanism of form-folding operation** and the other is how to **put time factor into transformation**.

2 RELATED RESEARCHES AND PROJECTS

From previous sessions, the related works can be divided into design issue and computational issue. The former is for discovering and surveying the possible diagrammatic exploration in form transformation. The latter is helpful for establishing logical description.

2.1 Design state

In [11], one state space is a description to illustrate configuration of state and applied to CAD system to solve problems with set theory and grammars mathematically. And each design process is one node in state space and represents temporal design result for adding following manipulation. Furthermore, transformation between nodes of state space also stands for operation has activated. Figure 2 indicates the design state transformation application [10].

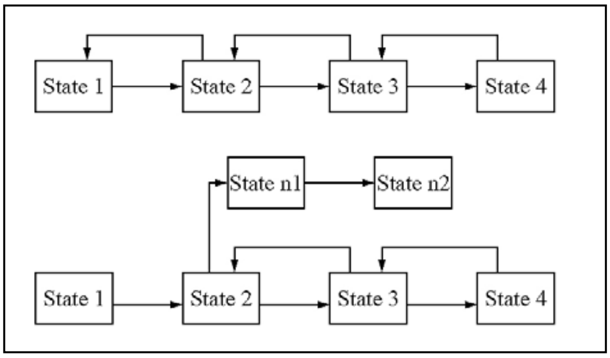

Figure 2: Design state and transitions

Therefore, in our research, we treat time as internal factor of diagrams generations. With interactive manipulating over time and geometry transformation operations, we can observe in-between geometry transformation, and explore alternative possibilities of geometry results within design process.

2.2 Fold-relative architecture

In the fold-related projects, there are three ones are noted clearly in “Diagram Diaries”[5]. There are Framkfurt Rebstockpark, Alteka Office Building, and Emory Arts Center. In term of operation, Eisenman treated fold could orient the direction of building volume and this new in-between shape beard no conceptual relationship with ground. “It was another step in the processing of moving away from ground as a defining condition of architecture” was addressed by Eisenman.

These related projects above are our focal point to search for and deduce the designer’s intention and process of creation by means of reading statement or working records. Apparently, this information reflected design concept and contour our ideas, but is rarely related to detail manipulation. Therefore, some practical study result has to be considered and extract workable method to follow. And related research about computational fold is described as followed.

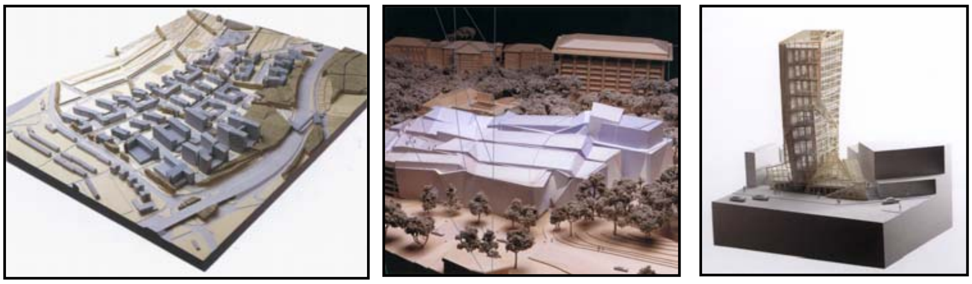

Figure 3: Three folded projects. RebStick Plane, Emory Arts Center, and Alteka Office Building

2.3 Computational folding

In handicraft art, the term folding is treated as paper-folding and it's the other usual call –"origami". Origami (pronounced or-i-GA-me) is the Japanese art of paper-folding, which means folding a sheet of paper without cut or intersection. That is how origami got its name. However, origami did not start in Japan. It began in China in the first or second century and then spread to Japan sometime during the sixth century.

- Axiomatic Origami

  According to [6], Huzita has announced a systematic study and a set of six axioms of defining a single fold by aligning various combinations of points, lines, and fold lines. Furthermore, Lang pointed out the seventh axiom to complete the basic folding operation.

- ReferenceFinder

  "ReferenceFinder" was one program developed by Robert Lang, which calculates angle and position of folding crease to supply certain crease lines for desired fold. Typing in a numerical or algebraic expression for the coordinates of a point or a line, ReferenceFinder immediately returns the five "best" short folding sequences that approximates that point or line.

- TreeMaker

  Throughout long history of origami, most origami design has been carried out by a combination of trial and error based on folder's intuition until Lang[7] presented a complete algorithm for designing an arbitrary origami. "TreeMaker" is one computer program constructed by Lang that implements the tree method for origami design. Lang's research is based on the geometry of crease line and mathematics behind it. Lang provides clues to help designers control their design process for achieving more complicated goal.

3 METHODOLOGY

3.1 Defining folding operation

In order to establish the parametric folding process, we adapted "crease pattern" form origami design to define folding operation and its relative elements.

● Crease Plane:

Crease plane is responsible to decide how to divide the initial cuboid into two volumes for folding. Assuming crease plane locates at origin. After dividing, four more new vertexes were added followed by Euler's equation. In this example, dividing initial cuboid equally would get two half cuboids.

● Folding-Base Plane:

Folding-Base Plane is perpendicular to crease plane and distinguishes vertices into two parts: top and bottom groups.

● Folding Axis:

The critical hypothesis is folding axis, which is the intersection line of two orthogonal planes mentioned above.

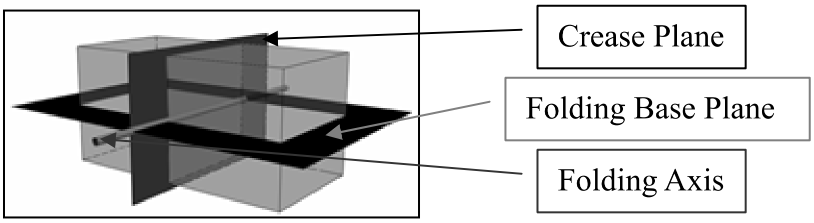

Figure 4: Three important folding components: crease plane, folding base plane, and folding axis.

Therefore, we could define one folding operation as one function with tent parameters – *x, y, z, Rx, Ry, Rz, one/two side folding, top, bottom, angle.*

The former six are geometry data of folding axis. First three parameters (x, y, z) indicates coordination value of pivot of folding axis and following three ones (Rx, Ry, Rz) stands for Euler rotation angles ordered by X-axis, Y-axis and Z-axis respectively.

The seventh parameter indicates three situations – folding one-side in +X of crease plane (1), folding one-side in –X of crease plane (-1), and two-side folding (2).

The eighth and ninth parameters are Boolean value to indicate top and bottom vertices of crease plane are movable or not respectively. The last (tenth) parameter is the folding angle by folding axis.

The default values of folding function are (0, 0, 0, 0°, 0°, 0°,-1, 1, 0, 0).

Figure 5 illustrates one folding operation with parameters (0, 0, 0, 0°, 0°, 0°, -1, 1, 0, -30°).

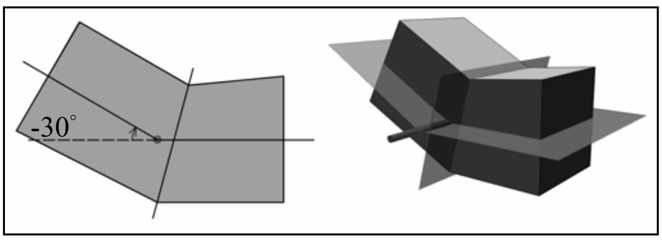

Figure 5: Front-view (left) and perspective view (right) of transformed form.

3.2 Folding phenomenon

● Rotating by folding axis:

Geometrically the movable vertices according to the eighth parameter of folding function rotate by folding axis, which provides one logical method to locate the transformed coordination of vertices.

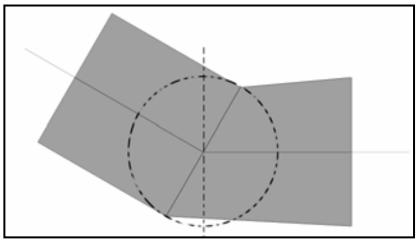

Figure 6: The movable vertices rotate by folding axis.

● Extension and Compression phenomenon of crease plane:

If the seventh parameter of folding function is 2 and the eighth or ninth is 1, the extension and compression phenomenon happens on crease plane.

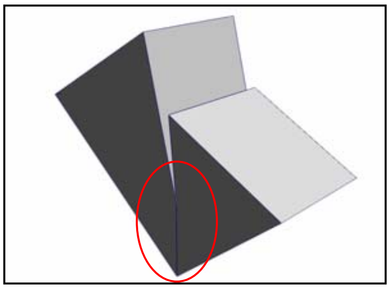

Figure 7: Compression phenomenon happens in double-side folding

3.3 Time involves

Once folding operation is parameterized, we could take angle as variable of time function. With time passing, the in-between folding transformation could be observed. Time-based transformation means time is the main parameter in the process of shifting transformation states. Enlarging distance of two adjacent states (Figure 2) and connecting them by mathematical equation while time factor is the variable, which would lead to bridge gaps with endless middle geometries. Briefly, we analyze geometric data of and locate the corresponding equation in order to accomplish operation of transformation with variable-time. For the reason, time-based method is introduced to describe this mechanism.

In continuous transformation, system would provide internal observations for designers to evaluate form results and manipulate at certain time point. For instance, at certain time point between two geometry states, designers are available to trigger another operation as will. Before that time point, original operation is activated gradually with time passing. But after this sudden operation is joined, the whole process will be redirected to alternative result. The influence of time-based operation is illustrated in Figure 8 and redirects to alternative geometry.

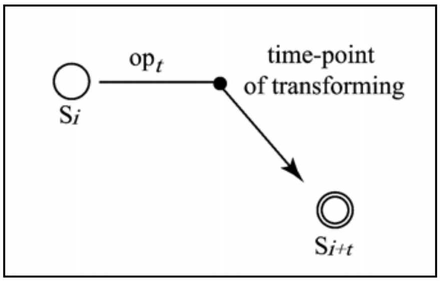

Figure 8: At certain time point, the other transformation could be applied.

With mathematical description, we could treat transformation as sequential steps but varied by time factor, which is determined by how much it takes form one operation starts until designer's manipulation is triggered. Moreover, reasoning design process as continuity could not depend on final result, but on observing in-between transformation, which provides more flexible and intuitive tool for inspiring.

4 IMPLEMENTATION

Consequently, Folding-Space (FoS) is implemented at the top of Maya with MEL (Maya Embed Language)/C++ extension, and the folding mechanism is simulated and implemented by means of dividing topological surfaces and control points. In other words, each folding action in the program will deal with transformed-topology (inner space and intersections) could help designer manipulate folded-space directly and visually. With the concepts above, time control parameter has been put into folding process contributing to various forms result because of different decisions.

4.1 System components

- 3D environment:

  Either commercial package or open source as long as the development could contribute to computer graphic such as display processors, pipeline architectures, transformation library and etc.

- Model data:

  Accessing element value of model including the crucial – vertex, normal of face, coordination and etc.

- Fold function:

  In According to parameterized folding function discussed in section 3.1, we could put these parameters into transformation matrix and terminate final position of vertex.

- Time factor:

  Since time-based media is responsible for observing transformation, especially folding angle. Mathematically, quaternion calculation has to been considered to locate the transformed coordination. Hence, the better choice is animation module. Accessing geometry data finds out ranges of angles and calculates the interpolation values.

Practically, we revise joint module and animation module in MAYA. In addition, adding our folding operation definition (section 3.1) to implement FoS system.

4.2 Examples

Assuming the dimension of initial architecture volume is 3 units in width, 1 unit in height, and 1 unit in depth (Figure 9).
Figure 9

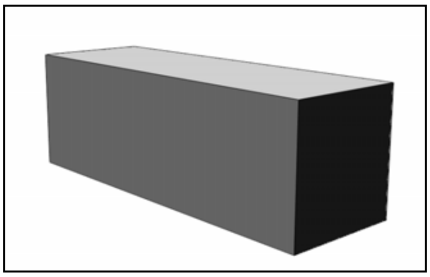

Figure 9: Initial architecture volume.

Figure 10 illustrates the temporary form diagram after three steps of folding, which are first folding (10, 0, 0, 0°, 0°, 0°, -1, 1, 0, -15°), second folding (-5, 4, 0, -30°, 0°, 0°, -1, 1, 0, 47.88°), and third folding (-3, 2, -1.5, 0°, -60°, 0°, -1, 1, 1,- 30°).

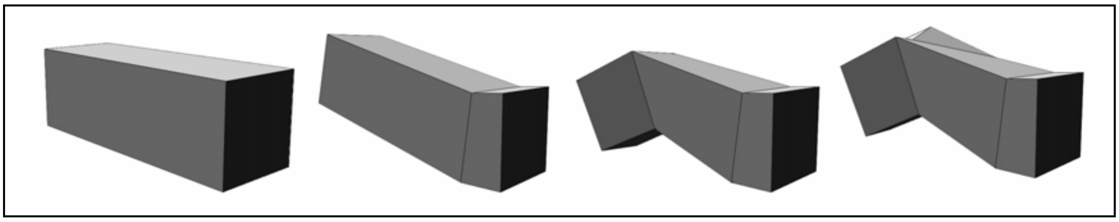

Figure 10: After three folding operation applied.

These folding operations follow the same mechanism to apply on this target volume. Hence the detail mechanism of the fourth folding transformation demonstrates in this example.

The following fourth folding (10, 0, 0, 0°, -30°, 0°, 2, 0, 0, θ) is waiting for user to decide. As for the seventh parameter is 2, this folding operation belongs to double-side function. As a result, the ranges of folding angle (θ) form -90° to 90°. Visually FoS represents these sequential transformation by means of animating for users to observe among the range.

In

Figure 11, the sequential form transformation of the fourth operation is shown and take start, middle, and end situation for demonstrate. And final angle is selected at -17° and contributes to the forth state.

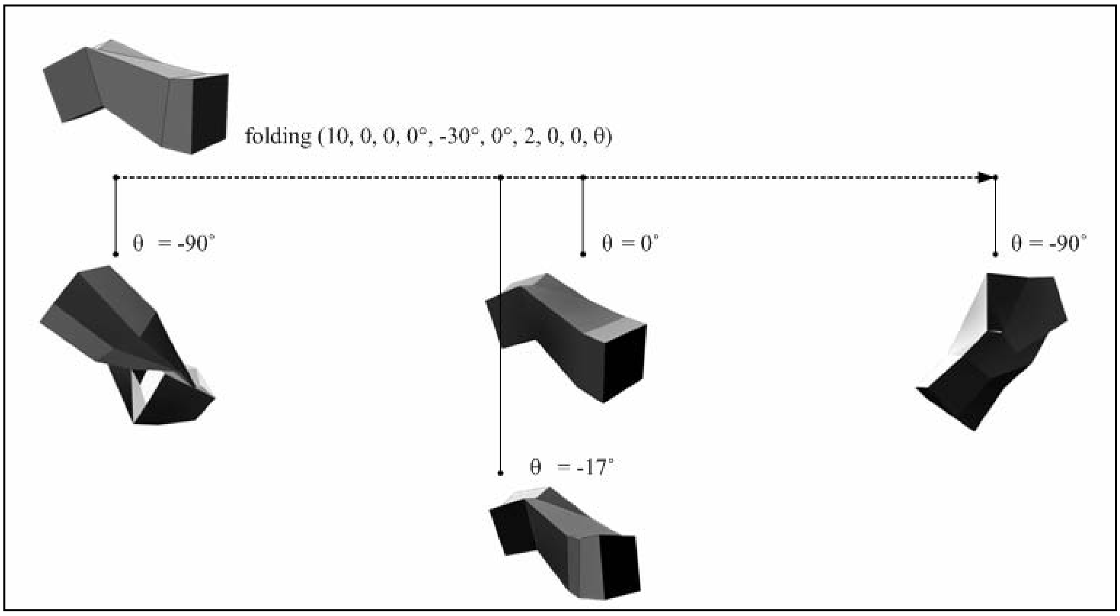

Figure 11: The sequential transformation of the fourth operation.

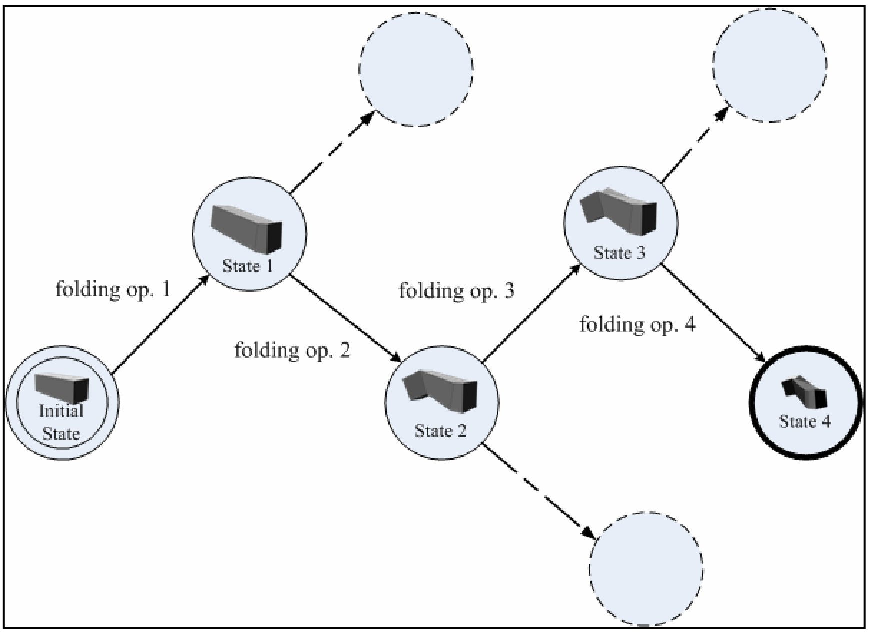

Figure 12: The time-based states transformation of this example. The dotted circle stands for the default end state for each folding operation.

Figure 12 illustrates the time-based form transformation of this example. Taking the initial state to begin and applied on four step-wise folding operation leading to temporary final state.

5 CONCLUSION

Time-based transformation implies the sequential form state for designer to observe or evaluate. But how to put time into to form is the key issue. In this project, defining the folding operation and extracting out parameters of folding angle for time involved. Since time is one attribute of geometry, the time-based form transformation could be reasoned more detailed.

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