Transformable, Folding Space

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ABSTRACT

A group of architectural students in an advanced computer applications course were asked to design a folding or transformable personal space. They were to approach the design using two metaphors - Origami (or paperflessa) and Transformer robot toys - in a digital environment. These are familiar ideas evident in toys and furniture. Students found this way of thinking about architectural design foreign and unusual. The results were tentative, but insightful. New architectural forms emerged out of the plasticity, temporality, and speed of the digital medium. Origami and Transformer robots are more than toys. Through them, the Bauhaus notion of point transforms into line, line into plane, plane into solid can now be stretched to include space generated from motion. The argument for conceptualizing and developing the design within a digital environment was that the operations implied by Origami and Transformers, can be carefully studied in this context. Both processes, or types of objects, are best understood in terms of change in time and space. Digital media offers the dynamic capabilities needed to study distortions, step transformations & movement.

INTRODUCTION

"If (...) the physical reality is understood and conceptualized as an analogy to our imagination of reality, then we pursue a morphological design concept, turning it into phenomena which, like all real concepts, can be expanded or condensed." (Ungers 1976, p.99)

"The world of symbolic forms and, most particularly, that of qualitative mathematics and geometry, have been reinvestigated in the knowledge that the world of intuitive thought or creative intellect is a necessary complement to our limited, contemporary base of rational design." (Aradanan et al 1976, p.158)

Tropes or metaphors are ancient ways of signifying. Lévi-Strauss contends that figurative language was the first to be born, thus preceding practical communication. (Hersey 1988, p.5) The use of metaphors as design initiators, and/or catalysts, is well documented in architecture. It has been challenged by those supporting quantifiable, measurable ways of designing, and upheld by those practicing a more holistic process. Metaphors are culturally-bounded. The objects or ideas selected as metaphors change with shifts in societies and their ways of perceiving and meaning-making. Therefore, through time some metaphors disappear, while others become popular. Architecture as a representation of the male body has been one of the most pervasive;[1] while architecture as a metaphor for memory has not. Interestingly, some of the ideas that are taken over by designers are not necessarily new, but are rather rediscovered. For example, Gio Ponti's 1940s minimal interiors are folding transformable structures.

Some metaphors arise from the structure of the dominant production process. For example, when referring to prefabrication in construction and design, it is common to use the "Tinker-toy", " Erector-set", or the Lego set concept. Just as production systems give way to new design methods and metaphors, so do new environments for designing.

During the first part of the 20th Century, machine-driven mass-production became one of the tenets of the early Modernist movement. Machines are still well-accepted metaphors. In the 60's along with the Design Methods movement, a wave of futurist designers produced: Archigram's Control & Choice and Instant City, (Jencks 1971,p.96) Ron Herron's Walking City, Peter Cook's Plug-in City, Ricardo Bofill's Valpineda Plug-in, Cedric Price's Fun Palace, and Coop Himmeleblau Cloud (Jencks 1995, p.161). In the late 80's and 90's, this attitude is exemplified by "technomorphism."[2] The rationale behind this posture is that "reference to the world of the machine is reference to the only significant contemporary reality."(Pfau/Jones et al 1987, p.47) Belonging to this last group is Neil
Denari's "machine-architecture" which utilizes heavy vehicles as models - airplanes, helicopters, boats - to compose a mechanistic organization of parts. In essence, these approaches borrow from numerous sources outside architecture among which are: fractals, new theories of creation[3], relativity[4] microelectronics, robotics, informatics, and a generation of new hybrid machines and manufacturing processes.

A few among the "technomorphists" endow the architectural objects with kinetic - foldable or transformable - characteristics. Michael Webb's design for an apartment building uses cars bodies to create the units, and includes a garden pavilion with a fixed floor slab, wall panel, and a movable skin. (Betsky 1991, p.134-135) However, the most direct reference to the idea of transformer robot toys in architectural design is credited to Holc, Hinhaw, Pflau, Jones. This firm has generated architectural proposals along the lines of Gobots toys.[5] Examples of these are the Primitive Hut, the Tract House, and the Astronauts Memorial at Kennedy Space Center. The work of Steven Holl (kinged-space), Michael Kalll (responsive intangible projected environment), Diane Lewis (architectural furniture) also exhibits folding or transforming kinetic characteristics, such as those associated with foldable and/or transformable. (Betsky 1990) Others are Francesco Pasquali "Existenzminimum" apartment, Lazzarini & Pickering "recessible furniture", Allan Wexler "Crate House", Douglas Ball "Office Capsule", Urban Architecture Mitusu Kiyu Atelier "Kibun" (outdoor food stand), Stephen Perolla's "hypersurface", and Chuck Hoberman's folding structures.[6]

Some designers have used folding and transforming to achieve a final form; process is eventually "frozen" to become the defining parameters of a building. Peter Eisenman's Max Reinhardt Haus project in Berlin, was developed in part through folding and resulted in a solid Mobius strip. (Jencks 1995, p.8) Zaha Hadid 'distorted rubber' process[7] can be likened to Geometric Origami, connected flat sections (in this case very flexible) that create irregular 3D grids. Her work has also been described as a result of "continuous tucking and folding". (Betsky 1991, p.165) Imre Makovec's work can also be compared to Geometric Origami.

Paperfolding, Origami and its derivatives - Transformers, Gobots, etc. - are useful metaphors for the architectural design process, as well as its products. Folding and transforming are congruent with addressing growing economic constraints and accelerated market change. They are demonstrably useful in exploring the concept of "economy of means", as it applies to space, form, and the relationship between building materials. In a learning context, they can be used as a means of improving hand-eye coordination. Finally, they serve as design motifs or imagination exercises, that can be well explored in a digital environment. Both are useful in considering the notion of the tectonics of architecture as an ordering of fixed wholes or/and parts.

Why Origami & Transformer Robot Toys?

The value of exploring folding and transformable processes in a learning context was proposed by the educator Friedrich Froebel. He argued that paperfolding was an excellent method to develop mind-hands coordination. In the 1890s the Japanese government adopted Froebel's educational practices, reinforcing Japan's tradition of paperfolding. Froebel's Laws: unity, development, and connections further explain their pedagogical importance of the two processes. More recently, the industrial designer Victor Papamak has highlighted transformer robot toys as an opportunity for young people to gain hands-on insights into biomorphic design. Manipulating contemporary theory with digital media allows for new linkages with ancient processes and philosophy. Thus reform in a new design environment ancient thought attains a present status, pushing forward the edges of current views.

The idea of folding and transformability are old and familiar to all. Just to mention a few in no strict order, there is the pre-Columbian three-legged stool, the teepee, the butterfly chair, pneumatic structures,[8] blow-up furniture, and paper airplanes. In architecture, a little known precedent is the use of Okoshi-e,[9] a folding paper model, during the Edo Period to design tea houses. Nomadic and temporary architectural artifacts usually exhibit these characteristics. An example of the latter dates back to 1966, the plywood[10] house for migrant workers in the shape of a concertina, designed by Herbert Yates. The plywood was made of a combination of paper, polyurethane foam, and polyethylene.

There are several types of techniques for folding. Traditionally Origami[11] requires using only one piece of paper. Other forms, such as Unit Origami uses strips of folded paper to make units that are then assembled to form a larger object. The pieces are called in Japanese haramaki.[12] Geometric origami does not require folding, but rather connecting flat sections through "slots" to create regular and irregular three-dimensional grids.

Instructions for making origami rely heavily on graphic symbols. It uses its own codes to represent discrete actions and procedures. Directions stress process rather than outcome. Typical symbols indicate twist, turn, pull,
push and fold. Because it requires choreographed changes origami has been referred to as a type of performance art. Discovering, or designing, new origami forms can follow a variety of approaches: from the scientific mathematical to the improvisational. Combinations of folds or procedures are known as bases. These are sometimes recorded as diagrams representing the crease patterns left on the paper after folding. Yet, discipline and experience are required to guide the process since not all diagrams can be folded.

The history of the robot toys is shorter, responding to a more commercial goal. Transformer robots toys were introduced in the U.S. by the Hasbro Company in 1984. These toys were based in Japanese models manufactured by Takara among other in the 1970s. (Huxford 1996, p.427). The Transformers' uniqueness is to actually transform from robots into transportation vehicles, war machines, or animals. The cartoons that accompany the toy justify the robots ability to change as a way to make their functions more versatile, and also as disguises for deception.[13] There are other transformable robot toys, such as the Z-Bots, the Robo-Bugs, and the Zords. The Tunka GoBot used as design metaphor by Holt, Hinshaw, Pfau, Jones are now extinct.

The metamorphosis of a transformer toy follows rules similar to Origami. Given a collection of parts related to each other through flexible joints, one must twist, turn, fold, push, pull to create a different whole. Origami and Transformers differ in that the former deals primarily with surface, and the latter with a collection of connected 3D solid objects.

Dealing with folding and transformable objects in a digital environment[14] requires reconsidering the usual manual procedures. Chuck Hoberman looks at "tiling" and "tweening" as essential operations in the digital world. Tiling produces the bases, patterns, or diagrams necessary for folding in origami. Each folding line is to be seen as a hinge. Hoberman's definition for a folding structures is very useful in understanding the intentions of this project. A transforming structure responds to external forces in a "smooth and controlled fashion." It exhibits "qualities of motion", such as "dependent structural stability and integrity" even when the structure is transforming (Hoberman 1991, p.35).

STEPS: DOING THE PROJECT

The literature research conducted for developing the computer course project revealed that the references available to do an in-depth study were not available through traditional means. The World Wide Web turned out to be in an excellent source for information about Origami and paper folding in general. In the first months of 1996 a growing number of sites associated with Origami have appeared. Joseph Wu's Web site[15] is a general starting point with many connections. Others are specific, such as the Origamic Architecture[16]; and the Interactive Origami in VRML.[17] Some of the information about transformable robot toys was also obtained through this means.

At the beginning of the semester students were given two weeks to generate the first trial version of the design for architectural artifact with a footprint of no more than 80 sq ft when folded or closed. When opened, the object should provide for space that could be occupied. This last requirement was intended to make a distinction between architecture and furniture. Each designer had to define a program. The precedents provided to the students were the Office Capsule, the Crate House, and a Japanese fast food portable stand or Kibun. Students were asked to use Origami and Transformer toys as metaphors to study transformation through folding and part displacement. Essentially, one concept involved a thin flat plane that became a structure which defined space three dimensionally; the other, the "Transformers", changed form depending on how the parts were twisted, folded, and reassembled. The tools available for 3D modeling were AutoCAD R.12, 3D Studio, and FormZ v. 2.7.

FormZ, in particular, offered an unfolded projection tool that allowed the user to derive a 2D object from a 3D source. These derivations can be obtained from surface and solid objects. The rule is that convex forms or conglomerates are unfolded as a continuous sheet, while objects with voids are not. This type of geometry is perhaps more familiar to industrial designers and engineers, for whom it is known as development. The direct application of the flat versions of 3D objects is to develop the patterns necessary to cut metal sheets to fold and form parts.

Students worked on the first version of the design on the computer, and made origami by hand. Origami was discarded early on. It turned out to be a difficult task without previous knowledge and considerable practice. These initial designs didn't exhibit any kinetic characteristics, with two exceptions. One of these, a hot-dog stand with a built-in seating area, was convincing on the animation, but absurd in reality. When unfolded, stools and counters would float in the air. This design appeared to be true only because it resided in an environment that defies the forces of gravity. As with paper drawings, a digital model can make almost anything look possible. The other architectural programs included a dog house, a radio station, a music room, a large pavilion, and a meditational space.

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For the second iteration students were asked to design anew and present models to which they had applied scanned textures to explore tactility. The idea was to remind designers that they were working with representations of objects that had to be made of matter other than points of light. The architectural programs for most of the designs submitted in the second set were different from the first. Students had had a chance to familiarize themselves with the scale of the project and the folding transforming operations. For example, the radio station was dropped and its designer proposed instead a traveling ironing board metamorphosing into a desk, the hot dog stand became a rock concert stage, the pavilion became a housing unit, and the dog house a portable kitchen. By the third repetition of the exercise the students were more involved with rendering and animation, and the design programs stayed the same mostly ignoring design issues were.

The final designs were required to be submitted as detailed digital models that could be used as 3D construction documents. Students were also asked to present their design as a "flip-book"[19], a cheap easy-to-view transformation animation. And the third presentation requirement was a folded book/poster providing a graphic demonstration of how the design would fold and/or transform.

CONCLUSION

"[The] eye envies the mind, which can understand everything without looking." (Chung-Tzu quoted by Albert Einstein)

The exploration of the design of foldable transformable architectural objects brought forth more questions than answers. Two important questions posed to the designers at the beginning of the investigation were left unanswered. How much of the ideation process can and should occur in the digital environment? Are folding and transformability two different ideas?

The exercise provided relevant lessons for designing in architecture, although of a superficial nature due to the briefness of the investigation. It confirmed that the construction of a fine grain digital model is as laborious and time-consuming as building a physical model using traditional media. On the other hand, it was argued that a greater number of alternatives were considered due to the ease with which pieces are copied, modified, and reused in the digital environment.

Students found a number of ways in which to build folding and transformable objects, based on a common perception of the work space. To be able to work with folding and transformable architectural objects, the work environment needs to be inhabited as a movable, dynamic, 3D construction site rather than as flat paper space.

It was also learned that the design and construction of foldable transformable objects requires a careful selection of primitives, modifying operators, and the types of assembly or assemblies that constitute the whole. For example, to be flexible planes need to be triangulated or created with meshes to allow for a maximum number of edges to pull, push, twist, and fold. A flat mesh can be distorted, while saving intermediate stages to record the process. A mesh or meshes can be created from a combination of profiles representing the unfolded object. In this case, unfolded would be the state in which the object encloses the maximum amount of space. Another alternative to deal with folding is to first build the space-enclosing object with surfaces and solids, and use FormZ to generate an unfolded projection. When transformations depend on moving connected parts, objects cannot be monolable. Transformer objects need to be constructed out of smaller connected parts, to provide for flexible articulations with a high degree of movement.

One of the limiting factors for the explorations was the fact that they occurred in a computer course, which engendered the perception that all models should be digital. To support the previous statement it is necessary to mention that although students were encouraged to move back and forth between physical and digital models, they all resisted this approach. Because mastering a skill was manifested in the representation of the product, students' efforts concentrated on the latter. The design challenge was transposed to generating the flashiest rendering and animations. The medium took precedence. Therefore, the rough, residual and preliminary was discarded. It is difficult to keep track of a process when a documentation system is not developed and followed, much worst when it is deemed to be irrelevant. This situation needs to be avoided in the future.

Making Origami by hand was found to be archaic due to a lack of knowledge, paper folding skills, and because of its complexity. To create folded forms one has to be able to manipulate a set of bases or patterns, to improvise, and find the object. Or, one has to unfold existing forms, like frogs, cranes and boxes, to reinterpret the base patterns and refold new forms. When designing through folding, the designer has to have an image of the
outcome, and labor until the result occurs. Or, select a collection of folds and repeat in different combinations, improvising until reaching a satisfactory result. There are no pieces but procedures, and the result is a summary of the intermediate states. These can be ordered as bottom-up or top-down. Both folding and transformation require explicit rules.

The geometry of folding and transformable artifacts moves away from the primary forms that Le Corbusier identified as the most beautiful forms. (Le Corbusier 1923) As design approaches, both differ from conventional conceptual procedures where form generation is achieved through the manipulation of basic polygons and polyhedra within a limited set of 3D grids. Yet, both are related to equally familiar canons such as: archetypes, building types, shape grammars, proportioning systems, orders, grids, and controlling lines.[19] Of all of these, shape grammars are the closest to the concept of folding and transformability.

Are these different modes of perceiving? They require the designer to assess the result of his/her efforts looking at various states of the object simultaneously. It is like being able to mentally visualize each frame in a morphing procedure. Guy J.P. Nordenson (Nordenson 1992, p.33) refers to this capacity as “taking thought”, thinking an image in motion to anticipate its behavior. Folding & transforming have to be understood both as a process and as a changing form. A folding and/or transformable architectural object exists in various states, and requires the simultaneous generation and collapse of voids.

Three subjects need to be included in further studies of foldable and transformable: knots, material assemblies, and the Virtual Reality Modeling Language (VRML). Knot theory falls within the domain of topology. In the mid-1800's Gottfried Semper authored important manuscripts about architecture, tectonics, and aesthetics. His thesis for the archetypal origin of all built form included considering the knot as the original joint. In this case, interweaving and looping could add a new dimension to the design of foldable, transformable objects.

One of the more promising assets of the digital environment is its capacity to allow for the representation of construction systems combining a variety of materials. The continuous surface that when folded or unfolded encloses space can be a composite, an assembly of systems. Then, it is possible to study combinations such as: hard/soft, rigid or flexible (plane versus mesh), opaque/translucent/transparent, textured or smooth, colored or uncolored.

Although VRML is in its infancy, it already offers a basis on which to explore long-distance generation, manipulation, and linkages of 3D digital spaces. Presently, it is a language of faces, lines and points, but it is conceivable that in the near future it will include solids. It can become an appropriate environment on which to demonstrate foldable and transformable architectural artifacts.

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ENDNOTES

[1] Consider the magic diagram of Brahma as the model for the design of ancient north Indian shrines, and the many variations of the Vitruvian Universal Man.

[2] Aaron Betsky labels these designers "technomorphists". (Betsky 1990, p.143)

[3] Charles Jencks suggests that architecture should embrace cosmogenesis. He proposes that "a new aesthetic is growing out of this new world view: language of building and design close to nature, of twists and folds and undulations; of crystalline forms and fractured planes." (Jencks 1995, p.9).

[4] Space as a complex, dynamic structure that bends and flexes. This structure is compared to a "sheet of highly flexible rubber stretched out like a trampoline," constantly reshaped by the celestial bodies. (Weithin 1995).

[5] Japanese toys that can be transformed from human beings to machines to buildings. (Betsky 1990, p. 196)

[6] Hoberman explores transformable objects that exhibit complete, three-dimensional, fluid, and continuous

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transformations. These he calls "hybrid structure/mechanisms." Some of the forms for which Hoberman has received patents are: the Iris Dome, Geodesic Dome, Expandable Truss, and various pleated surfaces. (Hoberman 1992)

[7] According to Charles Jencks, when analyzing the Cardiff Bay Opera House project.

[8] A more radical type is the Suitaloom by Michael Webb, a house that is like clothing. (Jencks 1971, p.103)


[12] Refers to any kind of sash worn wrapped around the belly. Maki is wrapped, and kara is belly. (Fusé 1990).


[14] Arthur Appel, working under IIIM in 1971 is recorded as the first to design origami on a computer. (Kenneway 1987 p.44)


[18] This technique was borrowed from Duncan Brown in Sites.

[19] This last is also known as lineamontia after Alberti. (Crowe 1995, p.170)

Figure 1 (a-f). Portable kitchen, excerpt. Designed by Matt Swain.
Figure 2 (a-d). Hotdog stand. Excerpts. Preliminary study by Michael Montgomery. Developed entirely with 3D Studio.

Figure 3 (a-c). From top to bottom, initial massing model for the music room unfolded. First iteration. Center and bottom final submission showing music room folded as a bench. Excerpts. Designed by Michelle McConnell. Developed with AutoCAD, 3D Studio and PhotoShop.
Figure 4 (a-c). Shelter excerpts. Designed by Raul Rivera. Developed with 3D Studio.

Figure 5 (a-d). Transformer object. Changes from shelving unit, to shelter, to vendor stand, to a coach. Excerpts. Designed by Weiping Zhang. Developed with 3D Studio.
Figure 6 (a-b). Rock Stage. Sequence excerpts. Designed by Michael Montgomery. This project was developed entirely with 3D Studio.
REFERENCES


Fusé, Tomoko. 1990. Unit Origami, Tokyo: Japan Publications Inc


