Adaptability in the Built Environment Through The Use of Transformable Architecture

An exploration into the architectural *why* and engineering *how*

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Abstract. Buildings are conceived as permanent-use structures, generally designed for a set function. However, dynamic markets and fast-changing societies require new accommodation and usually buildings are deconstructed and rebuilt to suit new uses before the technical life cycle of the building materials has expired and thus they are not used to their fullest potential. The solution is to anticipate the diversity of needs that are either dictated by the building's users, or by the changing social and economic market, and to provide a design that can adapt to these evolving demands. A flexible design not only increases the longevity of a building, but on a shorter timescale, enables the building to be multi-functional, serving a wider community of people. This flexibility can be achieved by means of transformable structures which can change shape, volume, or appearance, subsequently impacting how a space is used or experienced. In order to inspire a shift towards flexible design, the research seeks to expose the architectural "why" and the engineering "how" of transformable architecture by analyzing existing projects and exploring technical strategies for realizing transformable structures. A qualitative evaluation of existing transformable architecture projects is provides the context for experimenting with bistability as a potential mechanism for building transformable architecture. Digital and physical modelling reveals limitations and opportunities associated with designing movable structures with this type of mechanism.

Keywords. Transformable Architecture; Bistability; Architectural Design; Parametric Modelling.

Introduction

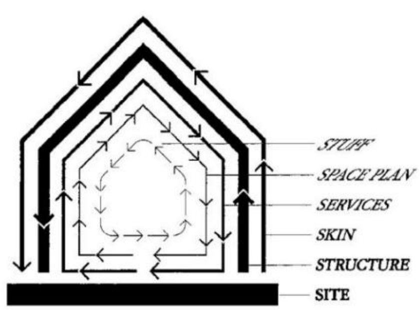
As the greatest investment supporting human activity, the built environment should be as efficient as possible, adapting to our changing needs. Transformable architecture is part of a family of time-based architecture typologies, including flexible, adaptable, and interactive architecture which are characterized by the ability to change over time. Transformable architecture has many benefits. It promotes both the short-term and long-term re-use of a building or space, thus reducing consumption of resources and production of waste. It can make spaces customizable to a variety of users and it enables the same space to be reused for multiple purposes. As the global community continues to grow, sharing spaces and the flexibility to adapt to changing user groups, as well as environmental, social, and economic conditions, will become increasingly more valuable. Transformability in the built environment "creates a more democratic form of architecture" that encourages interaction rather than reaction.

The basics: Transformation fundamentals

Before exploring the challenges and values of transformable architecture, it is important to establish a working definition for this type of architecture. Transformable architecture is part of a family of time-based architecture typologies, including flexible, adaptable, and interactive architecture. These types of architecture are characterized by the ability to change over time, but can be differentiated from each other according to the timescale of this change. In the context of architectural design,

- *flexible* spaces are often continuous flowing volumes that can be easily modified and reconfigured to meet the requirements of a variety of functions. Flexible architecture accommodates small changes that are predetermined by the user's desires or needs, and which occur frequently, for example, converting a living space into a working space. The change is driven by the user.
- *adaptable* refers to the ability of the built environment to evolve over time and remain useful in changing conditions. This suggests a slower change that is driven by changes in the environment (i.e. seasons), or changes in the collective behavior of the building's occupants. The change is more on an evolutionary scale and enables a response to possibly unexpected changes.
- *interactive* refers to an immediate feedback loop between the built environment and the user. Changes are driven by sensor input and translated to an almost immediate actuation.
- *transformable* describes the ability to change, and change back to the original state, referring to a cyclic timescale. It is a way to achieve the other three types in that it can respond to short-term fluctuations in the individual user's needs or a temporary climate, or it can achieve long-term change to meet new criteria. The transformation can be a physical movement (expansion, contraction, translation, rotation, inflation, etc.) or a change in the visual appearance of surfaces (i.e. media façade, lighting, etc.). Transformable architecture is indeterminate architecture having variable geometry, which can be reshaped in response to the changing needs of the user. The building is a mechanism and the designer defines a predetermined range of changes (Rosenberg 2010).

According to the "Shearing Layers of Change," the layers of a building (interior stuff, space, services, structure, and skin) have varying lifecycles, as illustrated in Figure 1. Timescales of change vary from the interior to the exterior of a building, where the interior stuff changes faster or more frequently than the exterior skin (Lee, 14), making the interior flexible, and the exterior adaptable, according to the definition above. Most transformable architecture occurs in the space layer, which includes walls, floors, and ceilings, or in the skin layer, referring to the façade.



Frequency of change

Stuff – daily
Space Plan – 3 yrs.
Services – 7-15 yrs.
Skin – 20 yrs.
Structure – 30-300 yrs. (not based on design life)
Site - eternal

Figure 1 *Stewart Brand's "Shearing Layers of Change" (1994) (Source: Lee 2012, 14)*

As summarized by Robert Kronenburg, author of numerous texts on adaptive and flexible architecture:

"Truly transformable architecture…must enable a dramatic alteration in the character of the whole architectural environment. A transformable building is therefore one that changes shape, volume, or appearance by the physical alteration of structure, skin or internal surface, enabling a significant alteration in the way it is used or perceived." (Kronenburg 2007, 146)

The Evolution

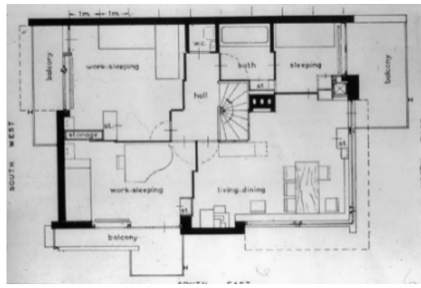
The earliest form of transformable architecture is the tent. The tent facilitated the nomadic lifestyle of early humans who traveled with the seasons. The flexibility and transportability of the tent structure aided our ability to adapt to changing conditions in the environment. This adaptability is the key to the success of humanity. Fast-forwarding to the modern era, examples of transformable architecture, such as Gerrit Rietveld's Schroder House, and Mies van der Rohe's Villa Tugendhat, suggest that flexibility seemed to be more of a luxury during that period. Having options for how the building could be experienced and the ability to customize a space was valued greatly by the users, but it was not a necessity. However, as the world population and the demand on resources continue to grow, flexibility will again become critical to the success of humanity and transformable structures will offer a standard solution to adaptable living.

A review of transformable buildings from the early modern period reveals transformability in the built environment was achieved primarily through the use of flexible partition walls, collapsible stairs, and walls and roofs that opened to the exterior. Gerrit Rietveld's Schroder house, built in 1924, is an early example of modern transformable architecture that used walls that slide on tracks and fold to convert the first floor from an open living room in the day to closed bedrooms at night, as seen in Figure 2. The adaptability of the design allowed Truus Schroder to personalize and optimize the use of her house, enabling her "to *live* in the active sense and not *be* lived." Villa Tugendhat, designed and built by Mies van der Rohe in the Czech Republic between 1929 and 1930, focused on functional amenities, and included an exterior glass wall which could be retracted into the foundation using electric motors, to completely open the interior space to the exterior environment, as seen in Figure 2. This "disappearing wall" made the impressive view from the house an integral part of the interior and made this unification of interior and exterior a customizable experience. A more progressive approach to flexible design was taken by architect Cedric Price who sought the use of "impermanent, improvisational, and interactive systems" to make architecture adaptable to rapidly changing social and economic conditions. Following up on his concept for the *Fun Palace*, a reconfigurable building which used travelling cranes to move building elements (depicted in Figure 2), in 1966, Price published his proposal for the *Potteries Thinkbelt*, a new type of university for science and technology, composed of a network of mobile classrooms, faculty buildings, labs, and student housing, organized along the abandoned rail infrastructure of the Potteries region. The container-style building units could be lifted by crane and moved by rail offering the ability to reconfigure the facilities according to the needs of the institution. Unfortunately, neither of these projects was realized.

SCHRODER HOUSE

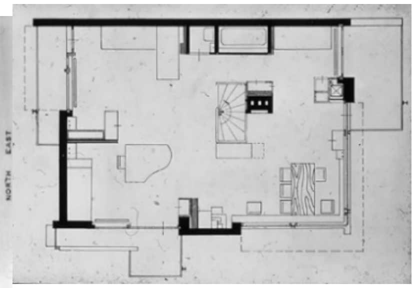
Source: (Arch Daily, 2010)

First floor, walls extended



Source: (Modern Architecture, UPenn, 2001)

First floor, walls folded

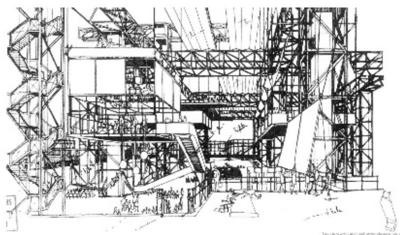


Source:http://www.arthistory.upenn.edu/spr01/282/w6c1i12.htm

VILLA TUGENDHAT

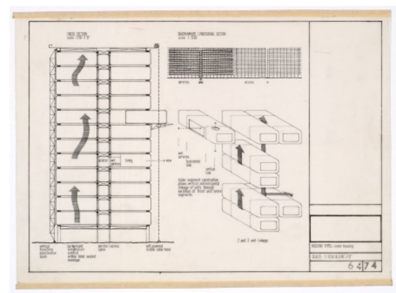
Source: http://www.tugendhat.eu/en/photogallery/photogallery-2010.html

FUN PALACE



Source: http://www.worldarchitecturenews.com/project-images/2012/21461/cedric-price/reader-review-fun-palace.html?img=1

POTTERIES THINKBELT



Source: http://discoversociety.org/2014/07/01/the-thinkbelt-the-university-that-never-was/

Figure 2 *Examples of transformable architecture from the early 20th century.*

More recent transformable structures and buildings explore beyond the movable partition and retracting roof and experiment with new mechanisms of movement, new materials, and more complex forms. The Prada Transformer by OMA, shown in Figure 3) brings Cedric Price's *Thinkbelt* project to life in the sense that it uses external cranes to lift and rotate an entire pavilion, which serves a different purpose in each of four possible orientations. The Sharifi-ha house by Nextoffice (Figure 4) expands upon the idea of unifying interior and exterior that was achieved by the "disappearing wall" of Villa Tugendhat, by sliding and rotating an entire room to expose it or close it off from the outside environment. The Hoberman arch takes the concept of sliding elements, like the movable walls in the Schroder house, and adds a level of complexity, by creating a system of 96 panel that are hinged together to create a rigid curtain, and slide over each other to reveal or hide the stage behind, as seen in Figure 5. These projects, along with many others, such as Santiago Calatrava's L'Hemispheric and (Figure 6), are testing the limits by scaling up transformations that are readily achievable on the small scale, to see what is possible on the building scale.

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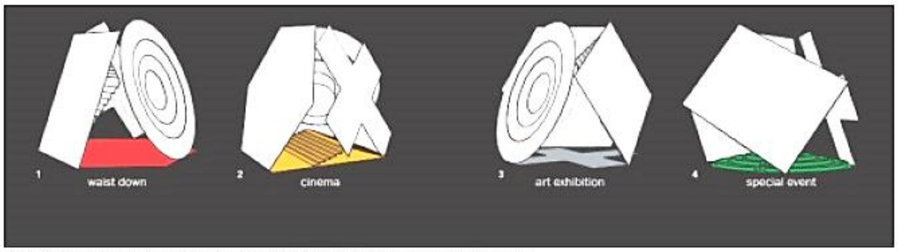
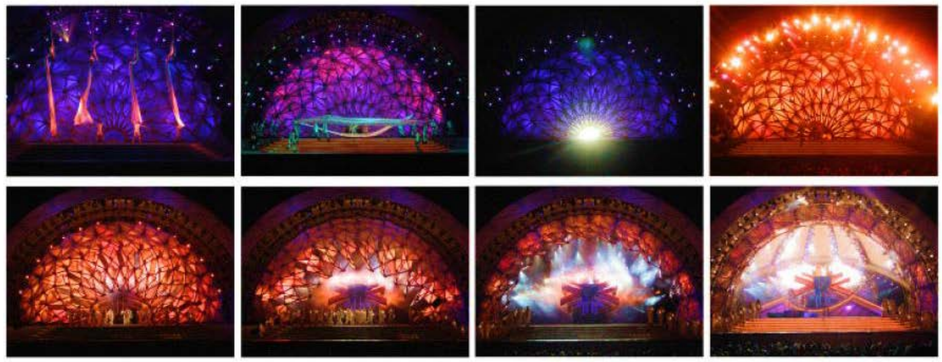


http://blog.kineticarchitecture.net/2011/03/prada-transformer/

Figure 3 *Prada Transformer by OMA, Seoul, Korea, 2009.*

http://www.archdaily.com/522344/sharifi-ha-house-nextoffice/

Figure 4 *Sharifi-ha House by Nextoffice, Tehran, Iran, 2013.*



http://www.snipview.com/q/Hoberman%20Arch

Figure 5 *Hoberman Arch by Chuck Hoberman, Salt Lake City, Utah, United States, 2002.*

http://firstmonday.org/ojs/index.php/fm/article/view/1563/1478

Figure 6 *L'Hemisferic by Santiago Calatrava, Valencia, Spain, 1998.*

Evaluating the Precedents

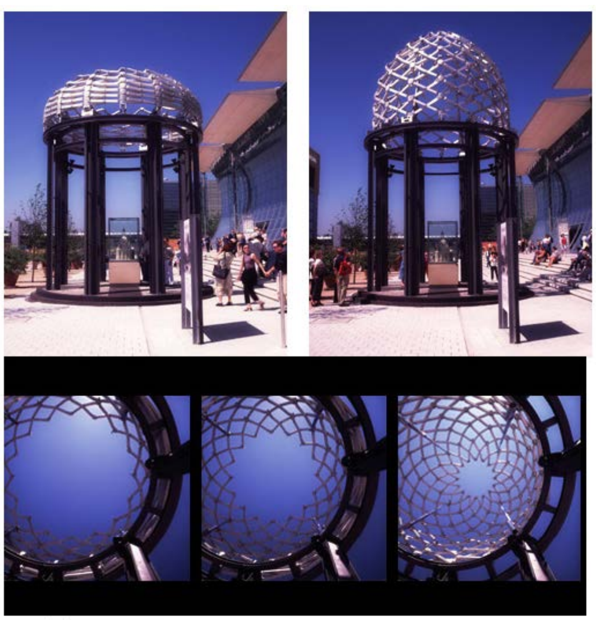
As we can see from the aforementioned projects, transformable architecture is definitely not a new concept. However, transformability seems to be something that architects/engineers/designers dabble in but do not commit to as a design strategy. What is holding it back from becoming 'mainstream'? Based on our research, the most common obstacles are related to the stability of the system, in terms of maintenance, scale, and reliability. The complexity of the design, in terms of geometry, number of movable parts, type of mechanism, mode of operation (hand powered or electrically powered), type of building element, and stages of transformation, pose challenges to the maintenance of the system. The ability to maintain the structure is linked to its reliability. "The mechanisms employed to enable movement to take places should be robust, maintenance free, easily operable and reliable." The issue of scale lies in the challenge of applying the principles of movement that we commonly see in smaller element such as garages, windows, and shading systems to larger spans and structures.

Scale

One of the biggest issues in designing a transformable structure is scale. Most common kinetic structures, such as garage doors, windows, gates, collapsible canopies, louvers, or even certain toys and household products, are small. While scaling up the movement principles of these structures and products to the building scale is theoretically feasible, the design of large building components over bigger spans poses a challenge. Furthermore, "…the expertise lies elsewhere for this work – it's in bridges and marine work for the large scale and the small scale lies in mechanical engineers/kinetic artists so it's sometimes difficult for building engineers to bridge that gap." (Rob Otani, CORE Studio, Thornton Tomasetti)

Reliability

Concern about the reliability of a transformable structure seems to be the main source of hesitation of designers and clients considering a moveable system. "The mechanisms employed to enable movement to take places should be robust, maintenance free, easily operable and reliable." (Kronenburg 2007, 146). For movable bridges, such as the Bridge over the Inner Harbor Duisburg (Figure 7), design codes generally require that the bridges are guaranteed to be fully operable for a specified number of days throughout the year (Edwin Thie, Senior Engineer, Arup). Redundancy in the system of movable parts can improve reliability. As suggested by the following example, a system whose moveable parts are connected in series rather than in parallel faces the possibility of failure of the entire system if only one part fails. According to structural engineer Daniel Brodkin of Arup, who was involved in the engineering design of Chuck Hoberman's Iris Dome (Figure 8), "…another obstacle was that the Iris Dome has a large number of joints that must always work properly in support of a single degree of freedom system. One local failure and your roof is stuck open!" (Daniel Brodkin, Arup).



www.hoberman.com

http://www.sbp.de/en/build/show/95-Footbridge_over_the_Inner_Harbour_Duisburg

***Figure** 7 Iris*

Dome by Chuck Hoberman, Hanover, Germany, 2000 (left; Footbridge over the Inner Harbor Duisburg by Schlaich, Bergermann and Partners, Duisburg, Germany 1999 (right.)

Transformable architecture has the power to improve spatial quality, improve environment, or improve experience. This is something that a static structure cannot offer. In order to inspire a shift towards transformable buildings, we must develop a trust in their reliability and advantages. This starts with collecting and evaluating existing projects and lessons learned from these projects as well as gathering the planning and technical resources that can guide designers in the realization of transformable projects.

A survey of about 50 architectural projects that incorporate transformable elements was carried out. For each of these projects, the following questions were answered:

1. What – building type, program, size, what moves and by how much
2. Why does it move?
3. When – frequency of change, how long the transformation takes
4. How – mechanism used, input force/power vs. weight of structure

Table 1. Reference Projects

PROJECT NAME	ARCHITECT/DESIGNER/ENGINEER	LOCATION	YEAR	MOVABLE PART
Aerial Assemblies	Skylar Tibbits	MIT Self-Assembly Lab	2014	Floating balloons within a light frame.
Bengt Sjostrom Starlight Theater	Studio Gang Architects	Rockford, Illinois, USA	2003	Roof
Carlos Moseley Music Pavilion	FTL Design Engineering Studio	New York, USA	1991	Pavilion
Courtyard City Hall Vienna	Schlaich, Bergermann and Partners	Vienna, Austria	2000	Roof
Curtain Wall House	Shigeru Ban	Tokyo, Japan	1995	Façade
Decibot	Skylar Tibbits	MIT Self-Assembly Lab	2009	Modular units
Dutch Pavilion Venice Biennale 2012	Petra Blaisse, Inside Outside	Venice, Italy	2012	Curtain/wall
Ernsting's Family Distribution Depot	Schilling Architekten	Germany	1999	Roof
Evolution Door	Klemens Torggler	Austria	2014	Two panels which form a door
Floirac House	Rem Koolhaas OMA	Bordeaux, France	1995	Room
Footbridge over the inner harbor Duisburg	Schlaich, Bergermann and Partners	Duisburg, Germany	1999	Bridge

Fukuoka Housing	Steven Holl	Fukuoka, Japan	1991	Wall
Fun Palace	Cedric Price	Unrealized	1960-1961	Pod
Green Flea Pavilion	Buro 213	Potsdamer Platz, Berlin	1999	Pod
Hoberman Arch	Chuck Hoberman	Salt Lake City, Utah, USA	2002	Wall
House No 19	Korteknie Stuhlmacher Architecten + Bik Van der Pol	Utrecht, NL	2003	Wall
Iris Dome, Expo 2000	Chuck Hoberman	Hanover, Germany	2000	Scissor pair
Kuwait Pavilion Expo 92	Santiago Calatrava	Seville, Spain	1992	Roof
Laboshop	Mathieu Lehanneur	Paris, France	2008	Furniture
L'hemisferic	Santiago Calatrava	Valencia, Spain	1998	Wall/gate
Living Room	Formalhaut	Gelnhausen	2005	Room
Matsumoto Performing Arts Center	Toyo Ito	Japan	2004	Ceiling
Merchant Square Bridge	Knight Architects	London, W2, UK	2014	Bridge
Meridian Buildings	Joachim Kleine Allekotte Architekten	Potsdam, Germany	2004 (renovation)	Façade
MIT m-cubes	John Romanishin, Daniela Rus, and Kyle Gilpin	MIT	2013	Modular robotic cube
Modular bench	Beyond Standards		2010	Bench
Naked House	Shigeru Ban	Japan	2000	Room
Nine-Square Grid House	Shigeru Ban	Hadano, Japan	1997	Wall
One Ocean Pavilion, Expo 2012	soma	Yeosu, South Korea	2012	Façade
Palatinate Cellar	Santiago Calatrava	St. Gallen, CH	1999	Floor
Prada Transformer	Rem Koolhaas OMA	Seoul, Korea	2009	Pavilion
Quba Mosque Umbrellas	SL Rasch	Medina, Saudi Arabia	1992/2011	Shading
Reclamebureau, Lifting table	ZW6	Haarlem, Netherlands		Table
Rolling Bridge	Heatherwick Studio	London, UK	2004	Bridge
Roundabout house	Bohumil Lhota	Velke Hamry, Czech Republic	2002	Container/pod
Rubiks snake toy	N.A.	N.A.	N.A.	Modular units
Schroder House	Gerrit Rietveld	Utrecht, Netherlands	1924	Wall
Self-Assembly Chair	Skylar Tibbits	MIT Self-Assembly Lab	2014	Modular construction units

Sharifi-ha house	Nextoffice	Tehran, Iran	2013	Room
Sliding House	dRMM Architects	Suffolk, East Anglia, UK	2009	Façade
Sosia Sofa	Emanuele Magini		2011	Entire form
Spielbudenplatz	Consortium Spielbude Fahrbetrieb Hamburg, Lutzow 7 Garten- und Landschaftsarchitekten and Spengler Wiescholek Architeckten und Stadtplaner	Hamburg, Germany	2006	Pavilion
Studio 8	Gruppe OMP	Rastede	2001	Wall
Ruhrtriennale Traversing stage	Bumat (manufacturer)	Germany		Seating
TurnOn	AllesWirdGut Architekten		2000	Room
University of Phoenix Stadium	Eisenman Architects	Glendale, Arizona, USA	1997-2006	Roof/floor
Valhalla	Rudi Enos	Sheffield, UK	1999	Roof
Venezuelan Pavilion Expo 2000	Fruto Vivas, SL Rasch	Hanover, Germany	2000	Roof
DSSI Elementary School	Daniel Valle Architects	Seoul, Souh Korea	2016	Wall
Exocet	Designarium	Montreal, Canada	2015	Chair
Transformable Meeting Spaces	MIT Self-Assembly Lab, Google	Boston, Massachusetts	2016	Wall
Transformable Table	Boulon Blanc	Paris, France	2016	Table
aeroMorph	MIT Media Lab	Boston, Massachusetts	2016	Material
Metamaterials	Hasso Plattner Institute	Potsdam, Germany	2016	Material
Open House	Matthew Mazzotta	Alabama, United States	2013	Wall
La Caja Oscura	Javier Corvalan	Paraguay	2013	Roof/Walls
Live Projects	Students, University of Brighton	London, England	2016	Entire structure
Undefined Playground	B.U.S Architecture	Seoul, South Korea	2016	Entire structure
Humble hostel	Cao Pu	Beijing, China	2015	Wall

A database of these references was created to compare projects within the categories listed in Table 1 in an effort to uncover trends which may provide insight into the current state of transformable architecture and help define potential areas of development.

Table 2. Categories of Evaluation

MOVEMENT	ACTUATOR	PURPOSE	SCALE	FREQUENCY
bend/rotate/pivot	cranes	artistic/experiment	small (i.e. furniture)	User preference - frequent
expand/stretch	electric motor	changing spatial	medium (i.e.	Daily

		configuration	wall/ceiling/floor)	
fold	hydraulic	climate control	large (i.e. building or bridge)	Weekly
free	magnets	open/close/access		Monthly/Seasonally
lift	manual	shapeshifting material		Event - infrequent
slide/roll	inflation	change functionality		

The frequency of occurrence of each category and various combinations of categories was tabulated and plotted, as shown in Figure 9. Several conclusions can be drawn from these graphs.

Figure 9 *Evaluation of reference projects.*

The most common reason for incorporating transformable elements into a project is the need or desire to be able to vary spatial configurations within a building. This change usually accommodates a change in program or user group. The second most common reason is the need or desire to change the boundary of a space in order to provide or limit access to the space or to merge interior and exterior space. A majority of the projects that were surveyed used rotational movement or pivoting to achieve transformations. This rotational motion was primarily controlled by a hydraulic actuator or manually driven. The next most common type of movement is sliding or rolling, which is primarily controlled by electric motor or manually driven. Transformation in most medium sized projects is actuated by manual operation, while electric motor or hydraulic actuators are used to driven the transformations of larger scale architectural elements. However, overall, the most common actuation method is manual operation.

Mechanisms for Transformation - Exploring Bistability

Connections are critical for both the stability and the flexibility of a movable structure. They must be flexible in order to allow movement, but they must also be able to lock into a static position after the transformation has occurred (De Marco Werner 2013, 51). This challenge was encountered in a previous project. The project was an interactive wall that changed shape when approached by users. The wall was designed as a 3D space truss and a 1:1 prototype was built using rigid aluminum struts connected by flexible rubber joints to allow for movement. Each module of the space truss had one telescoping element. Movement was achieved by lengthening certain telescoping elements as shown in Figure 10. The structure was stable in the static condition, but the rubber connections were too flexible and could not be locked out, thus causing instability when certain movements caused excessive deformations. Reflecting on this project, it became clear that a major challenge in designing transformable structures is finding the balance between stability and flexibility.

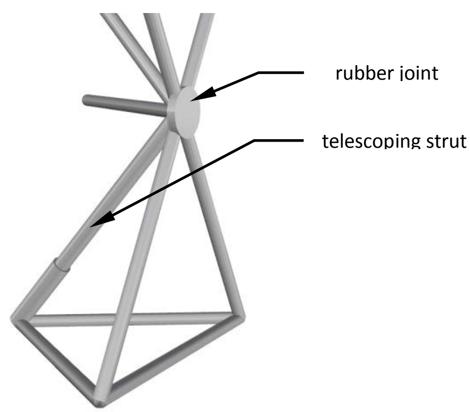


Figure 10 *Interactive wall 1:1 prototype (left); Unit module of 3D space truss (right).*

Exploring Bistability

A bistable mechanism demonstrates the ability to change shape, and then "lock out" in two (or more) stable positions. For this reason, bistable mechanisms were explored further as potential candidates for actuating movable architecture.

In a bistable system, the flexibility to change shape/configuration depends on the stiffness and configuration of spring elements. In the stable states, the spring is "at rest." During the transition from one stable state to the other, the springs undergo temporary compression and then "pop" into a stable state. Figure 11 illustrates this transition. Movement is driven by the natural tendency of the spring elements to reach the "rest state."

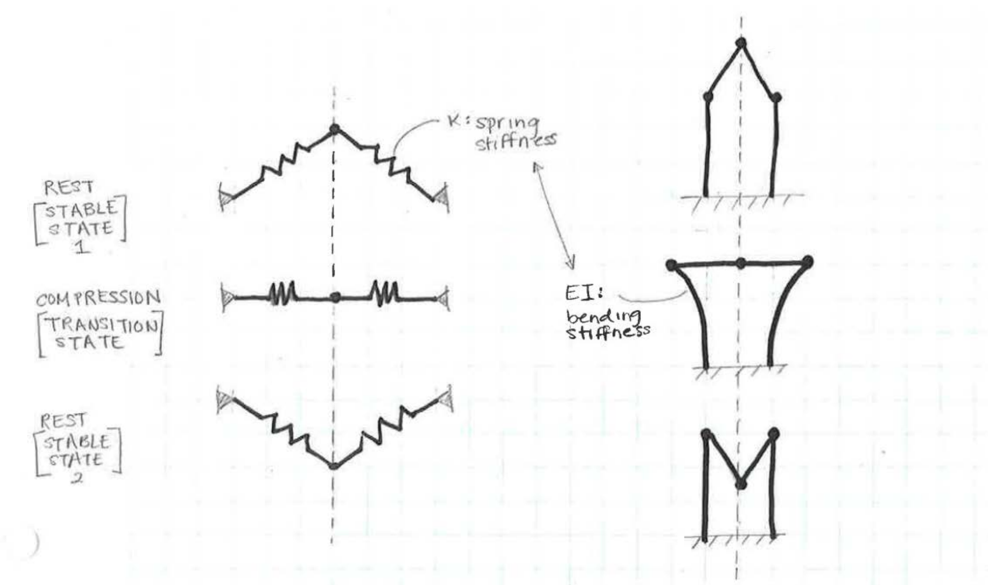


Figure 11 *Schematic representation of bistable mechanism and transition between stable states.*

Based on these principles the bistable system shown in Figure 9 was designed. In this system, the slender wooden strips represent the spring elements, and the bending stiffness plays the role of the spring. Therefore, the length, cross-sectional dimensions (used to calculate I, the moment of inertia), and the modulus of elasticity (E) of the material of the strips, dictates the stiffness of the system. The mechanism is activated by applying a force to the node at which all strips terminate, to push it through the "stressed" or flexed state, and pop it into the other rest state.

A parametric digital model was developed to simulate the movement of the mechanism. In this model, the bending of the rods was simulated according to the behavior of a cantilevered beam, as demonstrated in Figure 12. By setting the maximum deflection equal to m, the extension beyond the hinge, the force that is required to achieve this deflection was back calculated and then used to determine deflections at increments along the strip.

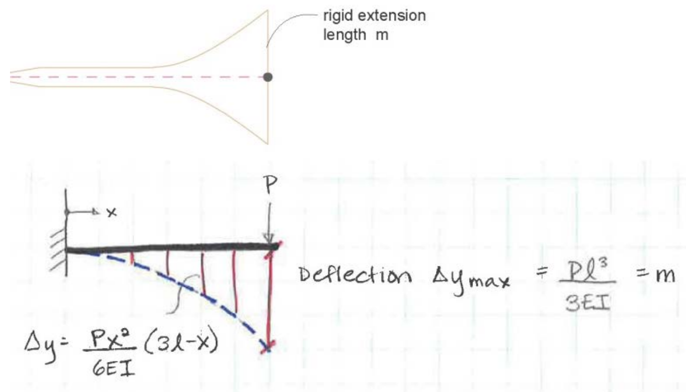


Figure 12 *The beam formula for a cantilevered beam was used to generate a digital simulation of the mechanism.*

A small scale prototype of the mechanism was fabricated in order to gain a better understanding of how the geometric parameters of the design affect the movement of the mechanism. The model was built using 3 strips of wood (pine) in a tripod configuration as the bendable elements, as shown in Figure 14. The rigid extensions, which are also wood (pine), are pin connected to the bendable strips. The rigid extensions terminate in a wooden block. The mechanism is activated by pulling this end piece away from the base or pushing it towards the base. The transition from one stable state to the other is shown in Figure 13.

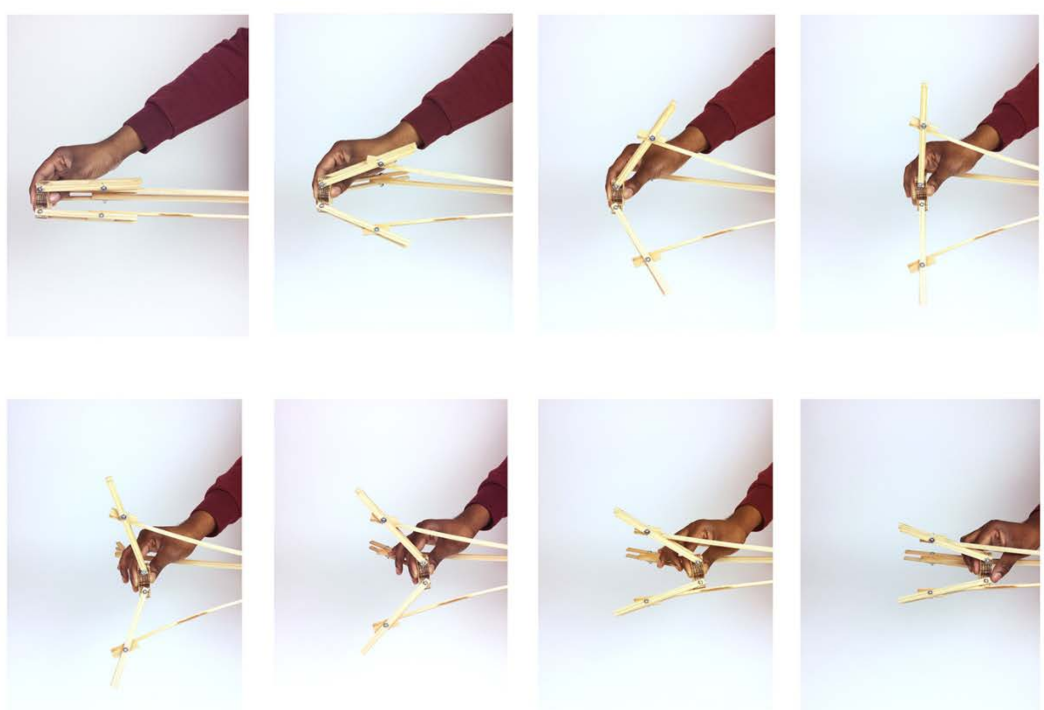


Figure 13 *Actuation of the prototype.*

Figure 14 *Physcial prototype of a bistable mechanism using flexible wood strips to act as springs.*

Concepts for Application for Lightweight Structures

In a world that is becoming increasingly more crowded, and in which globalization makes more places accessible to more people, making one place useful to a larger variety of people with different needs becomes increasingly valuable. The growing population also places a huge demand on a limited supply of natural resources. Instead of relying on new construction to meet the needs of the growing population, can we reduce our consumption of resources by making each building useful for multiple functions? How can we use transformable architecture to achieve this end?

The contextual background provided by the evaluation of reference projects, combined with the feedback gathered from fabricating and experimenting with the physical model, inspired concepts for application of the bistable mechanism into architectural elements. We explored two conceptual applications through digital modelling. The concept models assume that the bistable mechanisms actuate movement of lightweight structural systems. Each mechanism has 3 possible lengths, as shown in Figure 15. In our concept designs we assumed that three mechanisms were connected in series to create a module, and these modules could achieve variable lengths based on the stable state that each of the constituent mechanisms is in.

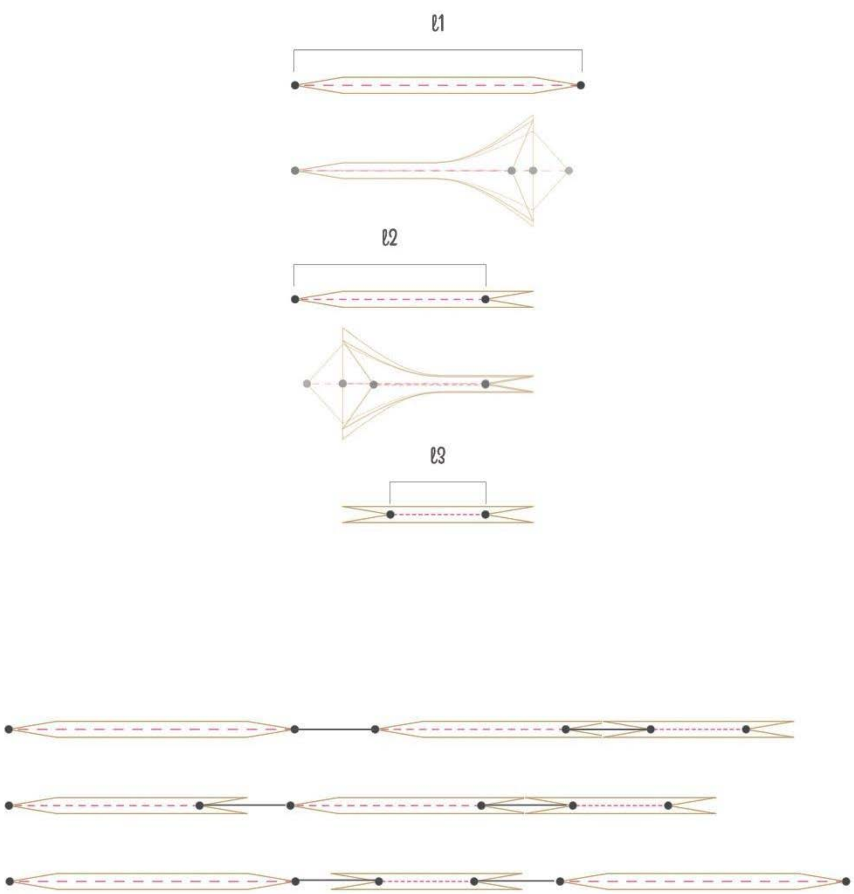


Figure 15 *The three possible lengths of the protoype mechanism (above); Variations on modules consisting of 3 prototype mechanisms (below).*

It should be noted that when these mechanisms are connected in series, they should be linked in such a manner that enables them to change length independently of one another. In other words, the change in length of one mechanism does not apply an activation force to adjacent mechanisms, but rather just changes the relative position of the adjacent mechanisms. This will prevent accumulation of resistance to the impulse force applied to actuate the system. The diagram in Figure 16 demonstrates a system in which the mechanisms are linked in series such that the force exerted by "popping" the end(s) of one mechanism causes a translation of the entire system.

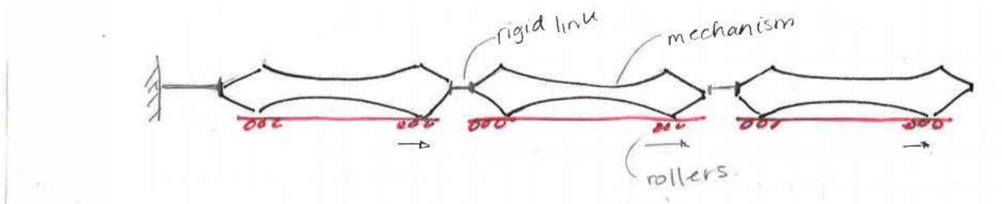


Figure 16 *Schematic representation of a linkage system to prevent accumulation of resistance during actuation of the module.*

The first application is a flexible wall system. The concept proposes a series of modules that are connected to a flexible wall (potentially fabric or a lightweight hinged frame) at its based and its top. By popping the mechanisms in each module into different lengths, the curvature of the wall can be changed. When two or more of these walls are used to define a space, the ability of the wall to change shape enables the user to create a variety of different spatial configurations, as shown in Figure 17. This system may be useful for changing room arrangements to accommodate changes in program or for influencing circulation through a space, or the change may be simply for experiential effect. It is assumed that this system would be able to be manually controlled by the user.

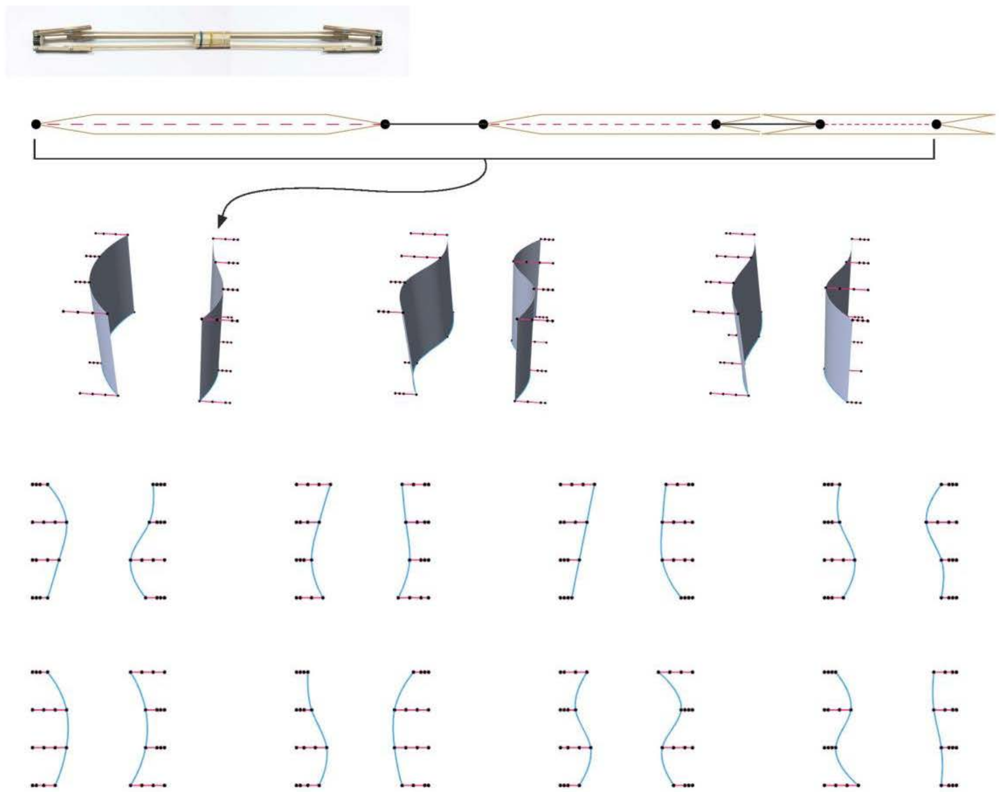


__Figure 17__ Potential application of the prototype mechanism to transform the shape of a wall. Grasshopper for Rhino was used to build a parametric model of the wall system and generate a series of wall variations based on random combinations of three prototype models at each wall control point.

The second application is a flexible roof or ceiling system, which expands upon the wall system by using a network of modules arranged in a grid to control the surface curvature of a lightweight ceiling or roof. By varying the lengths of the modules in the grid, variations in the surface geometry can be achieved as seen in Figure 18. This has potential applications for controlling room acoustics, or indoor climate. In this concept it is assumed that the actuation of the modules would be computer-controlled.

Future research will include experimentation with different materials and application of the mechanism to architectural prototypes at various scales.

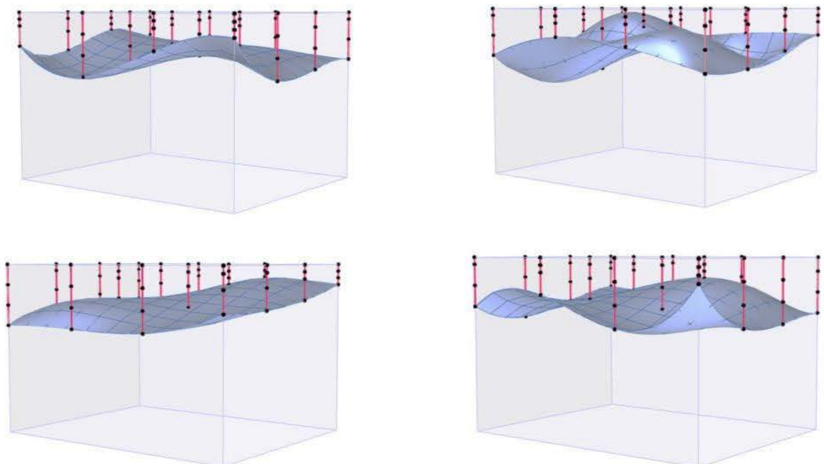


Figure 18 *Potential application of the prototype mechanism to control roof/ceiling surface geometry. Grasshopper for Rhino was used to build a parametric model of the ceiling surface and generate a series of surface geometries based on random combinations of three prototype models at each surface control point.*

Conclusion

An article entitled "The way we'll live," published in 1999 in the United States recognized that our increasingly more dynamic lifestyles require a more flexible way of living, and called for an architecture that can adapt to our changing needs. If we assume that the function of a space is defined by situations and not just a static moment, we can conclude that time is an essential factor in the creation of "place." Transformable architecture embraces this sense of time because it is dynamic in nature and therefore enables the creation of situations. In other words, the function of a place is not just a snapshot in time, but rather a series of happenings, and one can argue that transformable architecture, "as an equally malleable extension of who we are and how we live," can accommodate the evolution of situations.

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