SKIN DEEP: BREATHING LIFE INTO THE LAYER BETWEEN MAN AND NATURE

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Challenging the traditional presumption that building skins should be static and inanimate, this investigation examines the replacement of this convention with responsive skins that are treated as if they were extensions of man and the environment. With newer technologies and increased affordability, the wall separating the interior and exterior of architecture can respond to the slightest changes in temperature, light, movement or other stimuli. The measurement of sensitivity can be registered on both sides of the wall, reacting much like skin on our own bodies. With the emergence of smart materials, an elevated interest in utilizing unconventional building materials, and an urgent need to conserve energy, we must find ways to make our buildings more sensitive to the natures of the environment and of man. One smart material with tremendous potential is thermobimetals. By laminating two different metal alloys with different coefficients of expansion together, the result is a curling of the material as heat is increased. This deformation can be useful on a skin to either ventilate a space as the inside or outside temperature rises, or shut down when temperature rises due to the presence of fire. This report distinguishes two parts of the investigation. The first presents fourteen studies on the broad and more comprehensive notion of responsive systems, conceptually, programmatically and technologically. The second part focuses on the tectonics of thermobimetals as part of an operable, responsive skin.

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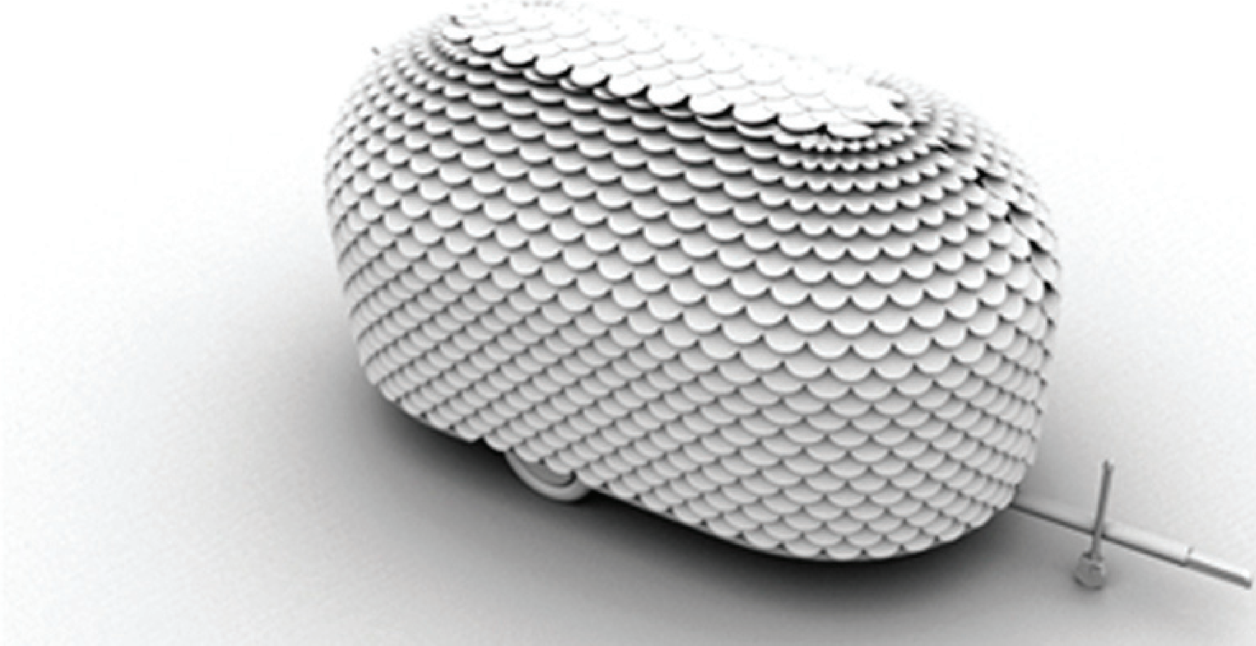

I. Responsive Architecture

"We hope for a profound participation in the world around us." [i]

—Philip Beesley et al, in *Responsive Architectures, Subtle Technologies.*

I.I Introduction

In the distant past, the exterior surface of a building passively protected, shielded and separated man from nature. Thick walls, small openings and heavy roofs ensured this security. "Rigidity and resistance to the external environment [were] normal qualities in building."[ii] In the 1930s, the modern movement and industrialization rejected the physical segregation of the indoors and outdoors and encouraged the use of glass walls as a means to visually bring the outside in. But, even though the glass was thin and transparent, the window wall remained physically impenetrable. This design/build investigation revisits the ongoing discussion of the *Primitive Hut* with a new position on balancing man with nature: skins of buildings can be designed to be porous, animated, and sensitive, performing as a tool, rather than an object. By making a skin that is responsive on the outside to changes in the climate AND on the inside to the movements of the body, it can connect man and nature harmoniously despite its material and physical presence. The manifestations would occur on the opposing surface of the skin: the outside skin's reaction would appear on the inside and vice versa, redefining "the 'body' whose expanded border embraces the surrounding environment."[iii] It would, in effect, blend inorganic matter with the organic.

Figure 1. 1948 Weewind Airstream Trailer.

This basic characteristic of building skins as a responsive skin is not new. It is one component of a sustainable low-energy concept, where performance is the primary criteria. One famous example is Jean Nouvel's *Institut du Monde Arabe*, where the skin responds to the changing light with camera-like shutters of its façade, reducing the heat gain for the building. Ironically, the kinetic wall was set too sensitively and subsequently was adjusted to not react to every minor change in light. Bodo Rasch's *Medina Umbrellas* is another responsive system that unfolds at dawn to shade the courtyard for morning prayers. The effect, although beautiful, is completely dependent on electronic sensors and motors. More recently, Fluidic Muscles, a silicon-coated polyamide rubber tube system, which cause linear movement as the "muscles" expand and contract using compressed air (created by a German company called Festo KG), were incorporated on a façade design by Kas Oosterhuis in the *Adaptive Facade in the Netherlands*. "Oosterhuis suggests the Fluidic Muscles can be used in conjunction with an inflatable cushion-shading device, fitted to the external skin of the building."[iv] The character of the façade changes with the passing of the sun on the exterior or the changing needs of the users for shading. Similar to this last example where interactivity occurs on both sides of the skin, the studies presented in Part I of this investigation attempt to consider the many layers of responsiveness. They consider conceptual soundness, programmatic flexibility, and human interactivity as major elements as a means to define responsiveness in a more comprehensive manner. Robert Kronenburg states this eloquently in the preface to his book, *Flexible:* "Flexible architecture consists of buildings that are designed to respond easily to change throughout their lifetime. The benefits of this form of design can be considerable: it remains in use longer; fits its purpose better; accommodates users' experience and intervention; takes advantage of technical innovation more readily; and is economically and ecologically more viable. It also has great potential to remain relevant to cultural and social trends."[v]

1.2 Responsive Context: The Airstream Trailer

In search of a context most suitable for the study of a responsive skin, it was clear that the architecture itself would have to be flexible or adaptable. A mobile structure that can travel one place to the next would be ideal in this case, since it has the flexibility to position itself in a select climate, ideal orientation and controlled setting. If its needs are not met and the context is incompatible, it can simple move. The Airstream trailer, an American icon and architect favorite, became an obvious choice for this skin project. Selected for its ideal grafting medium, the Airstream trailer is an independent, inhabitable unit, continuous on all sides (including the roof and the belly), and easily transportable. Each lightweight rendition since 1934 was a different study in aerodynamics, aluminum cladding and monocoque construction. "Monocoque is in an airplane fuselage a kind of construction in which the skin or outer shell bears all or most of the stresses. In an Airstream, it is the kind of construction in which the body and chassis are one unit."[vi] The actual model used in this study is a 1948 Weewind Airstream (see Figure 1). Its body is 14' long, which is 4' shorter than its famous cousin in the permanent MoMA collection, the Bambi. Stripping the trailer of its skin removed a large part of its structural integrity and technological innovation. For this reason, the Airstream shape was used an envelope, rather than a framework. A completely new model was developed and the monocoque construction removed.

The Weewind trailer was segmented into fourteen equal parts so that different designs of low-tech responsive systems could be developed and built at full-scale. The composite reproduction of the trailer was a patchwork or sampling of different skins, juxtaposed abruptly one alongside the next. Each design attempted to challenge different conceptual, programmatic and technological aspect of flexible living. For purposes of this report, the interior, although completely designed, is not presented.

2 PART ONE: Fourteen Tectonic Skin Studies

The following series of studies was designed in a studio setting of undergraduate students at USC in the fall of 2007. With the premise that technology can respond to physical stimuli and that theories of flux can manifest themselves in technology, each study focused on a specific facet of responsiveness (Figures 2 and 3). Even though the studies speculated on the potential that interior program and conceptual ideas of flux could inform the development of the skin of the building, the final themes of categorization were based on the resulting responsive systems as defined by Robert Kronenburg.

Those categories are as follows:

1. ‘Adapt’ includes buildings that are designed to adjust to different functions, users and climate change. It is architecture that has a loose fit and is sometimes called ‘open building.’
2. ‘Transform’ includes buildings that change shape, space, form or appearance by the physical alteration of their structure, skin or internal surfaces. It is architecture that opens, closes, expands and contracts.
3. ‘Move’ includes buildings that relocate from place to place in order to fulfill their functions better—it is architecture that rolls, floats or flies.
4. ‘Interact’ includes buildings that respond to the user’s requirements in automatic or intuitive ways. It is architecture that uses sensors to initiate changes in appearance and environment or operation that are enabled by kinetic systems and intelligent materials. [vii]

Limited to a tight budget, unskilled labor and simple woodshop tools, the group of students produced phenomenal results in a short amount of time. Brief descriptions of the studies accompany the wall sections and three-dimensional application of the skin.

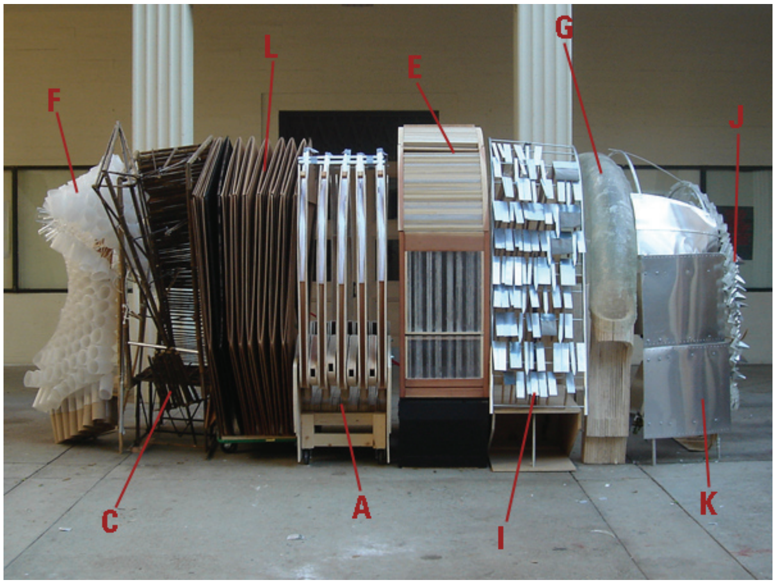

Figure 2. Reconfigured trailer with responsive skin studies.

2.1 Adapt

2.1.1 Mobile Cabinet: Removing the Skin, Removing the Structure, Removing the Walls (Cizek)

This study attempts to marry the structure with the skin so that when opened, the exterior wall would begin to disappear and the relocated elements would be transformed for some other use. The entire exterior skin is made of doors that would fold in or out leaving no framework behind. Each door then transforms into a chair, table, shelf, bed or other programmed element so that what was wall became door, what was door became furniture, what was indoors became outdoors. All movement is limited to hinging—vertically or horizontally. Materials are limited to wood and stacked plexiglass (laser-cut), so that all the elements are camouflaged in a transparent surface. When fully deployed, this cabinet-like domicile has strong references to Andrea Zittel's Living Units (1994) .[viii] In this case, unlike the others, the monocoque concepts of the original Airstream design is taken one step further. Materials: Redwood, plexiglass, fluorescent light. (Figures 2,3, and 4: Element E)

2.1.2 Illegal Immigrant's Rest Station: Camouflage of Found Objects (Arias-Ballesteros)

The skin of this investigation is intended to be so beautiful that it could mask what was hiding behind, so useful that it could incorporate discarded liter-sized soda bottles as building blocks and so performative that it could provide shade and ventilation in a hot climate. The result is the transformation of a mundane household waste product (the liter bottle) into an unrecognizable ethereal building material and ephemeral structure. White plastic ties are used to attach the bottles together and cardboard tubes for structure underneath. It is important to point out that in keeping with the concept of using found objects all materials were either found or donated. No money was spent on the purchase of materials. Materials: Plastic, cardboard. (Figures 2, 3, and 4: Element F)

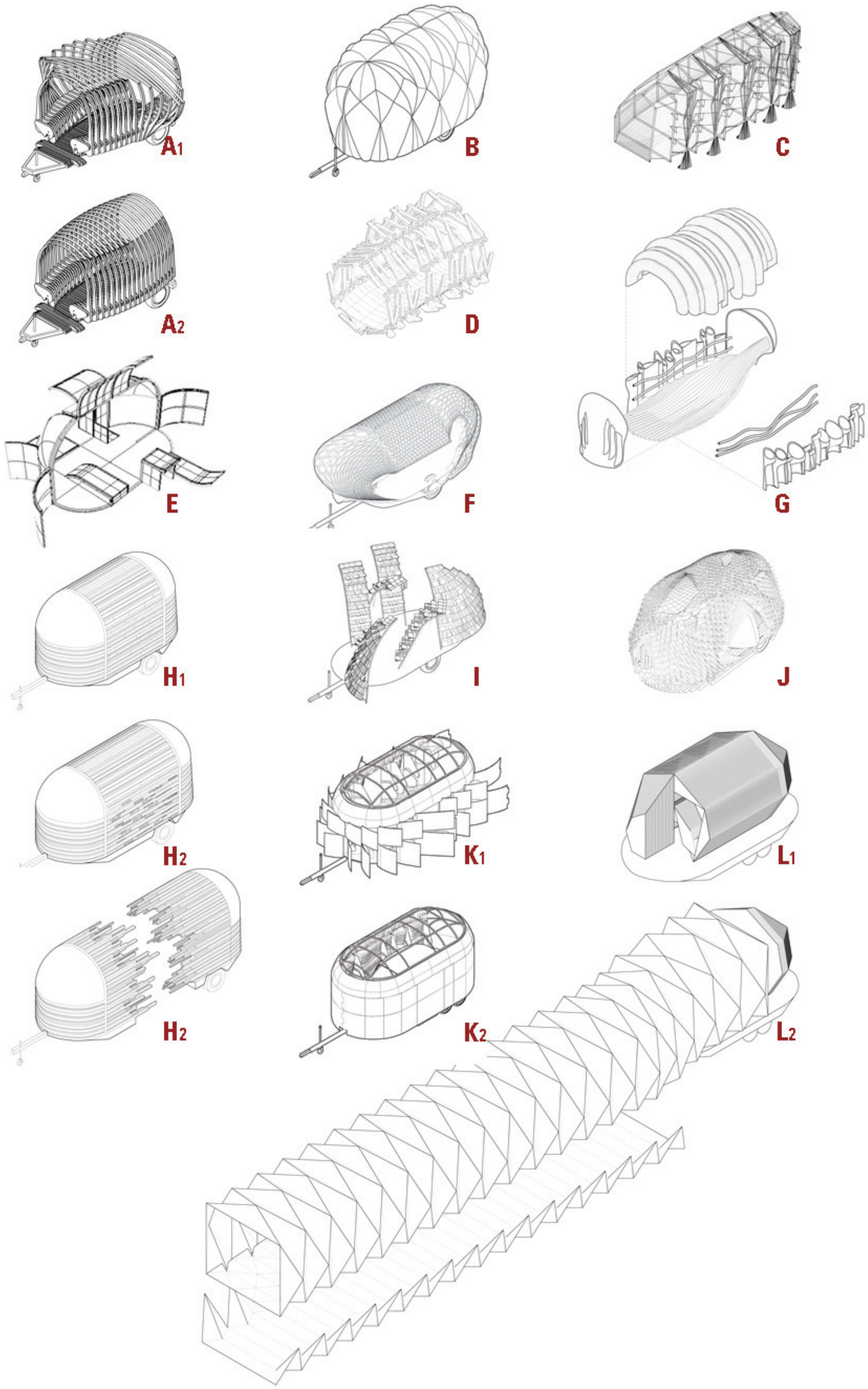

Figure 3. Isometric drawings of responsive skin studies.

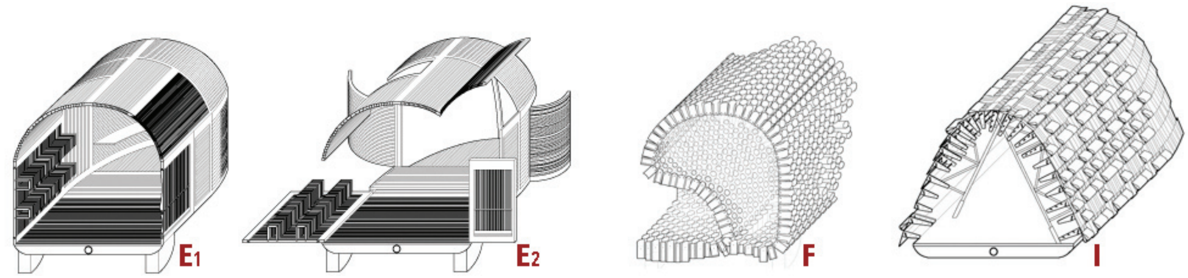

Figure 4. Wall sections.

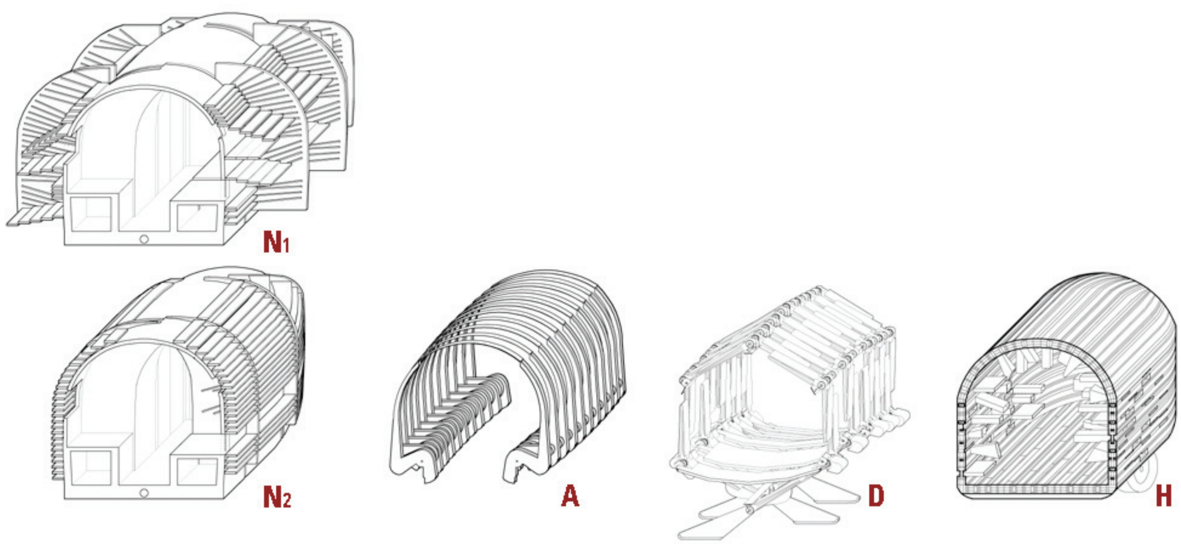

Figure 5. Wall sections.

2.1.3 Circus Fat Lady: The Theatrics of Water Collection (Van Hartesvelt)

Designing a folly that collects water can be a spectacle in itself. This study investigates water as a dynamic building material. Rainwater is captured and stored in stretchy latex bladders that bulge to "plus" sizes. Finding a material that could retain the water laterally and designing a structure that could support the weight vertically were the challenges in this project. Although ETFE is the ideal selection, the affordable material for the construction is high-strength neoprene weather balloons. As the amount of water increases, the gravity forces the structure down until it eventually sits directly on the ground. Hydraulic devices lower the trailer as the weight increases. To become mobile, the water is dispensed and bulk removed. Materials: Wood, latex, plastics, water.

2.1.4 Unmanned Charging Kiosk: Rain resistant and SAPs (Phung)

Anyone at any time can walk up to this charging kiosk and plug in their cell phone, laptop, pda or mp3 player, powered by solar energy. The entire surface of the trailer is a set of vertical panels, pivoted open and outward. Exposed to the elements, the entire structure, program and safety is readily compromised by a change in weather, namely rain. The focus of the design is on the development of an automatic system that could partially close with light rain or completely shut down when a downpour appeared. By capturing the raindrops in sacks of SAPs (Super Absorbant Polymers), the finely tuned, counter-balanced louvers instantly close from top to bottom. Given more water and weight, the larger panels begin to rotate and close the trailer into its iconic form. Once the rain stops, the reversible SAPs dry and return to their original form. Materials: Sheet aluminum, stainless steel mesh, wood, SAPs. (Figures 2, 3, and 4: Element I)

2.2 Transform

2.2.1 Reverse Objectification: Magnification and Reduction in the Skin (Perry)

Gender spaces often refer to the interrogation of the female space within the framework of male architecture. In Adolf Loos' Muller house, he objectified the female owner by setting aside an elevated space with controlled openings and theatrical positioning. Similar to Loos' design, this skin study initially presents an objectifying view of the occupant. As the occupant moves several interior panels, the view of the voyeur changes. The result is an interior program transformed from seat to bed by pushing interior panels connected to the exterior surface out, thickening the exterior wall, and strategically positioning a series of louvers in such a way to hide, hinder or divert the view. In doing so, the gendered condition becomes neutralized and asexual. Materials: Wood. (Figure 5: Element N)

2.2.2 Reality Architecture: Internet Polling and Physical Indexing (Chinn)

Reality TV, internet polling and cell phone texting have fueled our interest in popularity voting, top-ten lists and surveyed statistics. Architecture too can respond to this cultural phenomenon in a three-dimensional, epigenetic surface.[ix] In this case, the trailer reacts to changes in information technology as opposed to the environment or human occupation. Both the latter stimulants become bystanders to the spectacle of the information highway. As people vote offsite, the gears and ratchets move to represent the popular or unpopular vote in a shape or surface landscape, derivative of data graphs. The overall structure can crawl across the ground as voting continues around the clock. Materials: Cast aluminum, cast resin, galvanized steel ratchets. (Figures 3 and 5: Element D)

2.2.3 On Waiting: Unsocial Aspects of Sitting (Blaine)

Controlling heat gain is a basic function of architecture. There are many hi-tech, electronic devices and actuators that track light or heat. This low-tech one actively shades the user from the sun, utilizing the input and weight of the human as he/she shifts from one seat to the other. Consolidating the structure, the skin, the seating and the movement into the repetitive frame, the overall form will distort to expose the moving organisms on the inside while minimizing the surface area facing the sun, ultimately reducing heat gain. Made out of rigid members, the new trailer will appear to be extremely flexible and strangely pliable. Materials: Plywood. (Figures 2, 3, and 5: Element A)

2.2.4 Threshold: Maximizing the Peephole, Minimizing the Passage (Abiva)

The smallest pinhole can allow enough light in to cast an image. The inhabitable version of this space is called the Camera Obscura. A keyhole, the size of the pupil of the eye, can allow one to peep to a space beyond, establishing a situation of voyeurism. An even larger opening like a window can frame a display and feed a fetish. An even larger opening would be considered a passage. The design of this skin toys with the various sized openings and our psychologies associated with them. Divided in two parts, the trailer slides apart initially revealing small openings. These openings grow larger as the trailer continues to stretch. By the end, the entire trailer extends by several feet, exposing its contents fully. Materials: Douglas fir and pine, Teflon. (Figures 3 and 5: Element H)

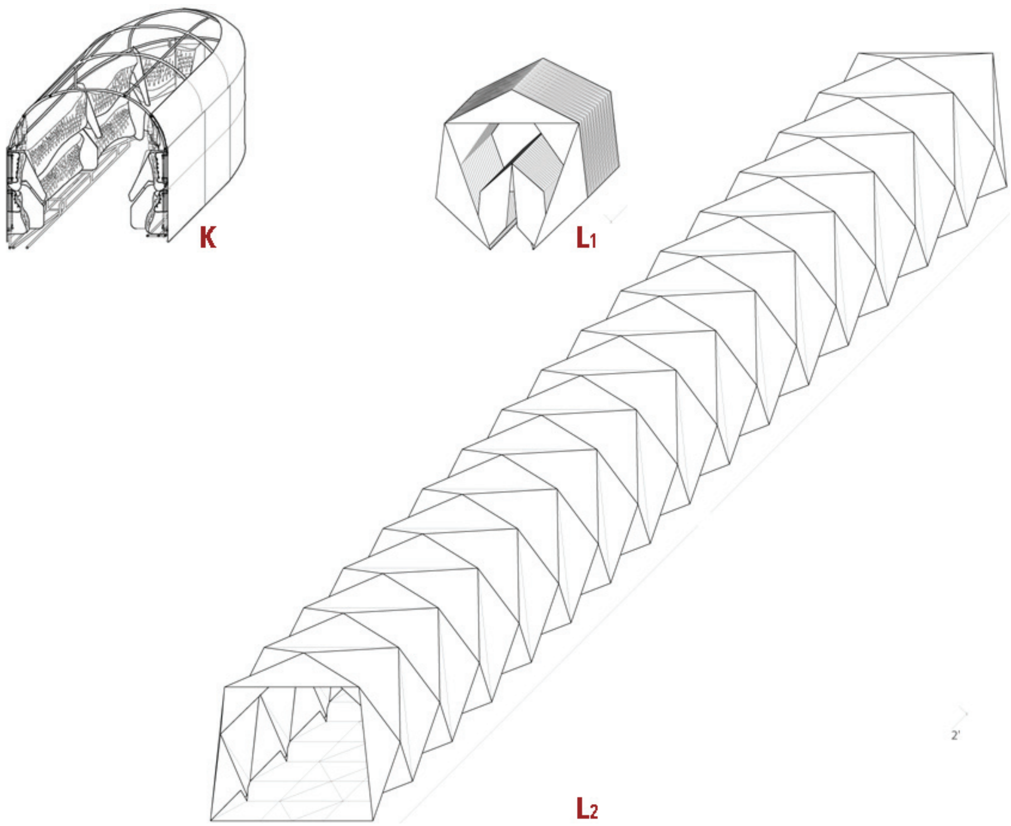

Figure 6. Wall sections.

2.3 Move

2.3.1 The Portable Nesting Garage: Bringing the Outdoors In (Flascha)

If clothing can be considered an extension of the human body, can the automobile be considered another layer and the trailer even yet another? Borrowing from the iconic "drive-in" scenario, the classic Volkswagen bug hauls the Airstream shell to its destination, and then disconnects the tow to drive *into* the Airstream from the rear. The entire skin of pivoting panels stands open when the Airstream is empty. As the VW bug enters, the skin clamps down to hug the automobile and privatizes an interior garden[x] of hydroponic plants. Ironically, the outdoors is brought in, but is still outside (there is no roof on this trailer). With no hat on one's head, no moon roof on one's car, and no roof on one's Airstream garden, how far or close are we actually to nature? Materials: Sheet aluminum, vacuum-formed plastic, aluminum tubing, plants. (Figures 2, 3, and 6: Element K)

2.3.2 Disposable Emergency Shelter: Creativity with Cardboard, Tarp and Community (Hovsepian)

Corrugated cardboard is a readily available material in most countries around the world. It is cheap, disposable and lightweight, with small amounts of insulation, making it an ideal material for emergency shelters. Using simple origami techniques to increase structural stability and ensure compactability, standard sized boxes were folded with minimal waste and secured by Velcro at select points to a folded tarp-laminated cardboard floor. The result is an expandable structure that can house a large number of occupants, and even a community. Sections of the structure can also be detached and distributed to families or individuals as needed. Openings for light and access are designed into the system. Materials: Corrugated cardboard, plastic tarp, Velcro, liquid waterproofing. (Figure 2, 3, and 6: Element L)

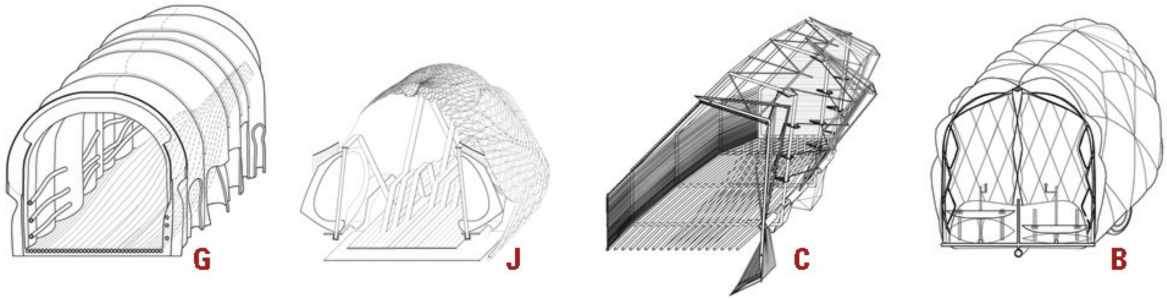

Figure 7. Wall sections.

2.4 Interact

2.4.1 Whispering Confessional: Wind, Secrets and Sound (Choi)

Similar to the whispering arches found in gothic architecture, this study investigates how the phenomena of sound travel can inform the shape and structure of architecture, especially in the use of non-loadbearing materials like resin-coated fiberglass. In this study, participants can whisper their secrets on one side of the trailer while others can listen to the anonymous monologue on the opposite side. The partial tubes take the shape of the Airstream trailer in one of the simplest structural forms, the arch. Lateral stability is gained by attaching rigid sound tubes to all the arches from front to back. As the trailer travels on the highway, these hollow tubes, like musical instruments, capture wind at its front and emit haunting sounds out the rear. Materials: Resin-coated fiberglass, plywood, aluminum tubing, aluminum expandable duct, silicon. (Figures 2, 3, and 7: Element G)

2.4.2 The Moving Image and Optometry: Blurring the 2D and 3D Surface (Chen)

Uta Barth, a photographer famous for her blurry photographs, captures the space of *in-between* by setting the focal length on her camera to a location between her body and the subject. Likewise, the *Blur Building* by Elizabeth Diller + Ricardo Scofidio also challenges the common hard-edged architecture by making a structure, or cloud, made predominantly of water vapor. This study challenges those same concepts, however, using tangible materials. When wind hits the surface of the trailer, the surface vibrates with blurry material. Hundreds of pinwheel-like units spin, making the skin translucent or even invisible. During the day, the metallic surfaces of the pinwheels reflect light in and out of the trailer, while at night, the movie projected from the inside oscillates from the inside of the skin to any surface outside, extending the surface beyond the shell of the trailer. Materials: Fiberglass, resin, aluminum, laminated wood. (Figures 2, 3, and 7: Element J)

2.4.3 Indexing the Quality of Water: A Study with Bamboo (Aguirre)

Many rivers around the world are contaminated with industrial runoff. Lacking the scientific technology necessary to detect acids or other poisons in the water, some places use lichen as a natural indicator of contaminants. It is readily available and can grow aeroponically, or without soil. This study, in addition to the lichen, considers the use of bamboo, another readily available material, in a building system that can be built wherever needed. Using the power of water running downstream, a large bamboo lever activates a simple pump, spraying the river water across the roof of the structure and soaking the lichen. If safe, the lichen is green. If not, it is orange. When safe, the mist becomes a natural cooling device. Materials: Bamboo, metal joints, lichen. (Figures 2, 3, and 7: Element C)

2.4.4 Dirty and Clean Oxygen: Air as Material (Gustafson)

For lightweight construction, nothing can weigh less than air. Combined with a program of air collection and dissipation, this study examined air as a building material and as a commodity. The two programs of opposite nature, smog collection and oxygen bar, were incorporated into the skin and the structure. Held up by structural air tubes of compressed air (and an adjustable low-tech system of compression panels in the floors), the skin was partially filled with clean O2 and acted as insulation, which is necessary to keep the smog samples cool. Patrons could breathe clean O2 from nozzles on the surface of the skin while collection devices for smog could suction air through the upper crevices of the design. As the exterior temperatures become cooler in the evening and the O2 pillows would become depleted and deflated, the insulation was less necessary. The interior could be accessed unconventionally by squeezing between the pillows. Materials: ETFE, aluminum, compressed air, oxygen. (Figures 3 and 7: Element B)

3 PART TWO: Smart Systems or Smart Materials

Once merely an element to build shelter, materiality has now become instrumental in the design of building skins. The experimental attitude to materiality has architects considering the use of materials in new and unexpected ways, in unconventional situations and conditions. Many of these newly developed materials are capable of reacting flexibly to external conditions physically or chemically in response to changes in the temperature, light, electric field or movement. The term Smart Materials has been used to define these materials that have changeable properties and are able to reversibly change their shape or color. These materials are important to architectural skins in that they allow the building surface to be reactive to changes, both inside and out, automatically. “Energy and matter flows can be optimized through the use of smart materials, as the majority of these materials and products take up energy and matter indirectly and directly from the environment.”[xi] This second part of this multi-faceted investigation focuses on the development of an old smart material used in innovative application—for architectural skins.

3.1 Thermobimetals

3.1.1 Introduction to Thermobimetals

Thermobimetals have been used since the beginning of the industrial revolution. A lamination of two metals together with different thermal expansion coefficients, it simply deforms when heated or cooled (see Figure 16). As the temperature rises, one side of the laminated sheet will expand more than the other. The result will be a curved or curled piece of sheet metal. Reacting with outside temperatures, this smart material has the potential to develop self-actuating intake or exhaust for facades. Available in the form of strips, disks or spirals, thermobimetals are commonly used today in thermostats as a measurement and control system and in electrical controls as components in mechatronic systems. So far, however, few applications in architecture have been documented. Automatically opening and closing ventilation flaps have been developed and installed in greenhouses and for use as self-closing fire protection flaps, but nothing has been published on the development of this material for building skins.[xii]

Thermobimetals can be a combination of any two compatible sheet metals. The combinations of metals with different expansion coefficients (see Table 1) and at various thicknesses can produce a wide range of deflection. TM2, the ideal thermobimetal for this investigation, had the highest amount of deflection in the temperature range of 0-120 degrees Fahrenheit. The low expansion material is called Invar, which is an alloy of 64% iron and 36% nickel with some carbon and chromium. The high expansion material is a nickel manganese alloy composed of 72% manganese, 18% copper and 10% nickel. This bi-metal is also called 36-10 and the ASTM name is TM2.[xiii] Made corrosion-resistant by plating with chrome and copper, this material is available in sheets or strips in several thicknesses. It can be fabricated into disks, spirals and other shapes. The amount of deflection varies dependent on the size of the sheet, the air temperature, the position of clamping and the thickness of the material. The charts (see Table 2 and 3) summarizes the simple deflection relative to temperature and length. Three different sizes were selected for this study, .01mm, .03mm and .0025mm.

All types

	x10^(-6)	°F	°F
ASTM Type	**flexivity (50-200)°F**	**low temp**	**high temp**
TM1	15	0	300
TM2	21.7	0	400
TM3	10.4	200	600
TM4	8.6	250	700
TM5	6.4	300	850
TM8	15.6	0	400
TM9	11.5	0	300
TM10	13.1	0	300
TM11	13.2	0	300
TM12	13.7	0	300
TM13	14	0	300
TM14	14.7	0	300
TM15	14.8	0	300
TM16	14.9	0	300
TM17	15	0	300
TM18	11.9	200	600
TM19	14.4	150	450
TM20	13.8	0	300
TM21	10.7	200	600
TM22	10.2	0	300
TM23	18.3	200	600
TM24	13.1	0	300
TM25	14	0	300
TM26	14.7	0	300
TM27	14.7	0	300
TM28	14.8	0	300
TM29	15.8	0	300
TM30	11.8	200	600
TM31	18.9	0	300
TM32	21.7	0	300
TM33	20.8	0	300
TM34	21.4	0	300
TM35	15.2	0	300
TM36	13.7	0	300

All types within our temperature range

	x10^(-6)	°F	°F
ASTM Type	**flexivity (50-200)°F**	**low temp**	**high temp**
TM22	10.2	0	300
TM9	11.5	0	300
TM10	13.1	0	300
TM24	13.1	0	300
TM11	13.2	0	300
TM12	13.7	0	300
TM36	13.7	0	300
TM20	13.8	0	300
TM13	14	0	300
TM25	14	0	300
TM14	14.7	0	300
TM26	14.7	0	300
TM27	14.7	0	300
TM15	14.8	0	300
TM28	14.8	0	300
TM16	14.9	0	300
TM1	15	0	300
TM17	15	0	300
TM35	15.2	0	300
TM8	15.6	0	400
TM29	15.8	0	300
TM31	18.9	0	300
TM33	20.8	0	300
TM34	21.4	0	300
TM32	21.7	0	300
TM2	21.7	0	400

Table 1. Comparison of different thermobimetal combinations.

36-10 (ASTM TM2)		Cantilever Strip			
		∆T=1ºF		∆T=10ºF	
t (in)	L (in)	D (in)	D (cm)	D (in)	D (cm)
0.03	2	0.0015	0.0038	0.01	0.04
0.03	4	0.0059	0.0150	0.06	0.15
0.03	6	0.0133	0.0338	0.13	0.34
0.03	8	0.0236	0.0600	0.24	0.60
0.03	10	0.0369	0.0938	0.37	0.94
0.03	12	0.0532	0.1351	0.53	1.35
0.03	14	0.0724	0.1838	0.72	1.84
0.03	16	0.0945	0.2401	0.95	2.40
0.03	18	0.1196	0.3039	1.20	3.04
0.01	2	0.0044	0.0113	0.04	0.11
0.01	4	0.0177	0.0450	0.18	0.45
0.01	6	0.0399	0.1013	0.40	1.01
0.01	8	0.0709	0.1801	0.71	1.80
0.01	10	0.1108	0.2814	1.11	2.81
0.01	12	0.1595	0.4052	1.60	4.05
0.01	14	0.2171	0.5515	2.17	5.51
0.01	16	0.2836	0.7203	2.84	7.20
0.01	18	0.3589	0.9116	3.59	9.12
0.0025	2	0.0177	0.0450	0.18	0.45
0.0025	4	0.0709	0.1801	0.71	1.80
0.0025	6	0.1595	0.4052	1.60	4.05
0.0025	8	0.2836	0.7203	2.84	7.20
0.0025	10	0.4431	1.1254	4.43	11.25
0.0025	12	0.6380	1.6206	6.38	16.21
0.0025	14	0.8684	2.2058	8.68	22.06
0.0025	16	1.1343	2.8811	11.34	28.81
0.0025	18	1.4356	3.6464	14.36	36.46

36-10 (ASTM TM2)		Beam			
		∆T=1ºF		∆T=10ºF	
t (in)	L (in)	D (in)	D (cm)	D (in)	D (cm)
0.03	2	0.00	0.00	0.00	0.01
0.03	4	0.00	0.00	0.01	0.04
0.03	6	0.00	0.01	0.03	0.08
0.03	8	0.01	0.02	0.06	0.15
0.03	10	0.01	0.02	0.09	0.23
0.03	12	0.01	0.03	0.13	0.34
0.03	14	0.02	0.05	0.18	0.46
0.03	16	0.02	0.06	0.24	0.60
0.03	18	0.03	0.08	0.30	0.76
0.01	2	0.00	0.00	0.01	0.03
0.01	4	0.00	0.01	0.04	0.11
0.01	6	0.01	0.03	0.10	0.25
0.01	8	0.02	0.05	0.18	0.45
0.01	10	0.03	0.07	0.28	0.70
0.01	12	0.04	0.10	0.40	1.01
0.01	14	0.05	0.14	0.54	1.38
0.01	16	0.07	0.18	0.71	1.80
0.01	18	0.09	0.23	0.90	2.28
0.0025	2	0.00	0.01	0.04	0.11
0.0025	4	0.02	0.05	0.18	0.45
0.0025	6	0.04	0.10	0.40	1.01
0.0025	8	0.07	0.18	0.71	1.80
0.0025	10	0.11	0.28	1.11	2.81
0.0025	12	0.16	0.41	1.60	4.05
0.0025	14	0.22	0.55	2.17	5.51
0.0025	16	0.28	0.72	2.84	7.20
0.0025	18	0.36	0.91	3.59	9.12

Table 2. Projected deflection values of thermobimetal cantilever strip and beam.

36-10 (ASTM TM2)		Spiral	
		∆T=1ºF	∆T=10ºF
t (in)	**L (in)**	**α (angular degrees)**	**α (angular degrees)**
0.03	2	0.09	0.89
0.03	4	0.18	1.78
0.03	6	0.27	2.68
0.03	8	0.36	3.57
0.03	10	0.45	4.46
0.03	12	0.54	5.35
0.03	14	0.62	6.24
0.03	16	0.71	7.13
0.03	18	0.80	8.03
0.03	20	0.89	8.92
0.03	22	0.98	9.81
0.03	24	1.07	10.70
0.03	26	1.16	11.59
0.03	28	1.25	12.48
0.03	30	1.34	13.38
0.03	32	1.43	14.27
0.03	34	1.52	15.16
0.03	36	1.61	16.05
0.03	38	1.69	16.94
0.03	40	1.78	17.83
0.03	42	1.87	18.73
0.03	44	1.96	19.62
0.03	46	2.05	20.51
0.03	48	2.14	21.40
0.03	50	2.23	22.39

Table 3. Projected deflection values of thermobimetal spiral strips.

36-10 (ASTM TM2)		Spiral (cont.)	
		∆T=1ºF	∆T=10ºF
t (in)	**L (in)**	**α (angular degrees)**	**α (angular degrees)**
0.01	2	0.27	2.68
0.01	4	0.54	5.35
0.01	6	0.80	8.03
0.01	8	1.07	10.70
0.01	10	1.34	13.38
0.01	12	1.61	16.05
0.01	14	1.87	18.73
0.01	16	2.14	21.40
0.01	18	2.41	24.08
0.01	20	2.68	26.75
0.01	22	2.94	29.43
0.01	24	3.21	32.10
0.01	26	3.48	34.78
0.01	28	3.75	37.45
0.01	30	4.01	40.13
0.01	32	4.28	42.80
0.01	34	4.55	45.48
0.01	36	4.82	48.15
0.01	38	5.08	50.83
0.01	40	5.35	53.50
0.01	42	5.62	56.18
0.01	44	5.89	58.85
0.01	46	6.15	61.53
0.01	48	6.42	64.20
0.01	50	6.69	66.88

36-10 (ASTM TM2)		Spiral (cont.)	
		∆T=1ºF	∆T=10ºF
t (in)	**L (in)**	**α (angular degrees)**	**α (angular degrees)**
0.0025	2	1.07	10.70
0.0025	4	2.14	21.40
0.0025	6	3.21	32.10
0.0025	8	4.28	42.80
0.0025	10	5.35	53.50
0.0025	12	6.42	64.20
0.0025	14	7.49	74.91
0.0025	16	8.56	85.61
0.0025	18	9.63	96.31
0.0025	20	10.70	107.01
0.0025	22	11.77	117.71
0.0025	24	12.84	128.41
0.0025	26	13.91	139.11
0.0025	28	14.98	149.81
0.0025	30	16.05	160.51
0.0025	32	17.12	171.21
0.0025	34	18.19	181.91
0.0025	36	19.26	192.61
0.0025	38	20.33	203.32
0.0025	40	21.40	214.02
0.0025	42	22.47	224.72
0.0025	44	23.54	235.42
0.0025	46	24.61	246.12
0.0025	48	25.68	256.82
0.0025	50	26.75	267.52

3.1.2 Process of Investigation

This on-going study (to be completed by May 2008) proposes the use of a thermobimetal as a smart material in the development of a responsive building skin. As the outside (or inside) temperature rises, it is intended that the skin will physically peel open, allowing the building to ventilate automatically. With further development, an active method of air intake and exhaust can be developed. To investigate the capacity of this material in this application, various tile shapes and forms are being considered and modeled digitally (Figures 8, 9, and 10). Quantities of the three thicknesses of thermobimetals have been ordered and will be physically tested in full-scale detail mock-ups in early January (after the publication of this report). In order to understand the responsive characteristics of the material in actual application, the tile types were separated in three different categories: flat shapes, curved shapes and folded (three-dimensional) shapes. The following diagrams begin to speculate on the possibilities of this material. Several full-scale mock-ups will be built from each category to confirm the theoretical presumptions. In addition, other detailing opportunities, like clamping, pivoting, hinging and twisting will be explored. In the folded shape category, a pivot point is used to allow the cell to rotate when the material expands. One side of the balanced cell would expand further from the fulcrum, initiating a gravitational momentum and resulting in the spinning of the cell on the pivot. This additional movement could be used as an additional, *active* component in ventilating a building. A complete report of the findings will be available in May 2008.

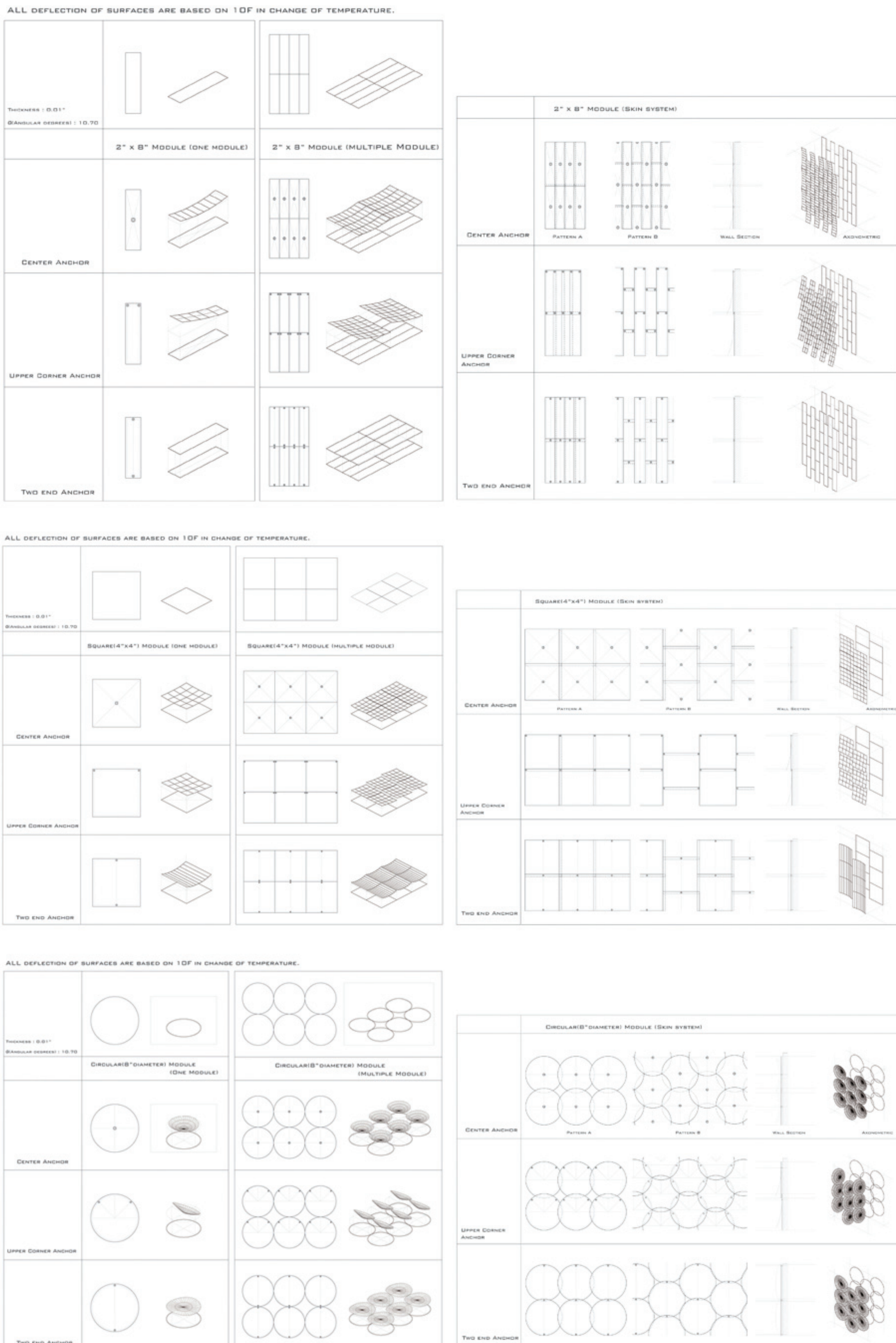

Figure 8. Tiling patterns with projected deflections.

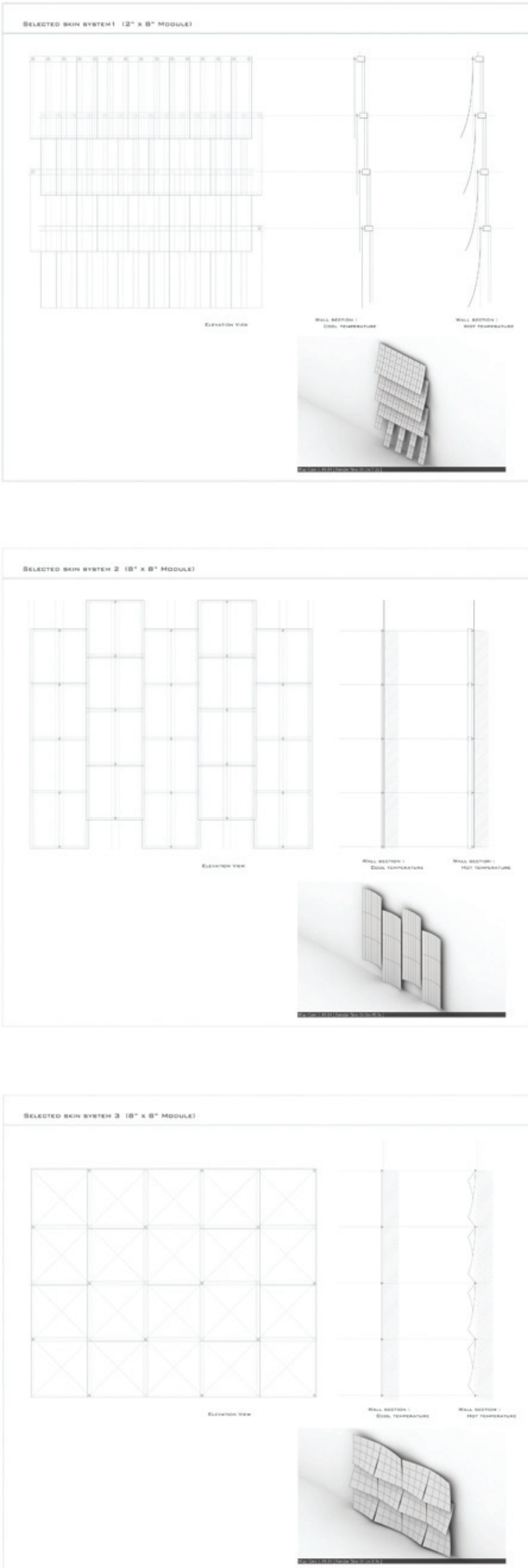

Figure 9. Deflection projections of tiles at various fixed points.

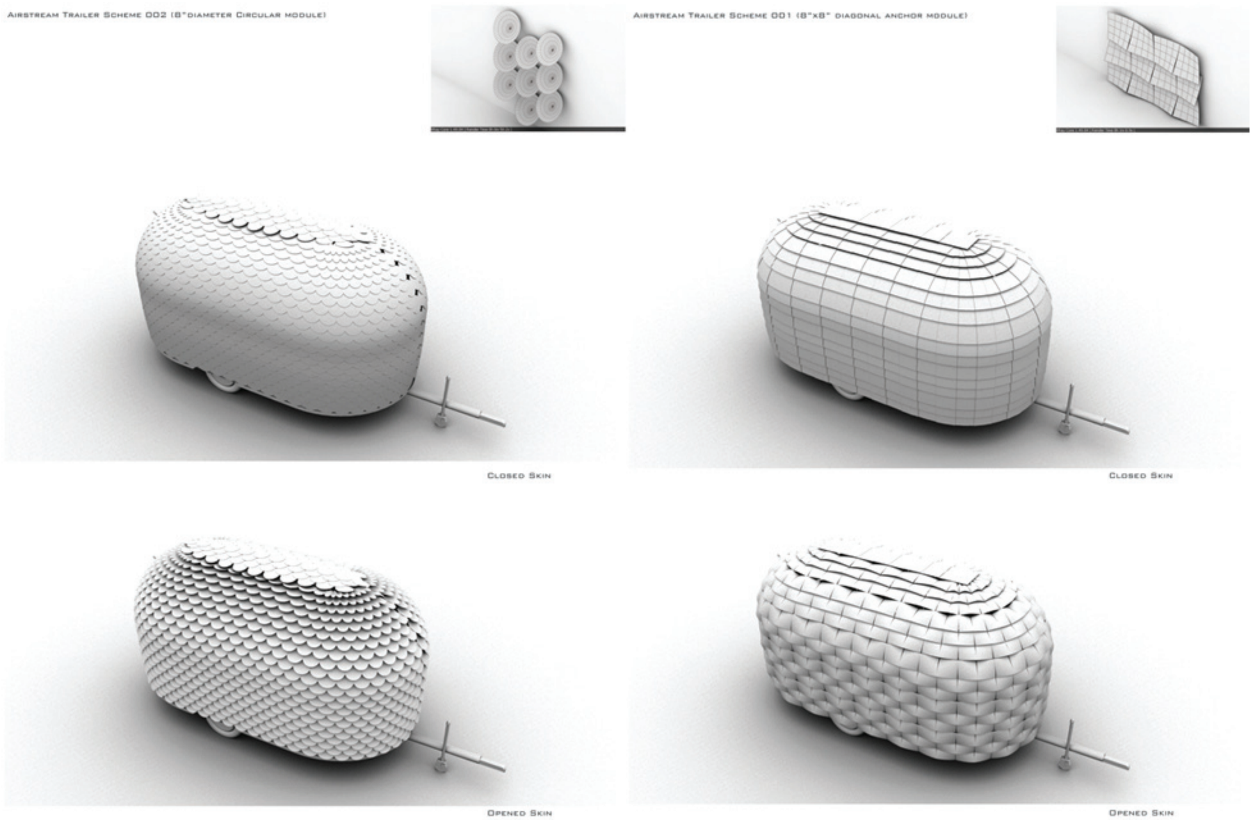

Figure 10. Trailer re-skinned with thermobimetal tiles in low and high temperatures.

4 Conclusion

Our climate has begun to change dramatically. Global warming will ensure its course. Political, economic and technological developments produce dynamic and globalizing cultures and virtual workplaces among other changes at logarithmic rates. Architecture must respond. In order to keep up with this dynamic world, architects need to reconsider design beyond the digital medium. As BIM (Building Information Modeling) and parametric modeling have advanced well beyond construction capabilities, more attention must be focused on the low-tech side of architecture—on construction. The development of new and smart materials, fabrication of affordable and customized parts, and implementation of complex building skins and structures must rise to the level of hi-tech, digital design. Studying various programs and experimenting with thermobimetals is just the tip of the iceberg. To become comfortable with aggressive sustainable design, more information, access, education, materials and applications of responsive systems must be made available to the public. Beyond that, we need to believe that architectural skins can be sensitive, interactive extensions of our own bodies and not just protection from nature.

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Acknowledgements

Responsive Skins Studies Team: Matthew Abiva, Alexander Aguirre, Francisco Arias-Ballesteros, Keith Blaine, Debbie Chen, Jeffrey Chinn, Paul Choi, Katherine Cizek, Krista Flascha, Kathleen Gustafson, Tina Hosvepian, Loren Perry, Christine Phung, Blaire Van Hartesvelt.
Thermobimetal Research Team: Yupil Chon, Daisuke Sato, Atsushi Sugiuchi, Kim Wiebe.

Special Thanks to:

Amcor
Ball Corporation
Coast Aluminum
Foam Sales and Marketing
Home Depot
Los Angeles Department of Water and Power
McNichols
Plastic Concepts Inc.
Plastic Depot of Burbank
Hood & Co., Inc.
Sani-tred
Santa Fe Bending
Wiretech EDM Inc

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