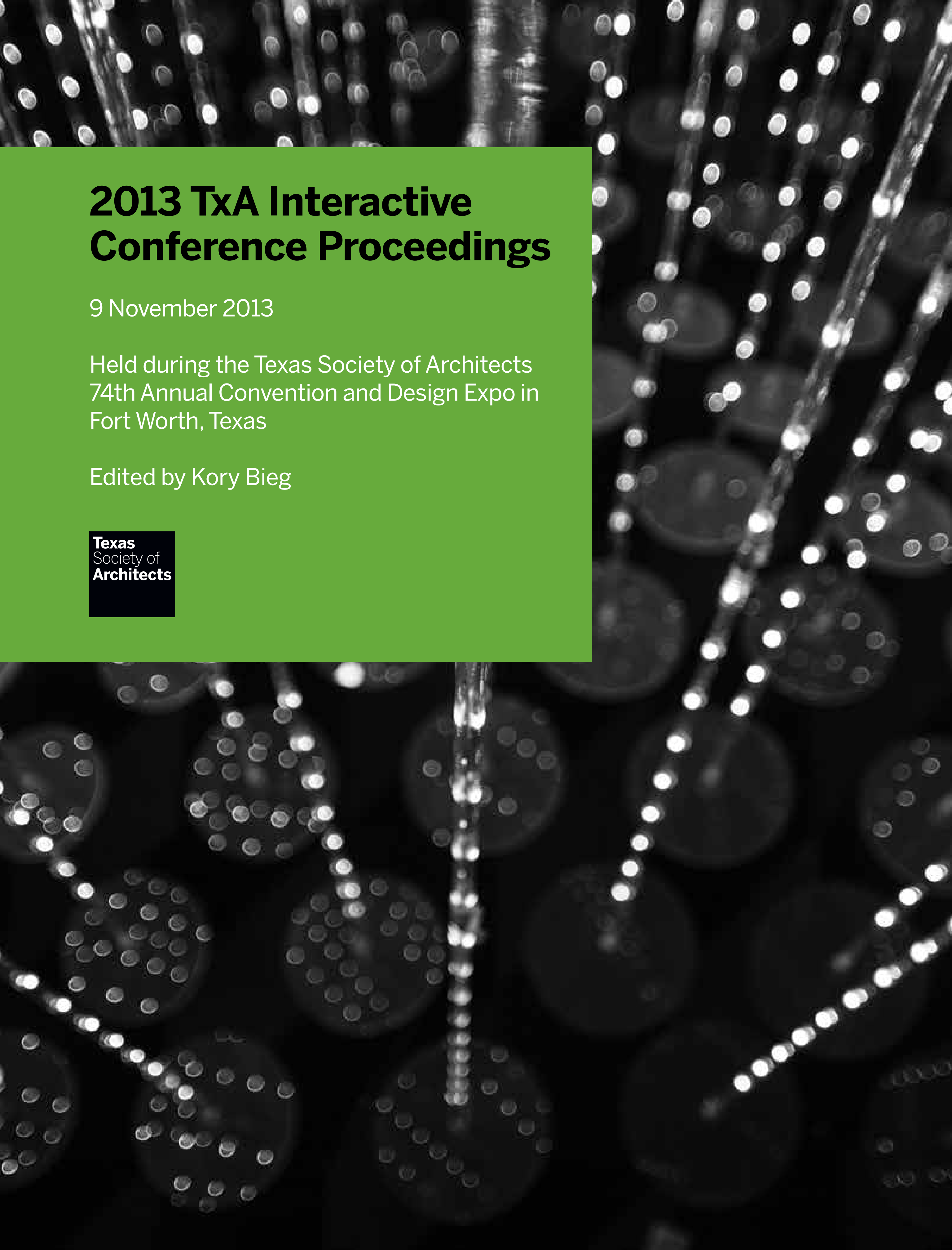

2013 TxA Interactive Conference Proceedings

9 November 2013

Held during the Texas Society of Architects 74th Annual Convention and Design Expo in Fort Worth, Texas

Edited by Kory Bieg

Texas Society of Architects

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Lawrence W. Speck, FAIA
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As someone who has always had one foot in architecture academia and one foot in architectural practice, it has always been frustrating to me that these two worlds do not have more constant mechanisms for dialogue.

When I go to a peer-reviewed academic conference, I am often blown away by the relevance and applicability of the content of papers to the professional world of architecture. And yet, the room is usually populated solely by a handful of academics deeply committed to the particular issues at hand. When I attend an AIA convention, I am struck by the hunger of at least a subset of attendees for intellectually stimulating and research-based programs that go beyond normal practice topics. And yet, the offerings are generally dominated by the same kind of content that is available in the proliferating world of continuing education "lunch and learns" across the country.

One of the goals of the Texas Society of Architects 74th Annual Convention and Design Expo, held in Fort Worth on November 7–9, 2013, was to try to remedy this problem by embedding a small peer-reviewed academic conference within the larger convention. We hoped to give the 1500+ architects and several hundred additional emerging professionals in attendance the opportunity to participate in sessions that were unapologetically academic. We also hoped to give the group of selectively chosen academics a larger and more diverse audience for their ideas and discoveries than they might normally get.

The conference topic—focused on all things digital in our field—was selected because it is fertile ground for current academic research, and it is also an area of rapid advancement in the profession. It is a particularly appropriate domain where dialogue between academics and practitioners needs to happen and could create great benefit for both camps.

The first year of this experiment was a resounding success that we hope to duplicate and expand in the future. We also hope to broaden the dialogue even further through distribution of the material presented at the convention via publications like the one you are holding in your hand.

Acknowledgments: 2013 TxA Interactive Peer Reviewers

We wish to thank the following reviewers for their generous assistance in evaluating the manuscripts submitted to the TxA Interactive conference in 2013.

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NICOLE MLAKAR

Introduction: Emerging Technology and the Mining of New Object Properties

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Through advances in digital design, fabrication, and computation, we are beginning to understand architectural geometries in a whole new way. Emerging technologies have opened up new methods for creating, modifying, and describing objects. We can understand objects by more than their basic physical properties, such as color, texture, and size. Through new methods of analysis, we have exposed countless additional properties, and not just those of an object in its static state, but even object properties that change over time.

The papers in these proceedings from the inaugural TxA Interactive conference all address a general concern for how we, as designers, engage the complex milieu that is within and around objects. By uncovering a vast new world of object properties, we are better able to understand, simulate, and ultimately control object behavior. Furthermore, we can test how objects react when linked to other objects or when placed in alternative contexts. If an object is incompatible with another object or context, variations of an object's parameters can be adjusted in real-time until some level of stability is reached—objects don't have to be discarded as quickly as they once were, opening a whole new territory for design.

As we begin using the new tools and techniques offered by emerging technology and understanding geometry in ways that are new to the profession, we find ourselves on some ambiguous theoretical ground. Although it seems that Parametricism is the prevailing style of our times, designers have been scattered in their intellectual discourse. A quick look at the emergence and subsequent evolution of digital practices reveals a multitude of pedagogical approaches that range from object-oriented ontology to some lingering postmodern tendencies. In the book "Bergsonism," Deleuze notes: "Dualism is therefore only a moment, which must lead to the re-formation of a monism. This is why, after the broadening out, a final narrowing follows, just as integration follows differentiation."[1] The papers at this conference find themselves nearing the end of this schism, contributing to the synthesis of a common position.

If fabrication plays a role in the application of a theoretical discourse, it does so by actualizing the virtual. Designers no longer have to rely on representation as a means of communication, but can construct their ideas in physical form. By building proposals that were once only ideas, we can better understand and evaluate a project's contribution to architecture and design. Though the papers here do not exclusively present built projects, they all explore emerging technology and its role in design of three-dimensional form, thereby reconnecting intellectual pursuits with the practice of architecture.

1. Gilles Deleuze, Bergsonism, trans. Hugh Tomlinson and Barbara Habberjam (New York: Zone Books, 1991), 29.

INFORMATION CONSTRUCTIONS

Hacklikes: Weird Interactions Between Things

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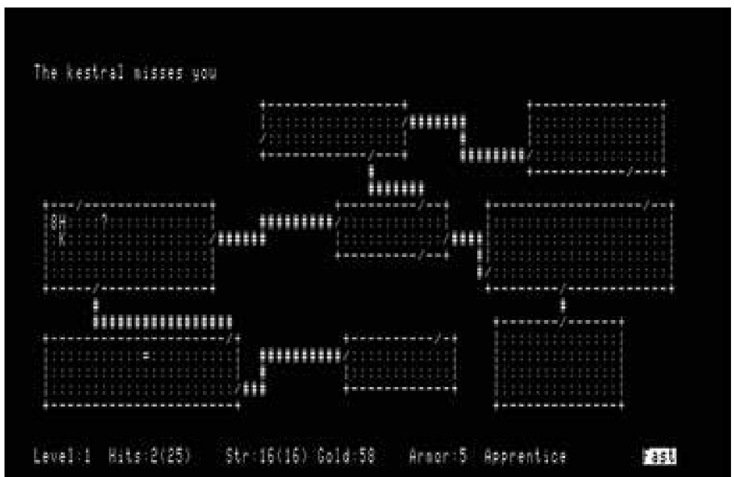
INTRODUCTION

While Roguelikes in general could be easily dismissed due to their usually rudimentary graphics composed by ASCII characters, most of such games contain an accumulated repository of algorithmic strategies to deal with procedural world generation and interactions between discreet units. The denomination 'Roguelike' is attributed to games that follow a series of principles first proposed by the game 'Rogue' 1980. In a Roguelike world, every 'tile' is an 'object' with properties or data. Each of these objects would be represented by the computer by a symbol allowing the player to differentiate a wall tile from a door, for example. The player possesses a limited visibility of the world and of the properties of objects, making exploration the primary objective of the world. Often, the only way of learning about the properties of an object is by trying to interact with it. The properties of the object will define if such interaction is resolved as a positive or negative effect to either of the units involved in it. Every interaction determines a 'turn,' allowing the simulation only to move forward once an action is performed. While the first games of the genre would focus on the interactions that would involve the player, later games have explored the idea that the relation between units is universal, player- or non-player-centric, allowing for the creation of vast algorithmic worlds that might never interact with a human player.

It is easier to understand Roguelikes by looking at the cellular automata (CA) algorithm by Stephen Wolfram.

Screenshot of Rogue – 1980



Screenshot of Minecraft

Such algorithm evaluates the 'state' of a cell or unit, and its immediate neighbors in a grid. The new state of the cell will be determined by rules that describe the state of its neighbors. Conceptually, the algorithm could be understood by a continuous interaction of data between neighbor units. Such interactions could be understood as 'transactions' from one algorithmic entity to another. Especially if we consider a CA written in an Object Oriented Programming (OOP) style, the transactions between 'objects' drive the simulation. The interactions can vary from flipping a Boolean state to altering of variables or killing the object altogether. A Roguelike game represents real properties of objects as several data fields within a tile allowing for more complex interactions and a larger inventory of possible tiles.

TIME VS. TRADE

The underlying concept of time within these simulations is discrete, as it is defined by the transactions themselves. There is not a continuous background time that allows the system to be played-out; on the contrary, only the interaction of one unit with another is what defines its temporality and (de)generative properties. This is easy to grasp by looking at the game of Tic-Tac-Toe; the game is constantly in a 'frozen' state. Nothing really happens until one of the players decides to make a move. Only that move can trigger the subsequent move, and then, slowly, the game plays itself out. Time is executed by the very objects interacting. This is why we could consider these simulations to be 'trade based systems' as opposed to 'time based.'

PROCEDURAL WORLDS

The universe of Roguelike games has developed into different directions, but for the most part, they are surrounded by a heavy repository of algorithms of world generation and data structures to handle procedurally generated worlds. One of the most iconic examples derived from some of the ideas living in the Roguelike community is Minecraft. Minecraft utilizes a large 3-dimensional voxel structure, meaning that there is a 3-dimensional grid of points, or tiles, each one representing a different object constituting a world. These objects can be collected and transformed by players using the right tools and combinations of materials. The simulation trades hi-resolution graphics for the vastness of a procedurally generated world with hundreds of different tiles for players to discover and build.

The video game Dwarf Fortress, by Tarn and Zach Adams, operates in a similar framework. Dwarf Fortress also uses a voxel structure, although it is constantly displayed in 2D. The player can navigate the different strata of the game at will. Each object defines a type of tile, like a 'soil' tile or a 'tree.' Each type in the game is represented with one icon in ASCII graphics. Additionally, each individual object has a series of properties, like resistance or humidity, making every tile potentially slightly different.

Dwarf Fortress offers the player the ability to influence and alter a world to its fitting. The key for Dwarf Fortress is the depth of the simulation engine. Each unit in the world is constituted by dozens of variables of data, qualities that define the physics and properties of every tile in the world. In the game, the interactions between units are not just simple rules like in the case of a CA, but rather a simulation between physical properties. The possible combinations of properties are vast, allowing for truly unexpected interactions. Mining a wall might end up in the discovery of a gold vent or in the flooding of your fortress due to the existence of an aquifer.

The whole world is procedurally generated once you start the game, simulating through hundreds of years of geological and cultural history—forking rivers through the land as seasons change, and the development of roads as new algorithmic civilizations conquer or decay over the landscapes of the game. After 250 years of game history (5 min. simulation) you are ready to start playing. In this initial stage, the player is just a spectator of the physics of the simulation. Geology and culture are developing and decaying to set the stage for every new version of the game. The algorithm displaying the procedural world generation process reminds us that the player is a small influence in such a world, and might not make much of a difference, dwarfing the ambitions to conquer and colonize the land.

Your objective as a player is to embark a small caravan of dwarves and build a fortress as you wait for more fellow dwarves to arrive. You operate seven dwarves that can perform different tasks, like chopping trees, digging caves, building chambers, or farming food, allowing the player to perform a series of tasks simultaneously and develop a design strategy.

The fortress needs to accommodate a series of needs; it needs to provide not only shelter for the dwarves, but also storage for the food or resources you obtain. It should host workshops and facilities to produce new items. Every little detail needs to be considered, as any little detail could trigger unexpected consequences.

Dwarf Fortress could be understood as a poli-performative design challenge; your concern of walking distances between areas is contrasted with the minimum amount of space that a dwarf needs to be happy and not develop bad thoughts. The proximity to water and drainage systems needs to be in consideration of the dry conditions that some food needs in order not to rot. Every decision in the fortress is a negotiation between systems that, for the most part, operate parallel to each other.

As the Adams brothers declare it, at the beginning of every game, losing is fun, and ultimately, your fortress will collapse usually because of something you did not anticipate.

Playing and losing (the only way to finish a game of Dwarf Fortress) is a statement of the blindness between networks, an anti-holistic system critic to contemporary design strategies, even if the designers themselves have not presented it in such a way. There is no possible optimization in Dwarf Fortress, as agencies within the world might be utterly contradictory.

'Dwarves' are just a fun skin for an algorithmic agent that develops design tasks. All tasks that an agent can produce is the permutation or arrangement of matter in the virtual world. A robust economy of permutations allows for objects not to disappear for some arbitrary rule but rather simulate an encounter with another object and determine an outcome for such an interaction.

The robustness of the object-to-object interaction of the Dwarf Fortress architecture allows for more combinatorics than players could play over thousands of years, making the game a perpetual Pandora's box. Due to the fact that it is also fully procedural, each game is different and might force the player to adopt a different strategy to endure an inevitable demise.

What emerges out of this challenge are behavioral design patterns. A player will find a way to organize storage or arrange rooms for efficiency and circulation, allowing for creativity to avoid topographical randomness adopting it into features of the fortress. Dwarf Fortress has been so extremely rigorous over more than 10 years of development that players have been able to forge a community that keeps the game alive even as the creators still suggest that they need another 10 years to finish it.

Dwarf Fortress has become a sandbox for algorithmic interactions, not in the form of code, but in the form of 'design patterns.'

Screenshot of Dwarf Fortress, world generation

THE SANDBOX

There is a denomination for these speculative combinatorial games: the 'Sandbox.' While most sandbox games are described by the ability of the player to create or modify a virtual world, it is important that the nature of the creation is one of combinations. Very much as with Legos, creations emerge from putting together units or parts that already exist. It is in this context that new objects emerge of aggregates of discrete units. It is in digital sandbox games like Dwarf Fortress where the power of combinatorics doesn't only remain in the aggregation of physical objects, but is further expanded in the realm of algorithmic behaviors. For this, we need to consider that NPCs (non-playable characters) are also objects or building blocks in the simulation. Forces and attributes manifest their own agency in the world, pushing matter and decisions. A simulation with hundreds of computational objects interacting, each one of them with their own agenda, trading and altering the structure of the design output, is certainly far from the design strategies which we architects use to design nowadays.

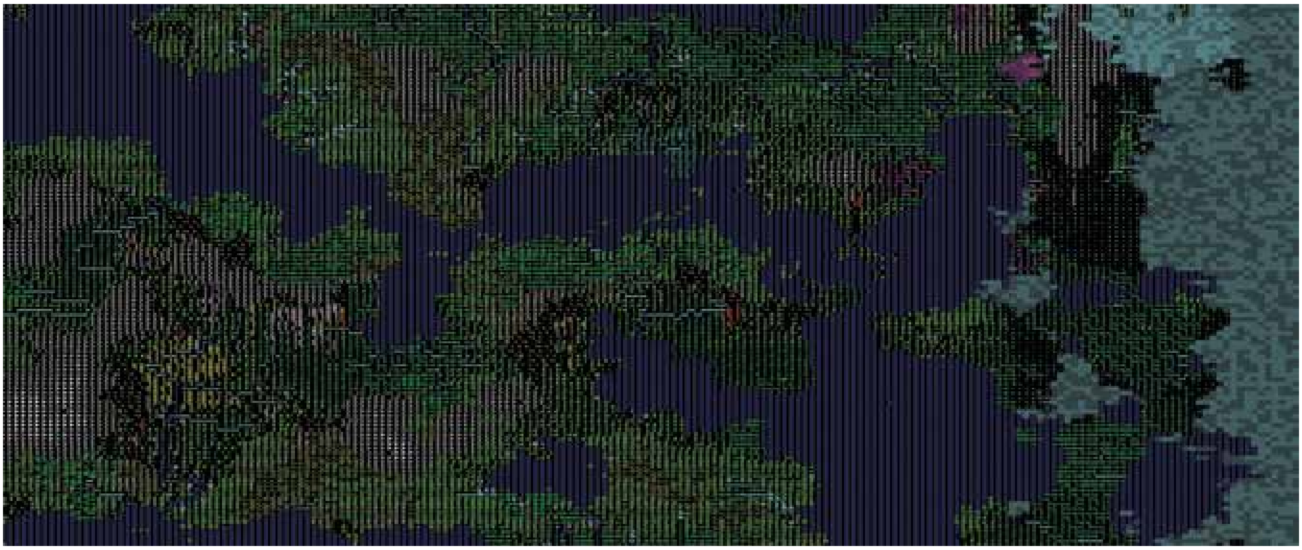
FLAT ONTOLOGY

When we analyze these games as 'trade-based systems,' we focus our attention to the objects, the actors that constitute the game. These objects are often just data, an algorithm that allows you to store a series of qualities in a "bucket" or unit. But objects could be much more than that; in a Roguelike framework, the units could be intelligent algorithms that interact both with the player and the world itself, influencing the player's decision-making or having agendas of their own, in complete isolation from the players' perspective. Is perhaps the realization that the player itself is just another object what allows us to talk of a 'flat ontology' within the simulation? Every unit stands on the same footing at the moment of the trade. Different agendas get played out simultaneously, often with unexpected consequences.

The philosopher Timothy Morton describes the relation between entities as 'strange strangers.' For Morton, the always-incomplete information available at the moment of an interaction between objects suggests that the outcome is always unexpected.

> *The strange stranger, conversely, is something or someone whose existence we cannot anticipate. Even when strange strangers show up, even if they lived with us for a thousand years, we might never know them fully—and we would never know whether we had exhausted our getting-to-know process. We wouldn't know what we did not know about them—these aspects would be unknown unknowns. (Morton 2010)*

It is this infinite unknown that allows for the inexhaustion of game-like simulations such as Dwarf Fortress. There is always a side of the object that 'escapes' the interaction, a side that withdraws.



Screenshot of Dwarf Fortress, resulting world

HACKLIKES

Within the genre of Roguelike games, we can find a sub-branch with the denomination of 'Hacklike,' following the game 'Hack' from 1985. There are several conditions to be met to be considered a Hacklike, but I would argue that the primordial one is 'Weird Interactions.'

Unlike Roguelikes, which usually contain simple rule-based interactions between entities, Hacklikes expand the complexity of properties of objects, allowing for unforeseen outcomes.

Here, the term 'weird' is used in relation to the literary tradition initiated by H.P. Lovecraft. The weird has become a literary style that draws upon those unknown forces that exceed human understanding. In the case of Lovecraft, this was a tool for horror, but the weird could be understood in a broader sense as the exploration of the withdraw space between objects.

> *Lovecraft stresses that the 'true weird tale' is characterized by 'unexplainable dread of outer, unknown forces.' (Mieville 2008)*

Hacklikes place the player in a testing ground. Every gameplay will inevitably explore new areas of the simulation, by confronting the player with qualities that he might have never interacted with before. The simulation is non-deterministic not because interactions might yield random results, but rather because a player will never be able to anticipate the outcome of every encounter.

For Graham Harman, Lovecraft's Weird Realism offers a non-reducible model, one in which the simple awareness of that which we are not exposed to forfends the forecast of a transaction.

> *No reality can be immediately translated into representations of any sort. Reality itself is weird because reality itself is incommensurable with any attempt to represent or measure it. (Harman 2012)*

Dwarf Fortress uses the 'inevitable death' mechanic to expose the flaws of a holistic systemic approach, one in which units could know and understand each other. Every game has one inevitable conclusion, the ultimate destruction of your attempt for control. This will often happen because of some unforeseen event—something in the blind spot of the player, something that wasn't programmed or planned.

Dwarf Fortress teaches us that even robust systems of control are incomplete and destructible.

NOT EVERYTHING IS A SYSTEM

It is considering these points that it becomes difficult to talk of a 'system,' as the emphasis in the simulation is awarded to the blindness between units rather than their relations. Ian Bogost suggests the mechanism of the 'List' to define non-holistic aggregates with no common interest. Lists offer the view of an inconsistent collective, one that does not necessarily create a coherent whole.

> *Lists offer an antidote to the obsession with the Deleuzian becoming, a preference for continuity and smoothness instead of sequentially and fitfulness. (...) By contrast, alien phenomenology assumes the opposite: incompatibility. The off-pitch sound of lists to the literary ear only emphasizes their real purpose: disjunction instead of flow. Lists remind us that no matter how fluidly a system may operate, its members nevertheless remain utterly isolated, mutual aliens. (Bogost 2012)*

The emphasis on the isolation between units provides for a framework in which opposed ideas could co-exist

Screenshot of Dwarf Fortress, player-generated fortress

without attempting to override each other or merge into a style: co-existence over convergence.

Simulations such like Dwarf Fortress succeed in creating enough tension and autonomy between building agencies to allow us to think that such simulation is not biased, attempting to prove a specific goal that was already clear from the beginning, but rather a design tool for the exploration and learning of new strategies—a space where the unexpected could be terrifying but also a generator of novelty. Dwarf Fortress pictures a designer *entangled* in the simulation rather than a spectator.

OBJECT ORIENTED DESIGN

When Graham Harman took the name Object Oriented Philosophy for the denomination of his philosophical agenda, he borrowed the name from computer programming culture without pointing to a direct relation to OOP. It has been Ian Bogost who has come to develop a comparison, detecting that although similarities between the two approaches do exist (Bogost 2009), there are also several inconsistencies. Regardless, object technology and the programming paradigms developed by Alan Kay do provide a powerful operational framework for design, one in which many of the Object Oriented Ontology (OOO) ideas could be explored.

As Bogost explains:

> *Software must exhibit four properties to be considered Object Oriented: abstraction, encapsulation, polymorphism and inheritance. Abstraction is the programmatic representation of an object, disassociated from any specific instance; only modified or instantiated version of an object model or class actually exist. Encapsulation means that the content of the software is hidden from other parts of the system. Polymorphism means that different derived instances of a class can be different behaviors. And Inheritance means that the class itself can be used to create other classes, which adopt or inherit the parent's classes' structure, attributes and behavior. (Bogost 2008)*

Some of these object oriented attributes like abstraction and encapsulation have a direct implication on the way we conceptualize and design, while polymorphism and inheritance have direct implication on the design and community culture, and the propagation of knowledge. The format of OOP is rigorous, as it attempts to allow communication from diverse different authors. It effectively becomes a language for operational ideas that could be read and understood by humans and executed by computers. Many designers, including myself, have started developing object libraries: lists of computational objects living in a pre-design space. These libraries, often having author denominations, constitute an ever-growing toolset for computational design that allows us to trace how design outputs hybridize concepts from different sources.

It is with object libraries that the design discipline has been able to start building a heterotopian and operation-

NetHack 1987 by Mike Stephenson – a 'Hacklike'

al landscape of ideas, one in which the building blocks take the form of code and could be combined in infinite number of ways—computational design objects that are described in a language for potential interaction.

It is precisely this state of pre-interaction of objects where the lists or libraries of algorithmic ideas take their stronger form. The design objective of such libraries describes a pre-actual medium that allows for an intense propagation of knowledge. The inevitable game of combinatorics that will place some of these objects together will always remain a fraction of the list they came from. To this regard, Luciana Parisi describes algorithms to a new actuality for architecture and design.

> *Algorithmic architecture is not a whole constituted by parts, but rather shows that parts are irreducible inconsistencies divorced from the totality that can be built through them; it works not against but rather with the chaotic parts of information that are comprised neither within mathematical axioms nor within the law of physics. (Parisi 2013)*

In this context Open Source is not only a political stance in relation to the democracy of knowledge but the very medium in which computational objects defined their vector of propagation.

It is perhaps in times where the discipline is threatened with convergence that it becomes relevant to acknowledge the limits of the medium in which we operate. The incompleteness living at the core of computational strategies is a lesson that games like Dwarf Fortress strongly point out. It is perhaps necessary to allow for computation to open more speculative attitudes towards combinatorics of logic and desire without the necessity of complex formal output, but rather a search and exploration of the weird, the unexplored territories of contemporary design.

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World Building: Responsive Architectural Environments in the Context of Interdisciplinary Collaboration

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INTRODUCTION

Ideas relating to issues of ecology have recently resurfaced as a topic of inquiry within the architectural discipline, and few contemporary research trajectories are better suited to address them than interactive and responsive environments. From the collection of data from sensors for evaluation, to the custom-developed "brains" that interpret this data, to the actuators that then respond to the instigated decisions, all of these technologies, including hardware, software, and the result of bridging the two, lend themselves to the advanced development of constantly evolving, ecological, architectural environments. In fact, it could be argued that the development of these technologies within the discipline over the past 20 years has been the driving force behind the reemergence of ecology as a topic of study within architecture; their use has uncovered formerly unknown areas of potential and possibility for these previously explored conceptual positions. In many ways, we aren't simply exploring a new line of inquiry based on previous conversations, but instead witnessing the evolution of these conversations as an established branch of architectural investigation.[1]

Much has been written and presented on both the novel technologies and affect-driven results of these responsive environments, and many of their images have been published in the recent explosion of catalogs, periodicals, and books on the subject. But simultaneous to all of these architecturally specific developments has been the parallel evolution of a huge array of interdisciplinary collaborations between an equally large assortment of non-architectural professionals working in immediate proximity to architects and designers alike. Unfortunately, the extremely successful conversation surrounding the responsive technologies and their results has seemingly missed these collaborations and the interdisciplinary worlds that have increasingly come to inform digital technologies and their relation to architecture and design.

In addition, running parallel to these developments is an equally interesting series of new questions about the constitution of ecologies and collaborations. For quite some time, the basic notion of non-reductive, systemic approaches to understanding assemblages set forth in the 18th century has been distilled out of the natural materials of the meadow and applied to disciplines ranging from the social, to the industrial, to the political.[2] But giv-

Blue Eyed Sailor – Environment One

Vivarium –
Fast Biomass

en this broad ranging applicability, why is the default understanding of both ecologies and interdisciplinary collaboration that of self-stabilization and naturalization?[3] If we are to truly begin to imagine building architectural worlds within which ecologies and collaborations exist in a consequential way, we must begin to challenge this default condition with out-of-equilibrium states.

VIVARIUM

In 2010, our firm set out to explore this position through an installation at the Southern California Institute of Architecture titled "Vivarium." Until that point, the most common condition of ecology had been that of "holistic" approaches that attempted to focus on the "organization and internal/external relational dynamics of wholes or assemblages"—an approach that looked to continuous "interconnectivity" and stability as a means of understanding complex systems as they exist in equilibrium or near-equilibrium states.[4] The benefit of this approach was that it allowed for a fairly clear, complete picture of a complex system to emerge regardless of the turbulence, extremes, or singularities that exist within as anomalies. The work of 18th century landscape designers such as William Kent, Lancelot Brown, and Humphry Repton are clear examples where the desire to move away from reductive ideas of ornamentation led to the translation of ideas about natural processes into immediately self-stable landscapes—landscapes, not accidentally, composed of equilibrium (climax) species.[5] This approach was continued in the late 20th and early 21st centuries in the form of certain approaches to biomimetics, where idealized versions of ecological conditions or aspects were translated to stable architectural constructs minus any potential disruptive extremities. Our interpretation of this was that the effort to create romanticized changelessness within architecture undermines the complexity inherent to an ecology, be it part or whole, natural or artificial.

Vivarium attempted to challenge this long-held normative condition through a series of collaborations that injected constantly evolving extremes and singularities into both the installation itself and the architectural space that surrounded it. Materially, organic substances worked with inorganic processes: insects were hatching while sensors converted their movement into data streams; water turned brackish, after which, machines would introduce freshwater; biomass created humidity that geometry and materials attempted to control and evacuate. Computationally, data streams collected within Vivarium from hardware (microphones and movement, temperature, humidity, and salinity sensors) worked with custom written software to evolve a series of decision-making processes which could make changes to the physical environment of the installation—changes in the soundscape, changes in temperature, etc. The continuous evolution that was created through these processes working simultaneously embedded the dynamics of an ecology into the architectural space itself, which created an alternative position to the idea of simply indexing one formally.

This position was made possible through collaborating with Rise Industries and Nicholas Pisca to develop the custom synthesizers, software, and hardware that worked to collect, analyze, interpret, and deploy the previously mentioned physical changes. As the collaboration evolved, so, too, did Vivarium—only instead of the relationships and project becoming more stable as things progressed, they became more extreme. Each collaborator worked to develop aspects that would influence additional portions of the project, which would also influence the other members. If the inner robotics added too much fresh water, for example, it would completely change the humidity profile, the geometry needed to control it, and the soundscape that was responding to it. This created a constant feedback loop that never attempted to find full resolution. Vivarium's deployment was, therefore, never able to achieve any kind of constant equilibrium. During its existence, parts failed due to this condition—insects died, speakers blew, and software froze. In the end, Vivarium existed as a responsive environment not simply because of its software and robotics, but also because of the separation, death, and destruction that it produced in and around the world it created for itself.

Fast Biomass and Media Sensors

Flood Stains – Autopsy of the Monolith

FLOOD STAINS

Continuing this exploration further was Flood Stains, which was conceived as a standalone project meant to route latent and shadowed aspects of Vivarium into a performance that transformed the common de-installation process of a gallery piece into an opportunity for creation and evolution. It was delivered as a live broadcast and chronicled in a single-take film, scored with a "Bacterial Opera" composed and performed live by No Wave legend Lydia Lunch (Teenage Jesus and the Jerks). The raw material for the piece was mined out of specific components of Vivarium: sound samples from its interior (natural and digital), corpses of insects as preserved by the high salt content of the environment, and physical debris made from the disassembly of the structure and skin of the built work. Both biotic and abiotic material, usable and unusable components, as well as rarely compatible human interactions transformed the collaborative performance into an ecological world within which stability only existed as a point of departure.

Particularly important to this piece was the complex circulation of human interactants. While Lydia Lunch performed her opera, others were moving through the gallery and creating constantly evolving environments that she would then be forced to adapt her performance to. The opening and motion of the main Vivarium structure propelled her into one area while the distribution of salt and other organic matter drove her into another. The video feed and film attempted to trace both aspects, working as a foregrounding device simultaneously for the performance as well as the disassembly. The constantly changing movement patterns and material interactions also had a destabilizing effect on the surrounding environment—temperature, humidity, and light levels varied based on what was happening and where at any given moment, which had additional effects on Lunch's area of operation.

The complex and constantly changing interactive conditions that were created during Flood Stains caused an emergent, ecological condition that was at once both a conventional responsive environment and a postdigital architectural event.[6] Responsiveness in this case is used in the traditional sense of simple cause and effect where environmental changes led to occupancy adaptation. The reframing of digital and material interactions from Vivarium towards the sustained human interchanges in Flood Stains established the ground from which a conception of postdigital affects can be understood as developing out of digitally and materially driven environments.

BLUE EYED SAILOR

Blue Eyed Sailor was designed to evolve the relationship of ecology and collaboration through the concept of an alternative, estranged nature and its imaginary envelope of time through a short film/music video. The project attempted to readjust both foreground and background through visual camouflage, duplications, and abstractions, which, in turn, provoked visual difference and non-equilibrium. Mia Maestro, the writer and performer of the video's song, continually materialized from, and dematerialized back into, familiar architectural flora patterns. These patterns (which are based on the art of Cecilia Paredes), as well as Maestro's interactions with them, worked to explore this estrangement and the potential embedded in embracing it.

Collaborating with Academy Award winning cinematographer Guillermo Navarro transformed the previous experience with Lydia Lunch from a single-take, continuous ecological experience to a multi-take, constructed one. Each day, Maestro spent nine hours in makeup prep in order to produce the material affects necessary to create the resultant visual effects, which led to the project becoming a multi-day collaborative event. During this time period, weather changed, the movement of bodies changed, backgrounds changed, and the interaction between them all evolved through circadian fragmentation. Every moment of the event was an act of anticipation and adaptation, and the end result is an estrangement from the understanding of ecology that is typical of continuous, self-stabilizing concepts of nature and naturalization.

The very essence of the project was that of variance and divorce, moving from one scene to another with alternate makeup constructions and different backgrounds that responded to interaction in different ways. Nature was removed from its life cycle and then reanimated through a foreign body—new ecological cycles of actuality were created through which the relationship between architecture and nature could be reexamined and redefined. An alternative world was created through which fragmentation and singularity were the defining conditions for existence.

Blue Eyed Sailor – Environment Three

CONCLUSION

While these projects embrace the contemporary condition of creating technologically informed responsive environments, they challenge this concept to move beyond the simplistic notion of systems in equilibrium. They do not merely attempt to unite multiple visions and environments under a singular, holistic, and stable image, but rather frame the very contradiction of such an assertion through the development of its inverse. Architecture as an out-of-equilibrium state opens up the field of potential to include not just what is designed and controlled, but also what is disorderly and uncontrollable. Interdisciplinary collaboration has the ability to assist in driving architecture towards these unstable states, creating a potential far beyond that of the typical design vacuum. This potential is crucial to the discipline beginning to embed, actualize, and expand ecological thought and its relationship to architecture—crucial to it being able to build worlds.

Blue Eyed Sailor – Environment Two

ENDNOTES

1. Look to the proceedings of ACSA 101: New Constellations/New Ecologies for this ongoing conversation.

2. Morton, *Ecology Without Nature*, 2-4.

3. Skender and Solander, "Naturalizing Architecture – Beauty Becoming Beast."

4. Goodbun, "Gregory Bateson's Ecological Aesthetics," 35-36.

5. McHarg, "Ecology for the Evolution of Planning and Design," 239-240.

6. For a detailed conversation regarding the postdigital in architecture, see Neil Spiller's "Plectic Architecture: Towards a Theory of the Post-digital in Architecture."

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IMAGE CREDITS

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Toward a Pedagogy of Material Systems Research

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INTRODUCTION

At one time, in the words of le Corbusier, architecture was described as the "masterly, correct and magnificent play of masses brought together in light." Now our attention is turned far more intently to the processes of formation and production that define these "masses"—which are increasingly understood as thickly layered assemblies with very specific material characteristics and environmental behaviors. They are not just in light, they shape and control it, as well as energy, air, humidity, acoustics, and with increasing frequency, information. Not only are we developing a deeper understanding of the characteristics and behaviors of materials themselves, but also we are now able to synthesize entirely new materials—polymers, composites, fibers, smart, and energy converting materials. This, combined with the increasing sophistication and pervasiveness of computationally driven design and fabrication technologies, has radically changed the design, composition, and modes of production of everything from clothing to cars—and architecture is trying to catch up.

The term *material system* intends to encapsulate the multifaceted aspects of a spatial architecture and the means by which it is formed. Christopher Alexander shapes the term *system* into an architectural context referring to the "unselfconscious process" as the manner by which architecture is continually and concurrently defined by its interaction with culture and environment (1964). This expands the notion of architecture and form as a dynamic entity that encapsulates activity as well as physicality. Materiality serves as the medium by which formal relevance, as a reflexive engine to social and contextual pressures, can be determined. Where form is defined as performing and responsive, its nature emerges via material's behavior in relation to a specific and specialized environment (Menges 2008). A material's behavior is articulated as a direct repercussion of the processes of formation. The *material system* poses a perspective that necessitates both the study and execution of material formation, in simultaneity with the measure of contextually responsive behavior.

Mobius Rib Knit Installation (Sean Ahlquist, University of Michigan, 2014)

Designing within this paradigm requires the forming of new tools, skills, and methods, which serves as a primary focus for the Master of Science in Material Systems (MSMS) program. The program fosters an understanding of materials—physically and also chemically—as well as the logics, processes, and machines that give them form. The program is also based in a deep engagement with computational tools that extends beyond form-finding and fabrication logics to encompass material behavior, systemic performance, and integration with communication and sensing technologies. The work is based in an understanding that material itself, intrinsically, has the capacity to compute, process, and exchange information with its environment. Design methods are put forth to engage matter's own computation and its informational exchange with environment. A design framework emerges where iterations move rigorously between digital and physical modes of experimentation evolving operational prototypes through filters of measure and evaluation.

The specification of such performance emerges from the both the formation, articulation, and manipulation of existing and bespoke means of fabrication, manufacture, and assembly. In addressing a scope that spans from the details of making to the prototyping of application, content is borne of faculty-driven research initiatives which sample from the fields of tooling, computational design, material behavior, and responsive architectures. The confluence of these topics take place through the curriculum of the MSMS program, engaging the students in forming and executing multimodal design methodologies developing new materials and fabrication methods with priority on the advancement of materially and spatially adaptive architectural systems.

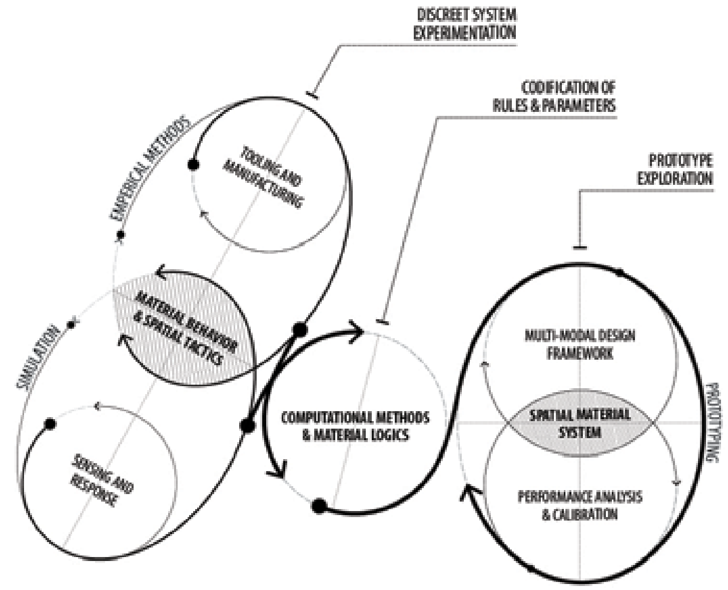


Figure 1: Extensible design framework for research in material systems (Sean Ahlquist, 2014)

Key to a pedagogy that supports the study of material systems is a framework for computational design thinking and sequences of experimentation at ever-increasing levels of complexity (fig. 1). This framework defines the critical foundation of material system research at the generation of system logics through empirical methods and studies through physical experimentation and observation. As mentioned previously, the term *computation* is not explicitly confined to the domain of *virtual* methods. The factors that drive a specific material behavior are most readily deducible through iterative exploration of physical simulations. It is rather through abduction (rule + result = case) that the rules exhibited in the physical precedents serve more exhaustive virtual means. Prototyping encapsulates the design space as a proving ground for methods of study as well as a generator for new vocabularies in material form and spatial performance (Coyne 1990). This is posed as a scalar framework where layers of material performance and spatial complexity can be engaged through continual embedding of parametric rules, tacit material knowledge, and calibrated responsiveness.

RESEARCH AGENDA ON DEVISED SKINS

Framed under the primary theme of the program *Devised Skins*, design methods are focused on the intimate control of material formation to realize material systems that operate as structural, spatial, and contextually-aware architectures. Within this framework, we explore the textile as both a literal deployment of fibrous conditions parametricized for specific multi-capacitive performance and a figurative expression of interlaced multilayer systems. Such a premise demands an expansive knowledge from the direct forming of heterogeneous materials (as opposed to the destructive manipulation of homogenous materials) to the comprehension of behavior in interaction with other material elements and in the presence of contextual (environmental) pressures. This necessitates embedded and evolving expertise from multiple disciplines for the deployment of critical relationships between material formation and system operation.

Within *Devised Skins*, research is approached through a drawing together of diverse and conflicting concerns in the context of specialized knowledge. The distinct primary research specialties of each director can be broadly summarized as (i) tooling in the discovery and articulation of material attributes and behaviors (ii) computational design methodologies, and (iii) embedded sensing, response, and environmental mediation. Collectively, these three territories constitute overlapping domains of concern, each replete with their own modalities, methodologies, and theories to which students are exposed in the development of their design research projects over the course of a one-year program. The involvement of external advisors in engineering specialties, material science, information systems, computer science, and advanced manufacturing methods complements these intra-disciplinary priorities with interdisciplinary perspectives and knowledge. Rather than the transmission of an isolated perspective and single stream of technique, the combinatory model delivers a broader approach that enables students to customize their inquiry enabling a learning experience that is scalable and transportable to future research and practice challenges. We imagine, then, the development of post-professional specializations as an opportunity for a depth of exploration, in shaping extensible methods of interdisciplinary research and forming specific knowledge of operational material systems that foster new ways of drawing together as well as drawing forth.

Material attributes, behaviors, and tooling

Fundamental to the design of more complex assemblages is the comprehension of innate material behaviors and their specific and individual computation and response to environmental pressures. Strictly linked to specific qualities of matter, each element of a system can be defined by its own attributes. These underlying properties range from physical qualities (including strength, elasticity, and tactility) to environmental responsiveness (of conditions such as thermal, humidity, and pressure changes) and finally more atmospheric and appearance-based attributes (emission of light, smell, and electromagnetism). Further, materials must also be understood through qualities inflicted by manufacturing processes such as the cut direction of wood, the pour of steel, or the thickness of glass. Defined by this myriad of properties, it can be argued that a material, with such capacities, is already a system: responsive to its surroundings through its own innate physical, behavioral, and immaterial characteristics.

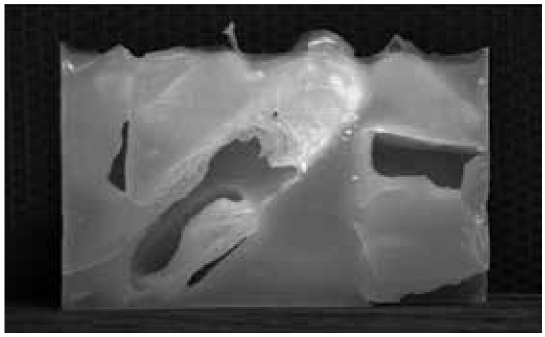


Figure 2: Wax forming studies (Lauren Bebry, Master of Science in Material Systems—Assistant Professor Catie Newell, University of Michigan, 2013)

The endeavors of the MSMS program maintain close design sensitivities towards the attributes of a material and its environment. This extends into manipulation of multiple materials, and the resultants of their system assembly. For example, in the Physical Attributes Core course, and as an underlying component in all subsequent research pursuits, students are presented with a research practice that demands a hypersensitivity to material attributes in designed-based decisions. Within the course, students are asked to develop a tool for the manipulation of a material and its environment. With the ambition of altering material systems *during* their production, the design of such a specifically focused tool presents a method that necessitates a direct coordination between all attributes of the system—making, form, and performance. Each material, either as the subject of study or a part of the tool, must be coordinated to align behaviors and intentions. The course is taught in a work-

Figure 3. Kinetic PETG system (Steven Beites, Master of Science in Material Systems—Assistant Professor Catie Newell, University of Michigan, 2013)

shop setting that fosters experiments harnessing and agitating material attributes while simultaneously aiming at the formation of typical building components with the expectation for atypical resultants, pressing students to project larger structures and implications on space. An early exercise by Lauren Bebry collapsed misaligned cooling temperatures of ice and wax to formulate a system of production for amorphous apertures that are otherwise formally complex spatial maneuvers (fig. 2). Under an entirely different technique, Steven Beites worked closely with the physical and immaterial qualities of a translucent PETG (fig. 3). Experiments worked back and forth to demonstrate a collapsing of material attributes with mechanized operations of production and assembly. Friction, light emissions, and patterning were coordinated alongside the tooling paths and pressures of a knife cutter, and the resulting performances of a motion-activated screen wall. These endeavors succeed in setting-up forms of practice and inquiry attuned to attributes at various stages of a manufactured material system.

This research practice is based heavily on the continuing research of faculty members in the MSMS program focusing on the manipulations of physical and immaterial attributes through the development of tooling and fabrication techniques honed to the properties of a specific material. The work of Catie Newell and Wes McGee challenges existing modes of working with glass across a range of applications and scales, interrogating the connections between craft and the explicit control offered by custom developed manufacturing processes and tooling. This research began by questioning the de facto application of glass as flat pane that reinforces the ubiquity of sheet materials throughout contemporary building tectonic systems. Such ubiquity remains a reflection of the industrialization of architectural products, whereby traditional materials have been modified and compressed into standard sheet goods and then fabri-

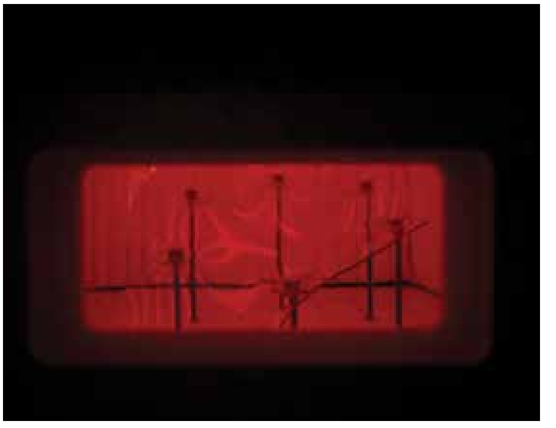


Figure 4: Custom pin-mold kiln (Wes McGee and Catie Newell, 2011)

Figure 5: Glass Cast: catenary slumped glass panes at Research Through Making exhibition at the University of Michigan (Wes McGee and Catie Newell, 2012)

cated using subtractive technologies. Arguably this has both driven and been driven by a lack of feedback between material properties and the design process. This research instead demonstrates an alternative methodology whereby material and process constraints are integrated into the design process through experimental and computational techniques, developing a feedback loop between design intent and materialized formal attributes. The related design projects represent a multimodal approach to design research, encompassing the latent materiality of glass as an amorphous solid, overlaid with an explicitly controlled, empirically verified process which seeks to advance the performative capabilities of the material both spatially and visually.

Integral to the larger body of research was the development of a digitally controlled, reconfigurable pin-mold embedded into a kiln. Articulated with 99 pins and hexagonal tiles, the kiln facilitates the formal alteration of flat sheet stock into geometrically defined curvatures (fig. 4). Developed and integrated with a parametric modeling plug-in to provide manufacturing constraint feedback directly into the design process, the equipment and software developed as part of this research is tied very specifically to particular material attributes and modifications, providing the potential for continuously variable formal output, while reducing the waste associated with dedicated molds. The fully integrated methodology includes feedback on the formability of specific geometries, material properties, and direct machine control of both the forming kiln and the post-form robotic abrasive waterjet trimming of panels. The research as resulted in three full-scale installations exploring the material and immaterial behaviors and relationships between glass and the physical and thermal environment of the kiln: Glass Cast (fig. 5) demonstrates formal curvatures as achieved through catenary slumping in coordination with tests of temperature and duration (McGee, Newell, and Wilette, 2012); Specimen is a spatial enclosure and amplification of the inherent light effects and different grains of reflection as provided by the created forms (fig. 6); and most recently, Displace is a study in material and optical distortions as captured in mirrored glass pulled and distorted through a studied pairing of the initial geometrical forms with an exaggerated heating cycle.

Topological description, structural action, and materiality

Material systems are shaped by the inextricable relationships of material make-up and assembly. This poses a unique challenge in terms of methodology as the critical design variables are dependent and indeterministic until the whole of the system is addressed and activated. To parse this complexity, a material system can be broken down by the definitions of topology, structural action, and materiality, with exploration of system behavior occurring across several modes of design between physical form-finding, spring-based simulation, and finite element analysis (fig. 7) (Ahlquist et al 2014). *Topology* allows for the componentry of the system to be addressed by count, type, and association, without the need for considering geometry. *Structural action* implements the conditions of internal and external forces. In the case of material-formed lightweight structures, pre-stress, such as tension, compression, and bending-active behavior, is the primary agent. The definition of *materiality* is two-fold. This embeds data of fundamental material properties. In the case of textiles, it involves defining bi-directional (warp and weft) performance as a tensile surface or in bending as a part of a composite matrix. Additionally, the functions of *materiality* include constraints of material formation, and methods for the translation from computational data to material assembly.

Managing both inherent properties and variable relationships for the behavior of a material system, a distinct set of design modes have to be engaged, shifting

Figure 6: Specimen: catenary slumped glass panes and light installation at The Not Yet exhibition for SiTE:LAB (Wes McGee and Catie Newell, 2012)

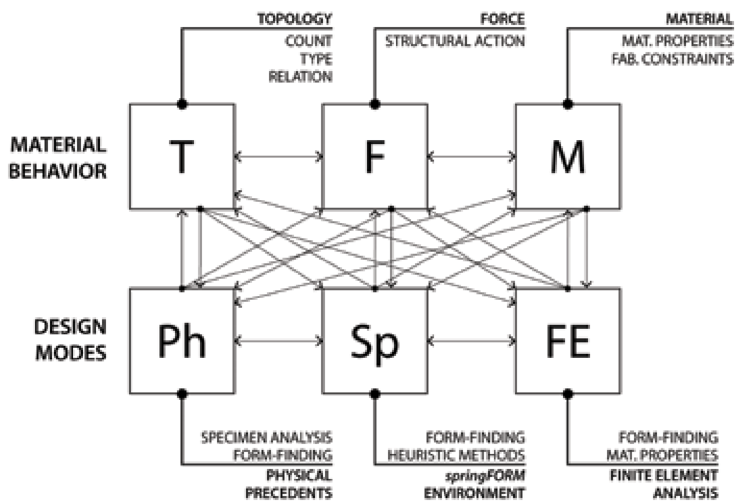


Figure 7: Components of behavior and modes of design (Sean Ahlquist, 2014)

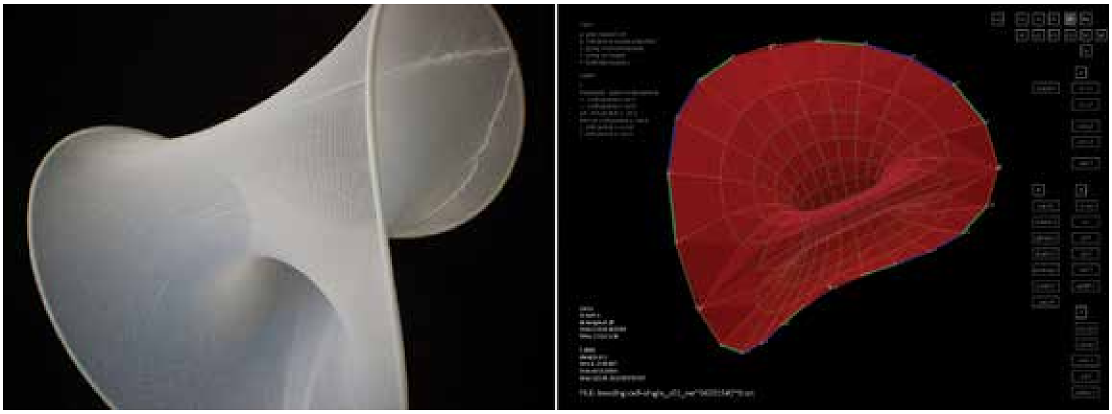


Figure 8: Physical model compared to spring-based simulation in springFORM (Processing, java-based) software (Sean Ahlquist, 2012)

Figure 9: Custom knitted textile with differentiated structures, significantly varying material size and performance (Sean Ahlquist, 2012)

between physical and computational exploration. This is a multimodal approach where methods are sequenced to form a fluid design framework. No single method is considered robust enough to manage the entire design space of a material system. It has been shown that the sequencing of methods can be predicated upon the topological complexity of the system (Ahlquist et al 2013a). As complexities in count, type, relation, and resulting behaviors increase, the ability to resolve form (equilibrium) through physical study is limited, as all facets of topology have to be more precisely *pre-planned* before engaging model assembly. Such coordination is often not possible without a great degree of prior practice and intuition. When topological complexity advances, behavior is more easily resolved and understood through a spring-based computational environment. This has been developed as a material-behavior based modeling environment in the *springFORM* software, a program developed in Processing (Java) as a part of the doctoral research of Sean Ahlquist. Once topology becomes fixed and resolved, finite element analysis (FEA) serves to define the exact mechanical description. It is important to note that ratios of force distribution are still variable within this environment, meaning FEA is still an active mode of design in resolving force to reshape form.

Aspects of this methodology are exhibited in the gg-ggallery installation in Copenhagen, Denmark, by Sean Ahlquist. The material system is termed a textile hybrid, where equilibrium form is generated at the balance of a tensile surface and the stiffness of a continuous glass-fiber reinforced polymer (GFRP) rod. The semi-toroidal form is studied comparatively through physical and digital simulation (fig. 8). The structure utilizes variegated knit textiles designed specifically for the project, in close collaboration with textile designers and knit manufacturers near Stuttgart, Germany. In examining a series of isolated knit samples, the complexity in behavior is obvious. In Figure 9, the samples all have the same number of loops, but because of changes in knit density (stitch/loop length), quite different textile size and behavior is produced. These facets of behavior are encapsulated within the diagram in Figure 10 (left), where variations in density are strategically placed in order to accomplish the large structure with only two textile parts—a cylinder and a four-side panel. The elasticity of the yarn is maximized and density minimized in the cylinder textile to enable a 16-foot static boundary to stretch to over 40 feet. The result is an architecture with minimal structural exertion into the gallery space and maximal spatial presence, as shown in Figure 10 (right).

As a part of the MSMS Capstone, Tom Bessai continued the study of bending-active structures by studying beams composed of GFRP rods with extremely minimal cross-section. Through study primarily of physical

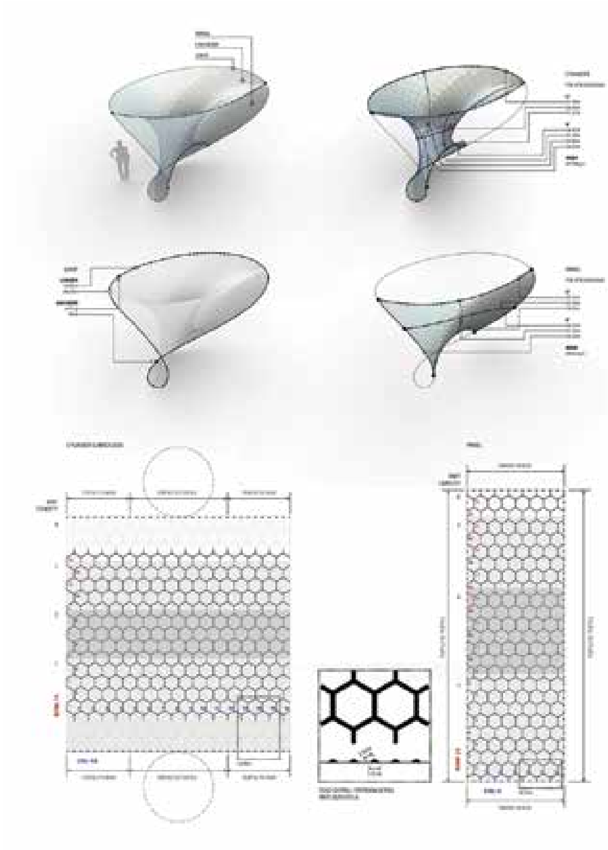


Figure 10: Semi-Toroidal Textile Hybrid installation at ggggallery in Copenhagen, Denmark, composed of GFRP bending-active boundary and two tensioned textile elements (Sean Ahlquist, Institute for Computational Design—Professor Achim Menges, University of Stuttgart 2012)

models, a method was developed in order to produce a large spanning and cantilevering structure within the Research Annex for the Taubman College of Architecture.

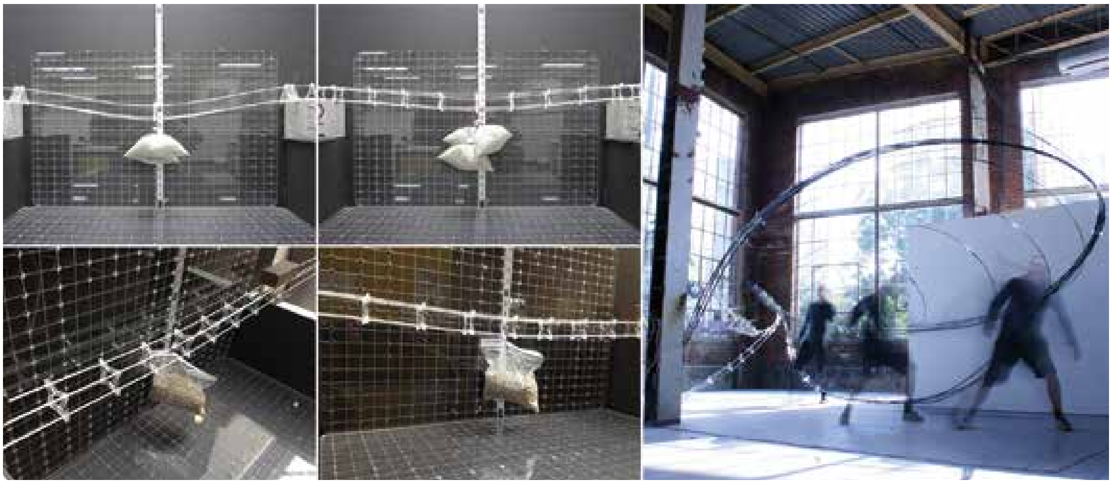
Sensing, response, and environmental mediation

> *Life is made possible by membranes. Part of their function is to provide a surface on or from which interactions and reactions can occur and be controlled... In all cases, plant and animal, the skin is specialized not only as a covering but also as a selective barrier to passage in both directions of mechanical, physical, and chemical stimuli such as force, heat, water and volatiles. Since this single layer has to perform many different functions, it is inevitable that there will be conflict between the various requirements. We make the assumption that in biology these conflicts have been largely resolved by evolution, and that we can benefit from the abstraction of concepts from these natural structures into a form that can be integrated into our own technology.* (Vincent 2009: 3)

Adaptation has been frequently identified as a characteristic fundamental to the pursuit of sustainable design. Within living and social systems, adaptation allows for fitness relative to external conditions, efficient energy usage, and resilience to changing conditions over time and through disruption. Like the biotic skins described by Julien Vincent, architectural skins are more than simply wrappers and can be considered quite literally as complex membranes capable of managing energy, material, and information exchanges, while adapting to variable environmental conditions. Integrated with other building systems, they can be designed to operate "as part of a holistic building metabolism and morphology" (Wigginton and Harris 2006: 3). One of the ultimate goals of this aspect of the work is to reclaim the environmentally performative domains of architecture, almost entirely relegated to engineering professionals, to within the purview of the discipline, as territories of material, formal, technological, and experiential innovation and exploration. In order for this to occur however, collaboration with engineering, material science, and computer science is required from the outset, and it is fundamental for designers to learn to collaborate productively with other disciplines, as well as industry specialists, as part of an exploratory design and research process.

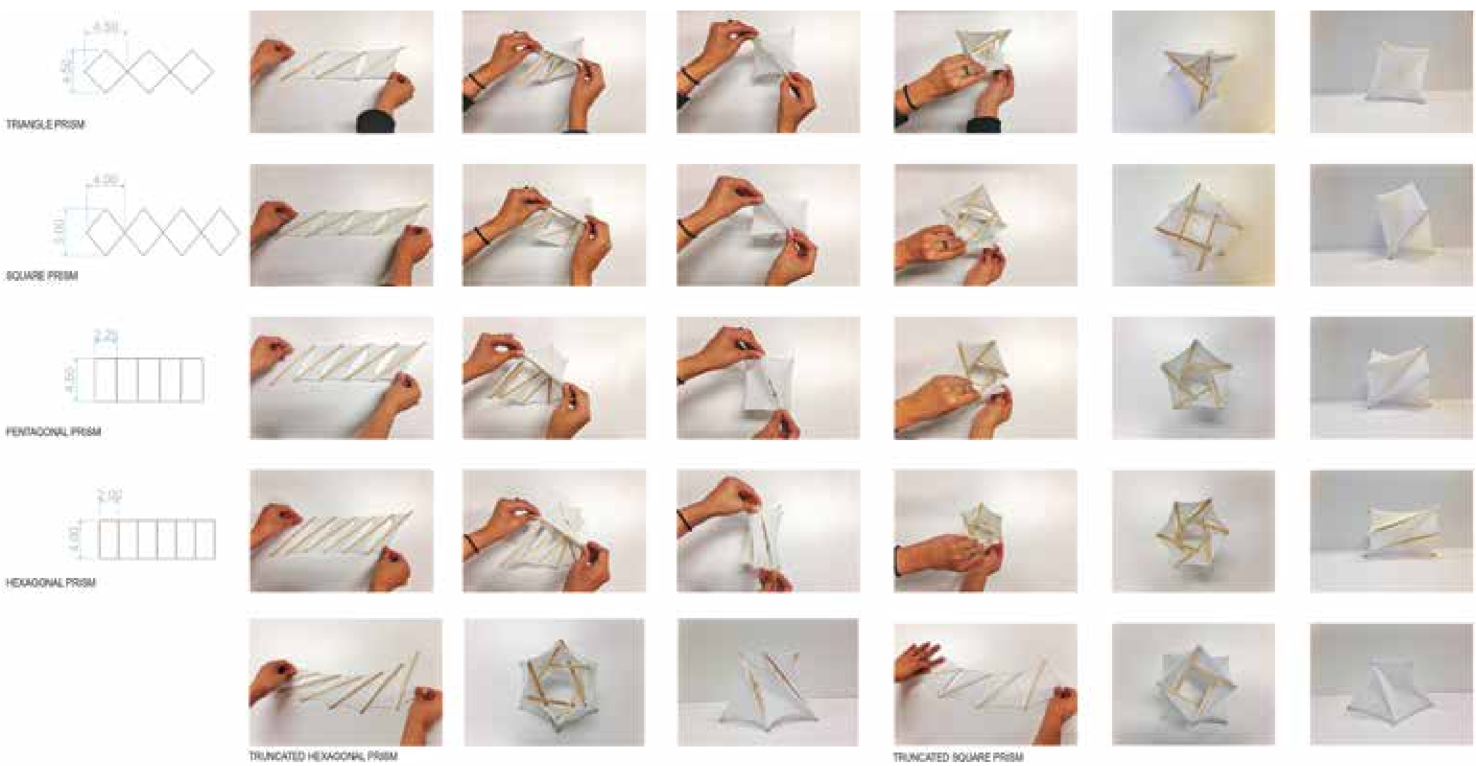
In the recent research undertaken by faculty and students in the Material Systems program, this question is being explored through the development of thick, sensing, and kinetic skins comprised of integrated as-

Figure 11: Variegated bending-active beam structure (Tom Bessai, Master of Science in Material Systems—Associate Professor Geoff Thün and Assistant Professor Sean Ahlquist, University of Michigan, 2013)



semblies of performative and interdependent layers and components. These serve individual as well as cumulative environmental functions, and are designed to adapt to variable environmental conditions while also developing responsive behaviors relative to human interaction. The work is explicitly integrative, advancing each project through a design ecology that operates through feedbacks between simultaneous research in lightweight deployable structures, new materials, logics of manufacture, and the integration of sensing, actuation and control technologies. The physical development of performative full-scale prototypes is also fundamental to this research. While computational simulations are able to model the anticipated performance of a specific component, the performance of the composite system is too complex to be predictively modeled. Further, human interaction and resulting immaterial effects requires the development of full-scale operational prototype installations.

The work of student Delia Guarneros explored the possibilities for 'texegrity' systems (structural systems based on tensegrity which utilize textiles in place of the tension members), to operate as kinetic skins capable of controlling light penetration (fig. 12). The research in-



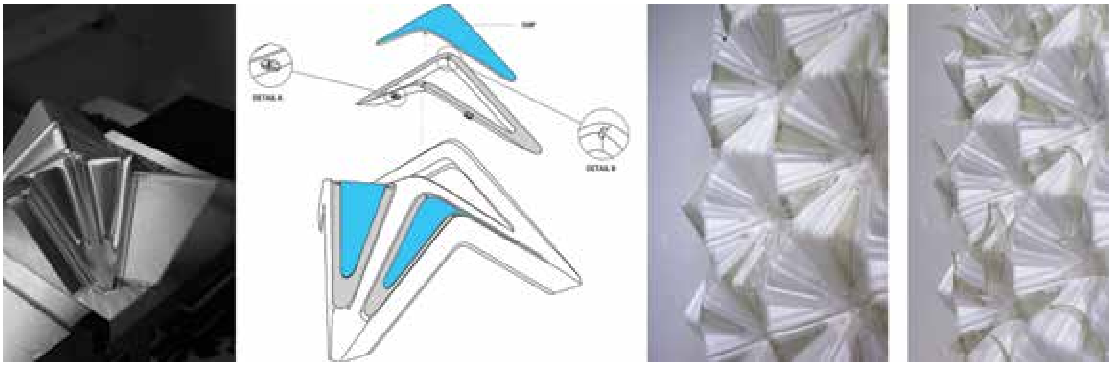


Figure 13: Transformable shading system using shape memory polymer (SMP) (Steven Beites, Master of Science in Material Systems—Associate Professor Geoff Thün and Assistant Professor K. Velikov, University of Michigan, 2013)

volved iterative experimentation with textegrity geometries, modeled both physically and computationally, that could achieve desirable results when actuated. The system's operation could be controlled by both integrated light sensors, as well sensors that detect human presence and negotiate the conflict between shading and view paradigms within the system. The work of Steven Beites explored the use of shape memory polymers (SMPs) as thermo-sensitive actuators for use in kinetic facade systems (Beites 2013). Due to the capability of SMPs to elastically deform at one temperature threshold, and to return to a memorized shape at another temperature, they allow for the possibility of adaptive architectural components that can be actuated without the use of mechanical components or external energy inputs. Steven's work involved exploratory research into methods of manufacturing SMP forms through injection molding, as well as their integration into a prototype skin system with deployable openings (fig. 13).

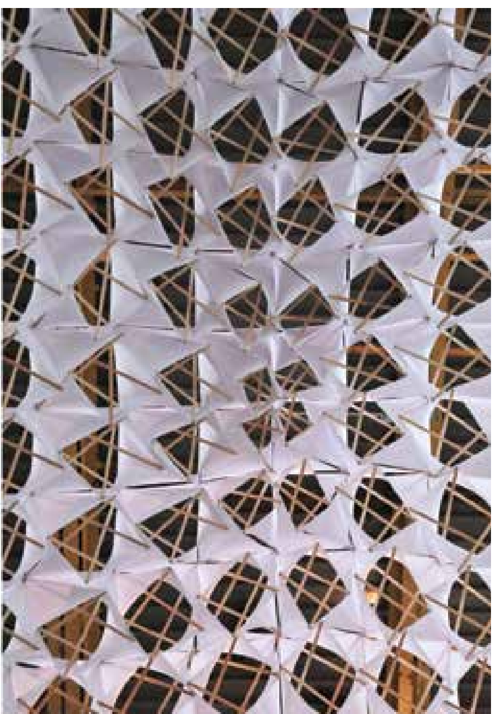


Figure 12: Texegrity transformable structure (Delia Guarneros, Master of Science in Material Systems—Associate Professor Geoff Thün and Assistant Professor K. Velikov, University of Michigan, 2013)

The Stratus Project, led by faculty Kathy Velikov and Geoffrey Thün, develops a distributed interior envelope system that modifies atmospheres while attuning our attention to the air-based environment and to the physical conditions that produce it (fig. 14). It is comprised of a deep suspended textile: a 'thick' surface consisting of a tensegrity weave whose nylon tension members provide deformational flexibility for spatial transformation, while also supporting a network of physical elements and technologies. The system senses movement, proximity, temperature, humidity, CO2, and airborne pollutant levels, and reacts according to individuated occupancy triggers and processing algorithms to modify comfort conditions. Light-based communication informs occupants of reduced air quality, so that this new skin also operates as an interface through which individuals might develop more sensible and cognitive relationships between their own actions, the spaces they inhabit, and the larger air environment (Velikov, Thün, and Ripley, 2012). Resonant Chamber is a subsequent prototype for an interior envelope system focused on transforming the acoustic environment through an integrated system that develops a spatially dynamic rigid origami surface comprised of acoustically specific material assemblies and electro-acoustic technologies (Thün et al 2012). This work builds on the North House prototype, a fully functional test bed constructed at the scale of the house, which combines a nested hierarchy of interacting systems, consisting of a high performance environmentally-responsive kinetic envelope, intelligent solar-powered HVAC controls and an interactive interface aimed at producing co-evolutionary behaviors between building systems and inhabitants (Thün and Velikov, 2013). Their most recent body of research in this area explores the architectural possibilities for lightweight deep skins based on biological models of densely networked assemblies of cellular pneus (i.e. tension-active membranes) that are capable of dynamic and variable performance primarily through the use of air pressure (fig. 15).

CONCLUSION

The work shown here has elucidated upon an approach and design methodology for the effective design, instrumentalization, and deployment of *material systems*. Such is being explored through the research by faculty and students involved with the Master of Science in Material Systems (MSMS) program at the University of Michigan. While the framework has been striated between studies of material formation, structural form-finding and responsive media, the research seeks to more exhaustively cross-pollinate these fascinating aspects of spatial and material phenomena. The stream of research, termed *Devised Skins*, moves through three stages—(i) *Topology, Materiality and Form*, (ii) *Sensing, Feedback and Transformation*, and (iii) *Performative Spatial Systems*—in order to foster the expansion of design considerations and performance as the research develops. Current studies have examined the repercussion of exploring topology and material behavior in the forming of lightweight structures. This has produced unique knowledge in the forming of textile- and composite-based structures that exhibit high degrees of controllable elasticity. In the next phase, this performance will be charged with means for sensing, feedback, and responsiveness, utilizing inherent flexibility as a way for geometric transformation avoiding the use of mechanical and kinetic means. This will involve, among other studies, the use of an industrial flat-bed weft-knitting machine, newly procured as a part of the FabLab at the Taubman College of Architecture and Urban Planning. With the concluding phase, we will compile the methods and material knowledge to study the possibilities for responsive spatial systems. Moving beyond the study of wall systems, this will engage projective imagination of material systems that engage the *extra-systemic*—the contingencies that lie outside (and interfere) with the tuned operation of a spatial, responsive material architecture.

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Figure 14: The Stratus Project installed at the University of Michigan, demonstrating operation of breathing cells and fans to dynamically adjust air temperature and pollutant levels (Assistant Professor K. Velikov and Associate Professor Geoff Thün, University of Michigan, 2011)

Figure 15: Nervous Ether installation undertaken through a workshop at the California College of the Arts, composed of a cellular pneumatic tessellated weave that registers and communicate remote environmental information through changes in inflation (Assistant Professor K. Velikov and Associate Professor Geoff Thün, University of Michigan, 2013)

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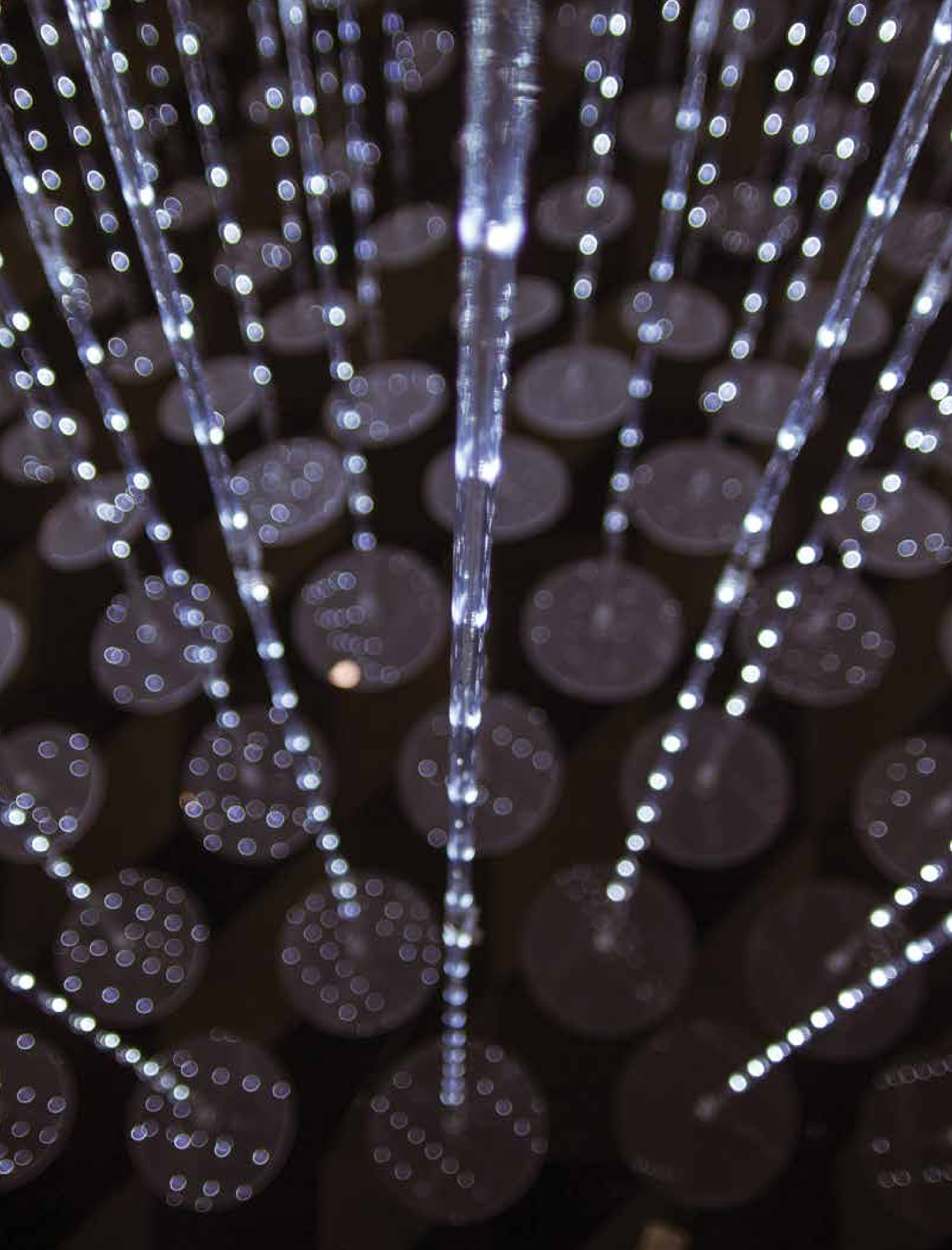

Code in the Clouds: Situated Technologies in Public Art

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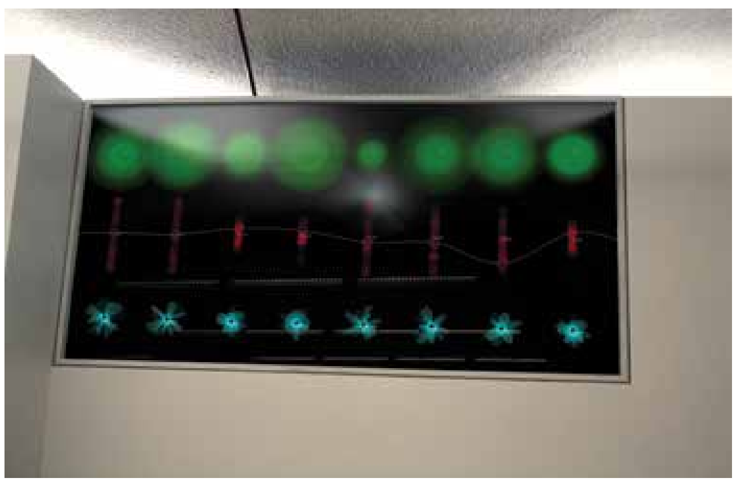
INTRODUCTION

The use of sentient technologies in managing building information for the surveillance and control of occupants is by now a ubiquitous presence in public space. By connecting sensing nodes to nested networks, the urban landscape and infrastructure is monitored and altered with feedback loops generated by individual actions and reactions. The aggregation of human behavior creates clouds of effects that can be measured as systems employ the use of algorithms to learn patterns, anticipate social tendencies, and push them to a desired outcome.

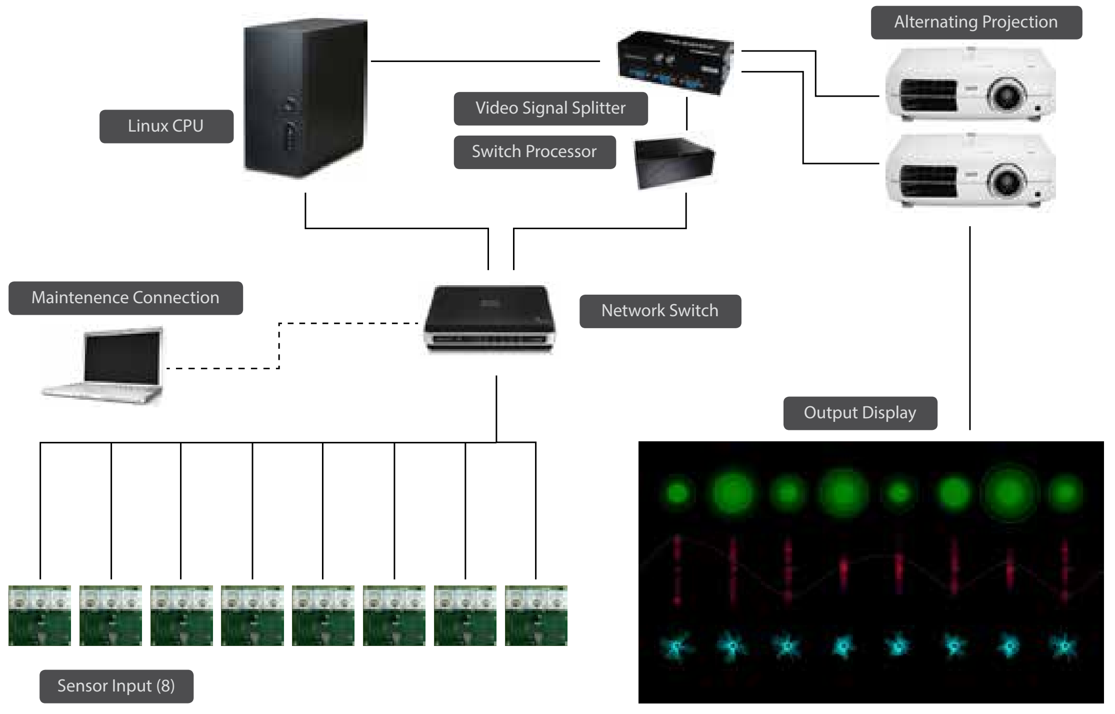
It is within this field of live phenomena that we have situated some of our work in the realm of public art to create threads of inquiry and produce a series of interventions that deal with the display of activated data in a custom temporal matrix. This art exists in four dimensions and is informed by variable input that forms a registration through variable output. Parametric design is not only a process of form-finding and static articulation of fluid form, but also an ongoing electronic process that unfolds in the past, present, and future of the spaces we sense.



Cloud Code, rear-projected image of animation on glass

The world of physical computing is, on the one hand, expanding in its reach to measure and control a global system of exchange of information. At the same time, the nodes of connection are shrinking to become integrated in the surface of things or disappearing altogether. The purpose of this art is to ponder the state of

CLOUD CODE SYSTEM DIAGRAM



technology at a given moment and produce content that measures the pulse of a space and repeats it as a mirror back to the subjects viewing and inhabiting it. These projects don't exist in the rarefied air of the art gallery but rather in public spaces, where their interpretation is based on the interaction of technology with everyday activities.

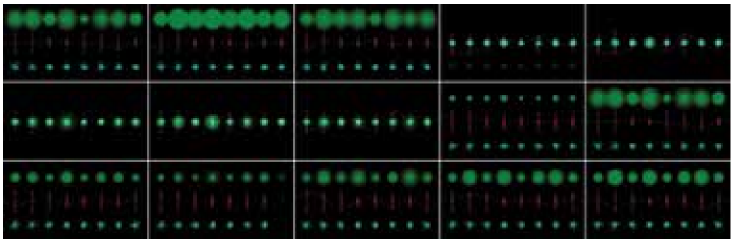
CODE CLOUD

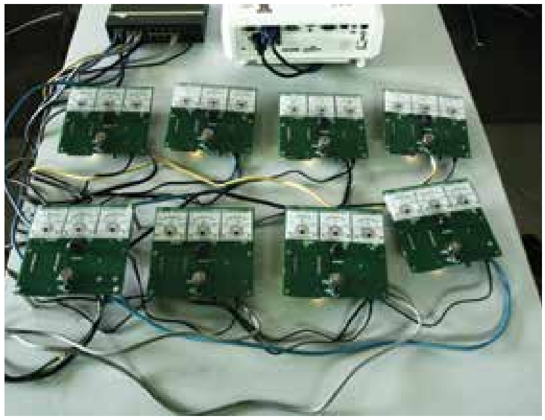
Cloud Code (2011) is a public art commission with which we sought to create a graphic display of real-time building information related to actions of the occupants and the air quality index of the space. By measuring motion, sound, and CO2 simultaneously, the domain of activity becomes a series of inputs into a system of sensors, processors, and visual projectors to produce an algorithmic painting of the space that is never the same twice.

We built a physical network from the electronic components up and coded custom software to process the data into an interlaced graphic display of building information. The qualitative effect of information parsed from the space was initially registered on analog meters at the sensor locations. We built custom enclosures with textual instructions and Shure microphone hardware that provokes interaction at the nodes in the network sited in the space. The sensors connected to custom circuit boards are hard-wired through the space to the computer that processes the signals into the layered interface that registers the activity at each sensor node. The algorithmic graphic is then projected on a large rear projection screen in the space. Each sensor node is located on one of eight existing columns of the space. The animation is organized as an abstracted floor plan of activity repositioned and scaled to a 5' x 10' rear projection screen.

The location for the work is in the City of Houston Code Enforcement Building, within the main lobby and waiting space. This facility has the capacity to measure the economic pulse of the city by regulating the commercial and residential building activity. We sought to channel the banalities of bureaucratic activities in a cybernetic event integrated with the space.

Cloud Code, screen shots of animated image based on varying sensor inputs at each column location. Green bubbles = sound, red waves = motion, blue sonar = CO_2





Left: Central Permitting Center waiting area, stainless steel sensor enclosure on existing concrete column

Right: Sensor boards connected to network for testing prior to installation

The animation patterns are differentiated with concentric circular swells, radial radar-type dials, and a waveform, each attached to individual motion, sound, and CO2 sensors. The effects in the display intensify and dissipate according to the levels of influence throughout the day. Cloud Code is an ephemeral work that is integrated seamlessly into the architecture of the space. It blurs the boundary between a moving spatial map as public art and situated technology that monitors activity for control of people and information.

Cloud Code is ultimately a comment on the relentless presence of enumerating technology in our lives and how it constantly tracks and quantifies without being transparent about the agenda of the operator—if there even is one. In this case, it is a perfectly useless apparatus, but it is integrated in such a way that it becomes a provocative presence in a bureaucratic system that lacks purpose for other reasons. It is this continuity of sentient technology with built architecture that we find so intriguing and beautiful to witness as an aesthetic expression of time in space.

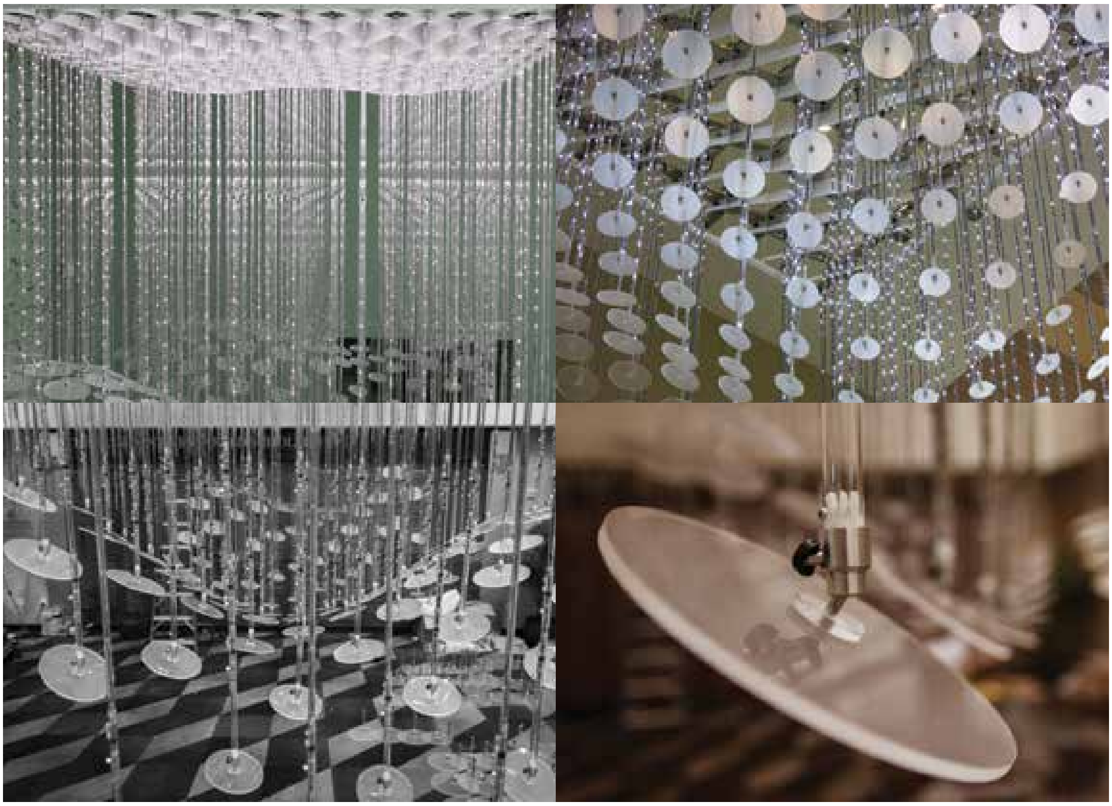
MEMORY CLOUD

Memory Cloud (2013) is a subsequent commission awarded to a team made up of RE:site (artists Shane Allbritton and Norman Lee) and our studio, which provided design optimization through parametric modeling, digital fabrication consultation, and construction management services. The project is sited on the Texas A&M University campus, in the Memorial Student Center. The request for a proposal suggested that the work should manifest the activity on the entire campus at a primary point of convergence of public pedestrian flows. The concept was to frame past, present, and future events in a sculpture that was in a constant state of flux. Like clouds moving through the sky overhead, the work would provide an evolving figuration of moving human silhouettes. The notion of timelessness was critical in collapsing the immediate present with events in the past as if an event from many years ago is happening again in synchronous real-time.

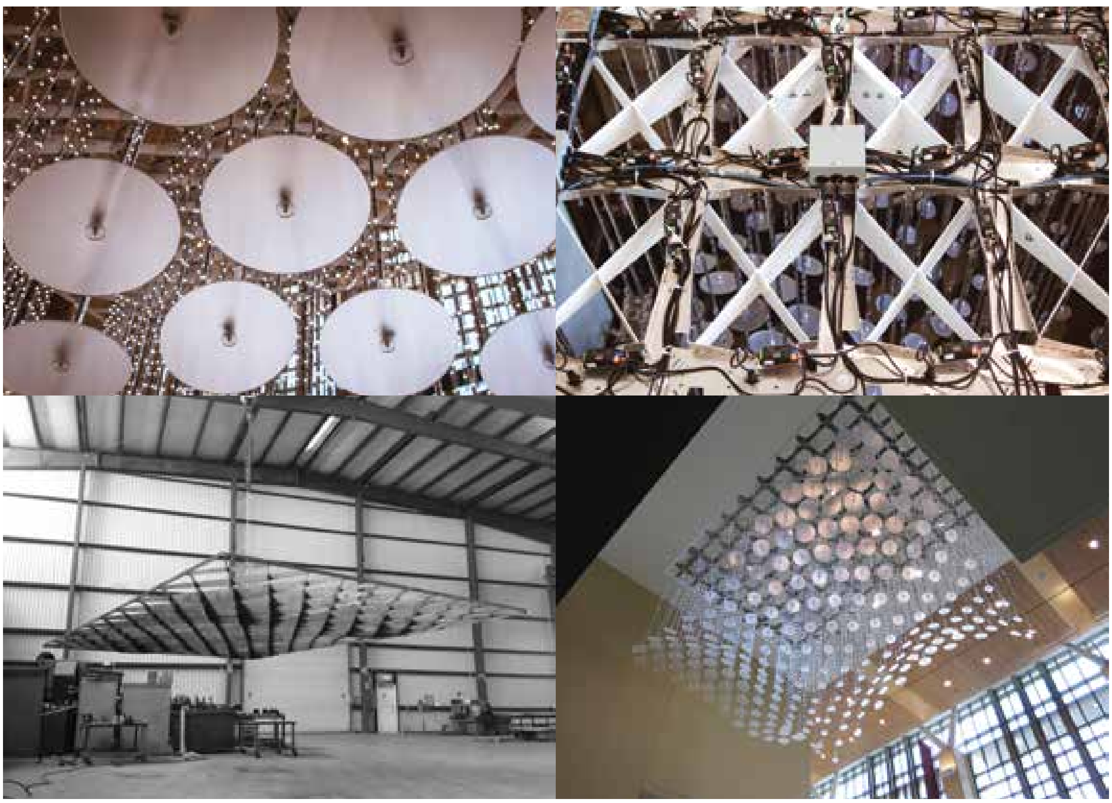
The culture of this particular university is one of deeply ingrained traditions that are played out each year in the student's activities. These actions are iconic in nature and provide an interesting tableau of content that could be fed into a system that abstracts it into nebulous moving apparitions in a field of light. A matrix of LEDs was proposed that could be programmed with video loops of recorded events with an intervening feed from a camera discretely embedded in the main concourse of the atrium. The video signals from the various sources are processed into a 2D pixel space that is mapped into the topological space of the 3D array. Cartesian coordinates are translated into UV points that extrude and warp the profiles into the space by addressing each node with a uniquely coded output. The algorithm allows for perspective correction to enhance legibility from the primary point of view. From other angles, the literal figuration is replaced with a vague registration of activity in the space projected to a monumental scale with subtle gestures made of flowing intensities of light.

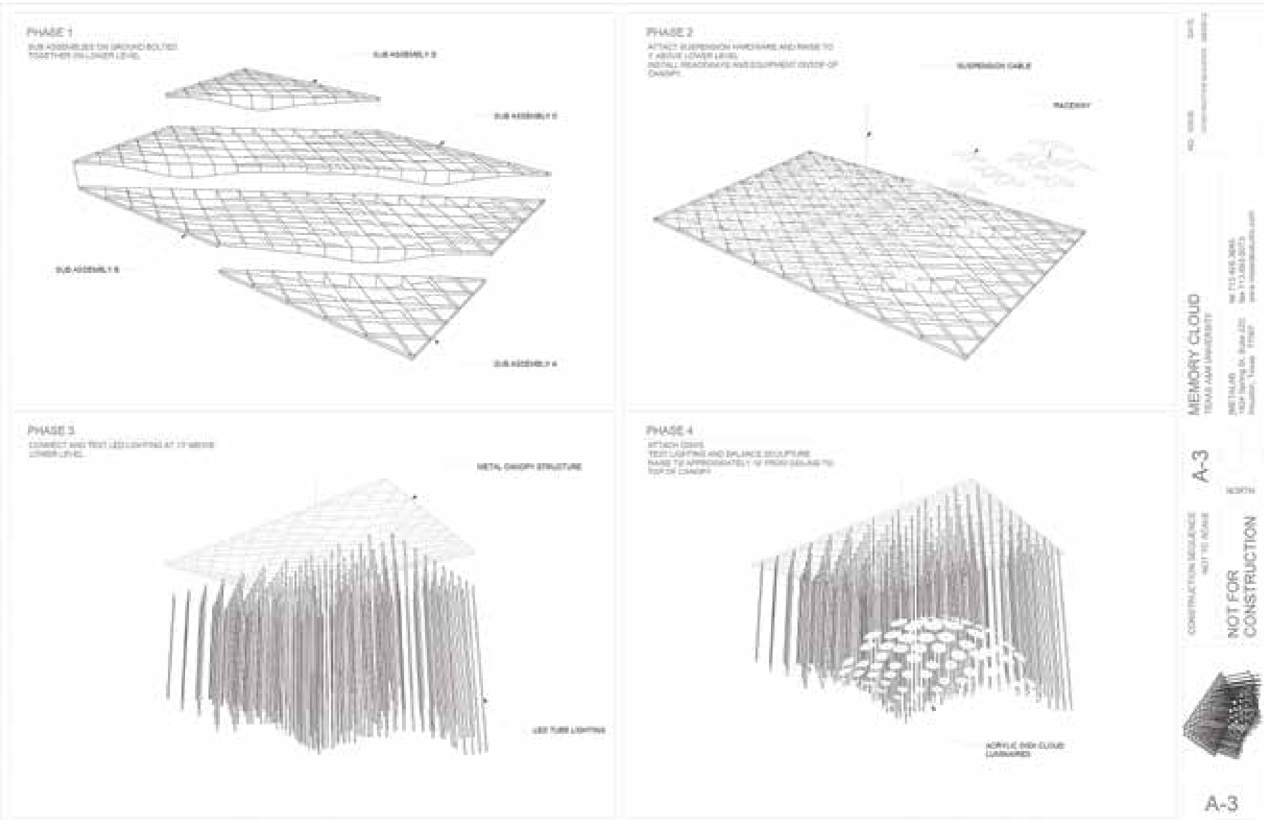
The project offered the opportunity to design and fabricate a physical computing network on a large scale with durability as a key concern for a permanent installation. The lighting system is controlled with DMX protocol, the standard for the theatrical effects industry. A media server is located in a remote space and transmits the data signals via a closed loop fiber-optic network to the top of the canopy. The sequence of 4000 nodes of light are split into 220 tube stacks and 11 DMX "universes," each with a different quantity of pixels connected in daisy chains. These data signals are conveyed on one network of cables while low and high voltage power are carried in a separate wiring system that provides electricity to each LED column in zones within the field. We developed a custom pan-formed raceway component with optional clips to manage the wires and provide platforms to attach pixel tube drivers, 5 V distribution panels, and power ballasts. This layer in the assembly allowed for selective wiring and pre-installation of parts as an aggregation of modules that expedited the on-site time as a plug-and-play operation.

Top left: Canopy and lights; Top right: Luminaires; Bottom left: Array of luminaire disks installed at the end of LED columns to produce the bottom of the cloud; Bottom right: Luminaire disk position is calibrated with a universal joint hacked from inexpensive camera tripods.



Top left: Dilated disks; Top right: Raceways installed; Bottom left: Canopy initial assembly; Bottom right: Installed work in atrium, view from lower level





Below the horizontal raceway is a vertical diagrid waffle structure made of 11-gauge carbon steel that was water jet cut and welded into four sub-assemblies that shipped and bolted together to form the main structural canopy. The constraints of the design required that the entire work had to suspend from one cable rigging point in the ceiling and be lifted into place with a concealed winch. This mandate afforded an opportunity to rationalize the form with parametric design that created a variable depth in the section of the 14' x 21' canopy—from 10" to a thin 1.5" at the perimeter with no deflection. The one vertical support at the ceiling splits into a four-point lift that connects to special saddles on the ribs at roughly .25 points from the perimeter. The structural engineering consultant ran a finite element analysis to assist in determining the optimum depth, suspension location, and how shallow we could go at the double cantilever. This process removed material from the ribs to make them as light and elegant as possible. There was a 3000 lb. weight limit to the entire project, and through this design optimization process, we were able to stay well below that and still use a heavier but cheaper sheet material.

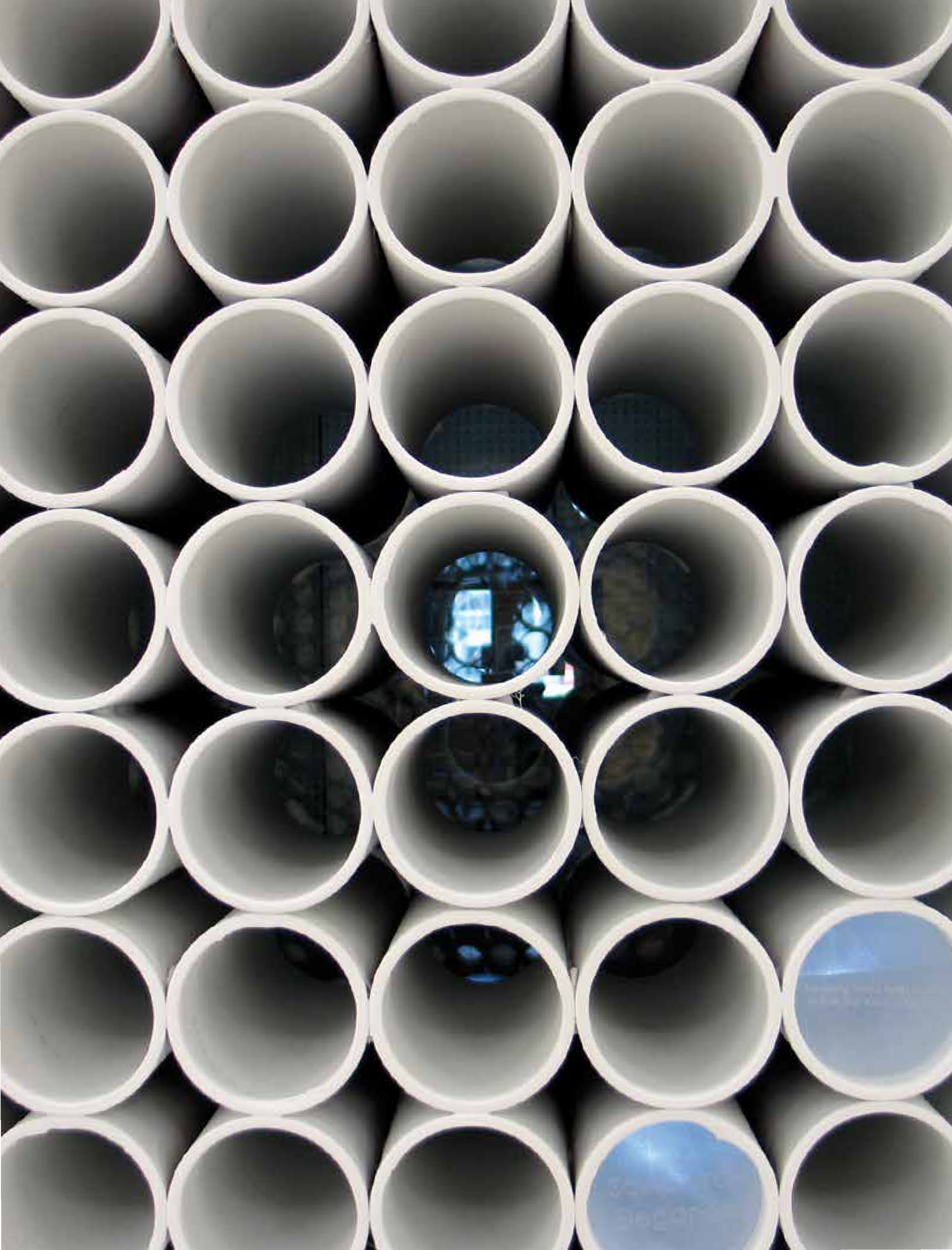
The design of the suspended lighting array played off the undulation of the canopy with a secondary 3D sine wave form that defined the underside of the assembly as a luminous suspended landscape. The design of the surface was informed by views and circulation patterns in the atrium approaching the piece from multiple heights and angles of encounter. Given the rough budgetary target provided by the lighting consultants, our parametric model was initially calibrated to allow no more than approximately 4000 lighting nodes in the system. As the design progressed after commissioning, an LED tube product was specified that was specially manufactured with the desired light color temperature and node spacing but came in set modular lengths of 1200, 600, 300 and 180 mm. Through a sorting algorithm, each LED column was divided into the correct sequence of tube units to add up to but not exceed a variable length between approximately 9' and 13'. The remainder of the aggregate length of each was translated into a field of disk-shaped luminaires that lock into the z-axis position. The disks vary according to their angle, rotation, and diameter. The diameters dilate to 18" as the tubes become shorter to help to return the center of gravity to the centroid of the canopy. They contract to 6" on the longest tubes to form a translucent surface that modulates the light when viewed from below, further disrupting the viewer's relationship to the legibility of the overt figuration of human forms in the lights. The normals of the lower cloud were referenced to find the form of the surface and set the angle of the disks, which was achieved in the field with a universal joint hacked from off-the-shelf camera tripods.

An infrared camera, part of the discrete surveillance system that captures movement in real-time, is installed in an adjacent concourse without visual connection to the work. This was to provide an intentional disconnection between the various paths of flow through the building and in the artwork itself. The viewer of the display, not knowing where the camera is, does not know if the silhouette transmitted in the lights is an image of themselves or another occupant, or themselves as they were in the recent past. It is this ambiguous relationship with the recording of movement on the campus and the resulting evanescent experience that this project sought to create. The architecture and our knowledge of materials, fabrication, and data networks were employed in service of the precise alignment of components to convey the effects of the concept on a monumental scale.

CONCLUSION

Cloud Code and Memory Cloud represent a thread of design strategies in our work that expands the notion of how art, driven by interaction, can be integrated into public spaces. They engage a fundamental inquiry into how an architectural project can channel and test some experimental trends of contemporary design technology. These projects represent an evolving set of tools as a work-in-progress that we seek to apply to more complex scenarios using distributed sensing to build responsive environments.

EMBEDDED SURFACES



Digital [Tactical] Viscosity

Jon Yoder
Assistant Professor, Kent State University College of Architecture & Environmental Design

Architects sometimes lament the fact that design usually proceeds through drawing and modeling (both analog and digital) rather than through full-scale building. Robin Evans called this "the peculiar disadvantage under which architects labor; never working directly with the object of their thought, always working at it through some intervening medium, almost always the drawing, while painters and sculptors, who might spend some time working on preliminary sketches and maquettes, all ended up working on the thing itself which, naturally, absorbed most of their attention and effort."[1] Indeed, apologies for the seemingly second-hand status of mediating representations proliferate in architectural discourse. Representation itself is sometimes even blamed for the dilution of culture. In the 1980s, Kenneth Frampton warned against the descent of architecture into the world of surface scenography that threatens to extinguish the last sparks of critical culture. And today, theorists including Sanford Kwinter and Michael Speaks dismiss certain projects designed by the current generation of digital formalists as vacuous (or "grotesque") representations that lack substance and intelligence.[2] As the impressive scholarship of Evans attests, however, architects have also reveled in the possibilities opened up by representation. The numerous process fetishes and software obsessions of recent times are prime disciplinary examples. This paper poses the difficult question: As new digital design interfaces, platforms, and output systems proliferate, how might architects operate consciously and productively with what Evans called the "viscosity" of projective media in the interest of digital design innovation?[3]

Too often, seeking to transcend the second-hand status of representation, architects retreat to the essentializing territory of digital utopias or the *Gesamtkunstwerk*.[4] In declaring Parametricism the "great new style after Modernism," for example, Patrik Schumacher posits a digital substrate from which parametric and algorithmic architecture emerges according to the rules of a brave new game. He describes a field of computational operations consisting of both negative heuristics (taboos) and positive heuristics (dogmas) that is nearly comprehensive.[5] Indeed, Schumacher portrays the projective potentials of Parametricism as nearly limitless. He promiscuously embraces many of the contested concepts of Modernism, including: manifesto, style, and avant-garde, in addition to the natural, the organic, and the immersive. In

Egg crate and acrylic broccoli flowers by Albert Jang (2012)

fact, Schumacher's casual perpetuation of the utopian myths of Modernism, coupled with his universal assertion regarding the ostensibly genetic status of Parametricism, make his thesis seem unpalatably naïve. It is as though the critical theories and ideological exposures of the Postmodern period never happened. In the interest of clarity (indeed, *purity*), Schumacher puts the parametric blinders on and forges ahead. But what productive Postmodern arguments might he have missed as he teleologically targets a brave new parametric future?

Donna Haraway, for example, announced a promisingly viscous model for cultural production in her seminal 1985 essay, "A Cyborg Manifesto."[6] Like Schumacher, she also mobilized the medium of the manifesto, but her writing was anything but naïve. "Cyborg imagery can help express two crucial arguments," she wrote. "First, the production of universal, totalizing theory is a major mistake that misses most of reality, probably always, but certainly now; and second, taking responsibility for the social relations of science and technology means refusing an anti-science metaphysics, a demonology of technology, and so means embracing the skillful task of reconstructing the boundaries of daily life, in partial connection with others, in communication with all of our parts."[7] In calling for "faithful blasphemy" that dispensed with the myth of organic wholeness and the "troubling dualisms" of critical theory, Haraway articulated a project of unsanctioned hybridization from which architects might learn.

The anthropologically saturated work of Pierre Bourdieu and Michel de Certeau might constitute another productive, if counterintuitive, blind spot for Parametricism. In *Outline of a Theory of Practice*, Bourdieu distinguished between rules and strategies. We might not be able to change the rules of the game, he argued, but playing strategically might open up some unforeseen pragmatic possibilities. In *The Practice of Everyday Life*, De Certeau celebrated tactics over strategies when it comes to finding economic ways to "obtain the maximum number of effects from the minimum force."[8] A tactical approach, he argued, is often the last resort of the weak, but it can have a surprisingly powerful impact. De Certeau described a tactic as follows: "Lacking its own place, lacking a view of the whole, limited by the blindness (which may lead to perspicacity) resulting from combat at close quarters, limited by the possibilities of the moment, a tactic is determined by the absence of power just as a strategy is organized by the postulation of power."[9] Within this framework of strategies and tactics, Schumacher seems to want to reverse engineer architectural authority. By operating strategically, and claiming universal application for recently emerging rules, he attempts to imbue parametric practice with an unprecedented cultural power. Indeed, most digital theory traditionally promotes strategic thinking. But what might happen if we invade Haraway, Bourdieu, and De Certeau's territory of social (urban) practice and re-appropriate their blasphemous tactics and hybridizations for innovation in formal (digital) practice?

Greg Lynn attempted just such a maneuver in the important "Folding in Architecture" issue of *Architectural Design* (AD) from 1993. He interpreted Gilles Deleuz in positing "smoothness" as a "post-contradictory" computational alternative to the oppositional and dialectical thinking that dominated architecture in the Postmodern period. "Smoothing does not eradicate differences," he insisted, "but incorporates free intensities through fluid tactics of mixing and blending."[10] Lynn's emphasis on tactical approaches seems odd today given the overwhelmingly self-reflexive strategies that are evident in many of his digital projects (his recent "Fountain" installation for the Hammer Museum is an exception). By *tactics* he still meant mainly internal digital operations. But like Evans, Lynn also celebrated *viscosity*. And like De Certeau, he pointed to the surprising potency of the powerless. "Vicissitude is often equated with vacillation, weakness and indecisiveness but more importantly these characteristics are frequently in the service of a tactical cunning," he insisted. "Vicissitude is a quality of being mutable or changeable in response to both favorable and unfavorable situations that occur by chance. Vicissitudinous events result from events that are neither arbitrary nor predictable but seem to be accidental. These events are made possible by a collision of internal motivations with external forces…In this sense, vicissitudinous mixtures become cohesive through a logic of viscosity."[11]

The landscapes of internal and external forces have changed notably since Lynn celebrated viscosity twenty years ago. For one thing, the internal motivations of computation and the external forces of materiality are no longer distinct valences of architectural production.[12] Jason Payne, however, fondly remembers the mid-1990s as a time before parametric practice had "congealed into an identifiable set of stylistic characteristics."[13] He distinguishes between contemporary parametric practices that are primarily invested in imagistic indexicality and those that explore "pragmatic indexicality" to produce specific effects or connect disparate systems. According to Payne, this second category "is more sparing and judicious, less naïve and therefore less glorified and totalizing."[14] He also identifies a "move from technique to tactics" that characterizes an opportunistic materialist approach in this second type of contemporary practice.[15] These architects are not using digital platforms and material systems *strategically* to realize some pre-determined utopian ideal in the Modernist sense of "emergence." They are instead using them *tactically* in unsanctioned, even blasphemous ways, to explore hybrid viscosities of design and fabrication.[16]

In three projects with my Syracuse University students, we explored digitally and tactically viscous approaches to fabrication. In 2009, a small group of graduate students and I organized an exhibition based on Neil Denari's HL23 tower on the High Line in New York.[17] After finding a supplier of thousands of free cardboard tubes in Utica (NY), we developed a modular system for a tube wall that filtered views between the gallery and atrium. Ironically, we spent an academic year researching the HL23 tower and Denari's practice, but found nothing inherently tube-like about them. With free material at hand, however, we decided to force-filter our understanding of HL23 through the viscous material logics of cardboard tubes. Among their many qualities, the tubes had the ability to imbue general viewing with the focused ocular parameters of peeping. They also efficiently intensified LED light sources into hot spots to advertise the exhibition. And perhaps most importantly, they introduced the logic of pixilation as a viscous matrix through which images of the already highly graphic and insistently surfacial HL23 tower could be projected. We used a remarkably cost-efficient production system of laser-cut chipboard templates, digitally manipulated anamorphic images, and spray-painted blue foam panels to mount the exhibition. Through numerous tactical decisions and carefully calibrated techniques, the final installation seemed like an intelligently rational and intuitively obvious framing of Denari's project.

Last year a group of second-year undergraduates and I produced an exhibition of biomimetic panels for the Biomimicry Challenge conference at the Syracuse Center of Excellence.[18] Even though I had no serious personal interest in biomimicry per se, the event provided an excellent excuse to explore the potentials of tactical viscosity. I asked the students to select a microscopic or telescopic image from the biological world and then fabricate a small panel using readily available materials that usually escape the attention of architects. Students developed their own hybrid fabrication processes that used laser cutting and CNC milling in conjunction with everyday materials—including plastic bags, colored pencil shavings, pins and buttons, egg cartons, plastic forks, and rubber bands—to fabricate the images they selected. Perhaps not surprisingly, the overtly image-oriented installation quickly found its way into university promotions. These published images of the installation might seem reductive in traditional phenomenological terms. But since the project started with the selection of images, we understood this "post-phenomenological" re-mediation as a chance to explore the viscous potentials of print, photography, and video to produce architecture.

The following semester, I took another group of second-year undergraduates to Los Angeles. We visited a number of architecture schools, museums, firms, and important buildings, but I also asked them to analyze a hilltop site in Culver City. The Baldwin Hills Scenic Overlook occupies the top of the highest point on the South edge of the Los Angeles basin. A rugged terrain of scrub brush and oil well pumpjacks, the site offers expansive views from downtown in the East all the way to the Pacific Ocean in the West. From this elevated vantage point, the infrastructural logics of Southern California development come into focus.[19] All the students documented these conditions and produced original site analyses. Two of them became intrigued with the exaggerated qualities of this vehicular landscape and tried to imbue their analysis with a similar sense of the sublime. They decided to cast the site in aluminum. With the help of Sculpture Professor Robert Wysocki, they melted down recycled auto parts to fabricate a site model of molten metal.[20] It was a complicated, even dangerous, process of trial and error that took viscosity to a hot material extreme. The students laser-cut a conventional chipboard site model (which would easily have satisfied the site analysis requirements for most studio projects), treated it with heat-resistant polymers, and made four small sectional molds for the sculpture workshop's sand bed. After the liquid aluminum cooled, they buffed and polished the metal to a high-gloss automotive shine. Although the model certainly relates to the topography of the Los Angeles basin, it does more than merely represent it. Neither is it purely an

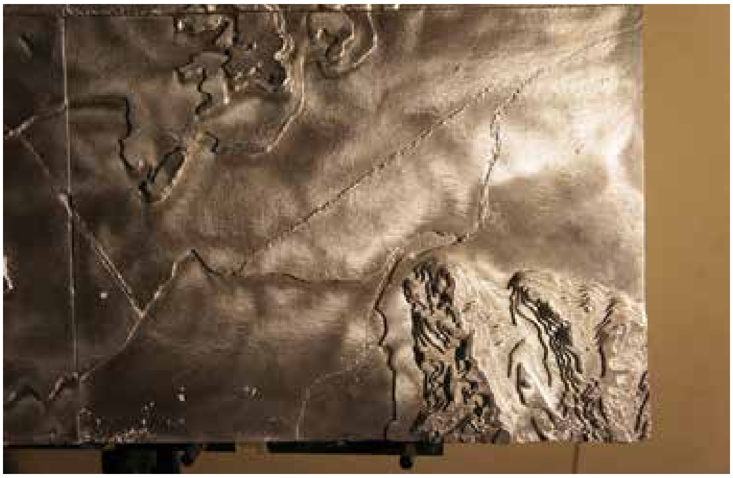
Cardboard tube exhibition wall by Syracuse University graduate students (2009) essay on process nor a vehicle for conveying the *content* or *meaning* of the site. It is a piece of architecture that is viscous with digital, material, representational, experiential, political, economic, and collaborative tactics.

None of these projects are the result of having started in the ideal place with the perfect strategy. Beginning variously with image selection, material procurement, site analysis, or fabrication process, these projects actually suggest that architecture can start with anything, anywhere, at any time. They emphasize the importance for architects to remain tactically open to design contributions from unanticipated and unsanctioned sources. The results are often impure, contingent, and residual in the spirit of social architectural engagement, but still rigorous, refined, and precise in the tradition of formal architectural autonomy. In short, *Digital [tactical] viscosity* abandons the naïve fundamentalist claims of digital geneticists, while exposing certain *critically* viscous tactics for incrementally refined and technically precise fabrication. It is carefully calibrated, opportunistically hybridized, and subversively observant. Several of its tendencies—including an open-minded approach to resource identification and management, iterative approach to design research and development, and collaborative approach to question formulation and resolution—already suggest, if not require, concentrated work with diverse media and across different disciplines. And perhaps most importantly, they might prompt architects to establish additional platforms for productive engagement that enhance the inherently projective capacities of this *digitally and tactically* viscous approach to design innovation?

ENDNOTES

1. Robin Evans, *Translations from Drawing to Building and Other Essays* (London: Architectural Association Publications, 1997), 156.

Recycled aluminum site model of the Los Angeles Basin by Cristina Abondano and Jessica Borri (2012)



2. In conversation with Jason Payne, Sanford Kwinter explained, "I see your third generation as having lost its connection to the material substrate in which the mind works, exiled within an equipment-saturated world, sold on the hype of cyberfreedom and cybersociality and compensating wildly with ersatz realities like 'special effects.'" Kwinter quoted in "A Conversation between Sanford Kwinter and Jason Payne," in *From Control to Design: Parametric/Algorithmic Architecture*, ed. Tomoko Sakamoto, Albert Ferre, et al (Barcelona: Actar, 2008), 231. Michael Speaks recently dismissed certain unbuilt parametric projects as "fluffy." He adopted a surprisingly conservative Marxian distaste for surface appearances when he celebrated the "real" projects developed by his faculty and students when he was Dean of the University of Kentucky College of Design. See Speaks's responses to questions by Sarah Whiting and Winka Dubbeldam following the session, "Panel 3: Collaboration between Architecture Education and Non-Academic Partners," (presentation, New Directions in Architecture Education: 3rd International Architectural Educations Summit, Aedes Network Campus Berlin (ANCB), Berlin, Germany, September 14, 2013): http://www.ancb.de/sixcms/detail.php?id=9708635.

3. The work of Michael Hansmeyer offers an intriguing case of "post-phenomenological" viscosity in that it often evinces a palpable materiality whether or not his digital constructions are physically fabricated. His projects sometimes simultaneously violate and embody the phenomenological parameters for material experimentation in architecture. While his digital renderings seem rich in material texture, it hardly matters what material is used to fabricate them. According to Hansmeyer, "The processes can generate highly specific local conditions, while ensuring an overall coherency and continuity. As such, the resulting architecture does not lend itself to a visual reductionism. Rather, the procedures can devise truly surprising topographies and topologies that go far beyond what one could have traditionally conceived." See Michael Hansmeyer/Computational Architecture: http://www.michael-hansmeyer.com/profile/about.html.

4. German opera composer Richard Wagner famously used the term *Gesamtkunstwerk* in his 1849 essay, "Art and Revolution." In this essay, he celebrated the Greek drama as the most highly developed art form because it successfully incorporated music, dance, and poetry. See Wagner, "Art and Revolution," in *Richard Wagner's Prose Works*, trans. William Ashton Ellis (London: K. Paul, Trench, Trübner, 1895).

5. Patrik Schumacher, "Parametricism as Style: Parametricist Manifesto," (paper presentation, Dark Side Club, 11th Architecture Biennale, Venice, Italy, 2008); and "Parametricism: A New Global Style for Architecture and Urban Design," in *Architectural Design (AD): Digital Cities*, vol. 79, no. 4 (July/August 2009): 14-23.

6. Donna Haraway, "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century" (1985), in *Simians, Cyborgs and Women: The Reinvention of Nature* (New York: Routledge, 1991), 149-81.

7. Haraway, "A Cyborg Manifesto," 181.

8. Michel de Certeau, *The Practice of Everyday Life*, trans. Steven Rendall (London, Berkeley & Los Angeles: University of California Press, 1984), 82.

9. De Certeau also insisted, "Power is bound by its very visibility. In contrast, trickery is possible for the weak, and often it is his only possibility, as a 'last resort': 'The weaker the forces at the disposition of the strategist, the more the strategist will be able to use deception.' I translate: the more the strategy is transformed into tactics." See de Certeau, *The Practice of Everyday Life*, 37-38.

10. According to Greg Lynn, postmodernism and deconstructivism—represented by the diverse practices of Peter Eisenman, Frank Gehry, Bernard Tschumi, and Robert Venturi—formalized contradiction and fragmentation in architecture from the mid-1960s to the late-1980s. He also identified a parallel trend to regain wholeness, or a "reactionary response to formal conflict," in Neo-Classicism, Neo-Modernism, and Regionalism. See Lynn, "Architectural Curvilinearity: The Folded, the Pliant, and the Supple" (1993), in *Constructing a New Agenda: Architectural Theory 1993-2009*, ed. A. Krista Sykes (New York: Princeton Architectural Press, 2010), 32-34.

11. Lynn, "Architectural Curvilinearity," 37.

12. As the Marxian ambition to unveil reality by stripping away ideology and the Freudian desire to therapeutically expose unconscious motivations through psychoanalysis are themselves exposed as ideological constructs, oppositional dualisms such as real/virtual, analog/digital, optical/tactile, active/passive, and formal/social begin to lose their power as well. Dualisms certainly still exist, but the lines have been redrawn. Almost all architecture schools are now digital, but they distinguish themselves according to digital platform: Revit/Ecotect versus Rhino/Grasshopper, for example.

13. Payne, "A Conversation," 219.

14. Payne, "A Conversation," 222.

15. Jason Payne, "Hair and Makeup," in *Log*, no. 17 (Fall 2009): 41.

16. Examples of these digital materialist practices include R&Sie(n) (Francois Roche, Stéphanie Lavaux, and Jean Navarro): http://www.new-territories.com/; Payne's firm Hirsuta: http://www.hirsuta.com/; and the firms of Payne's (and Greg Lynn's) former students, including WEATHERS (Sean Lally): http://www.weathers.cc/, and Sift Studio (Ellie Abrons and Adam Fure): http://siftstudio.com/.

17. These graduate student collaborators were Anastasija Gridneva, Erik Maso, Mina Panichpakdee, Cailyn Remington, Alex Raynor, Shannon Sturm, and Elijah Yoon. See H. James Lucas and Mark Linder, eds., *Neil Denari: Graduate Session 08* (Syracuse: Syracuse University School of Architecture, 2009) (Jon Yoder curator/faculty advisor for exhibition/interactive CD-ROM).

18. For information on the First and Second Annual Biomimicry Challenges, see the conference website: http://syrbiomimicry.com/.

19. For an account of the mid-2000s shift in architectural attention to infrastructure in the context of a graduate research studio, see my essay, "All That is Solid Melts into Infrastructure...," in *Thought Matters 2: UCLA Research Studio Works*, ed. Hitoshi Abe (Los Angeles: The Regents of the University of California, 2008), 88.

20. See Robert Wysocki's work on Vimeo: http://vimeo.com/user2061629; and his SU Lava Project: http://lava-dev.syr.edu/.

Gehry and the Glitch: Serendipity in Digital Design Processes

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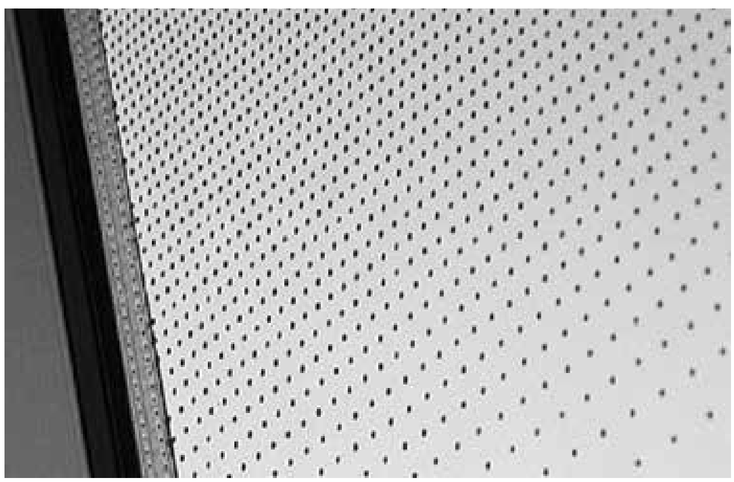
INTRODUCTION

In 2006, Frank Gehry completed his first building constructed entirely of glass. The Interactive Corporation Building in New York, or IAC as it is known, broke new ground in terms of the degree to which mass-customization of building components drove the design and construction process. In a time when visual programming was limited, 1,349 of the 1,437 exterior glass panels are unique in their shape and degree of twist. Additionally, baked-on ceramic white dots—so-called frit (fig. 1)—cover each of the glass panels and were coordinated and composed with regard to each individual piece of glass.

Tolerances were introduced by the glass panels' cold-warped assembly, or bending elements, in situ to fit the curtain wall's design. In contrast, the process of screen-printing ceramic frit onto the glass involved fusing it to the surface during the heat strengthening process. The resulting durable patterns in glass (fabricated by Saint Gobain in the Netherlands) required precise assembly of each distinctive piece. Post-fabrication required an on-site laser scanner to correlate and analyze the construction process as discussed by Brandt's essay on computational determinism.[1] Since these fritted glass products are tempered, or heat-strengthened, they cannot be further altered on site. Reflecting on the exactitude of the design, fabrication, and coordination prompted this investigation into methodologies experienced in the process, like digital serendipity or 'glitches,' turning them into "formal" aspects for future use.

Figure 1: Close-up interior view of the IAC fritted glass panel



FRITTED GLASS IN ARCHITECTURE

Ceramic fritted glass has recently become more salient to architecture as digital fabrication techniques expand the possibilities of combining graphics with architecture. Beneficial features of ceramic silk screening—such as indestructible enamel bonding, excellent scratch resistance, ease of cleaning, variation and customization of colors and patterns, sun shielding capacity, and spandrel blocking—make this process appealing. Projects such as Gensler Los Angeles, the Aqua Tower in Chicago by Studio Gang Architects, and One Midtown Plaza by Mack Scogin Merrill Elam Architects are just a few examples that demonstrate these benefits of frit as a building design element. Improved energy codes have also increased the interest in fritted glass. Even non-building related organizations, like the Audubon Society, endorse fritted glass as a sustainable design feature because these graphic marks make it easier for birds to see glass buildings, preventing them from flying into windows.

THE HALF-TONE SCREEN ON IAC

Not unlike Gehry's well-documented design process whereby rigorous model-making occurs at multiple scales[2], the same held true for the execution of the frit pattern. The pattern had to conform to several constraints: the height of the office desks, the necessity to see out without graphic obstruction, and the visual suppression of the spandrel panel or horizontal banding by a use of a gradient pattern (fig. 2). As a priority, the white silkscreen pattern had to achieve an overall 50% opacity across the building for the basic reason of reducing the HVAC tonnage. Beyond the inevitable aesthetic intent, the frit pattern element was primarily employed to reduce glare and enhance the building's environmental efficiency by acting as an integrated sunscreen. The pattern's requisite coverage adapts to the height applied in each panel to control solar heat gain and glare while providing privacy and views.

In keeping with Gehry's process, versions of lines and dots were first generated as hand-drawn, line sketches

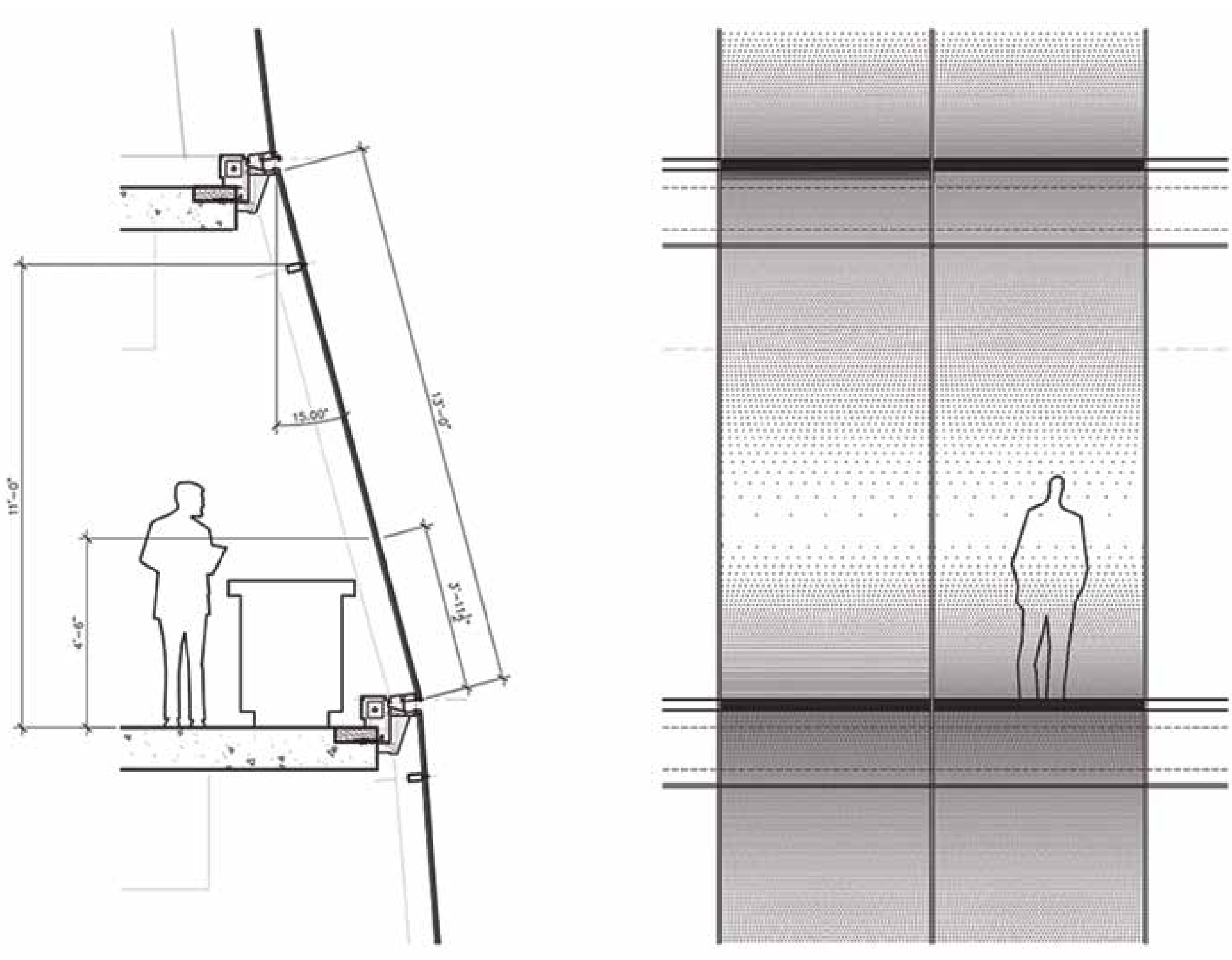


Figure 2: (left) Wall section showing constraints of frit pattern; (right) Intended gradation for typical glass piece and spandrel panel during design development.

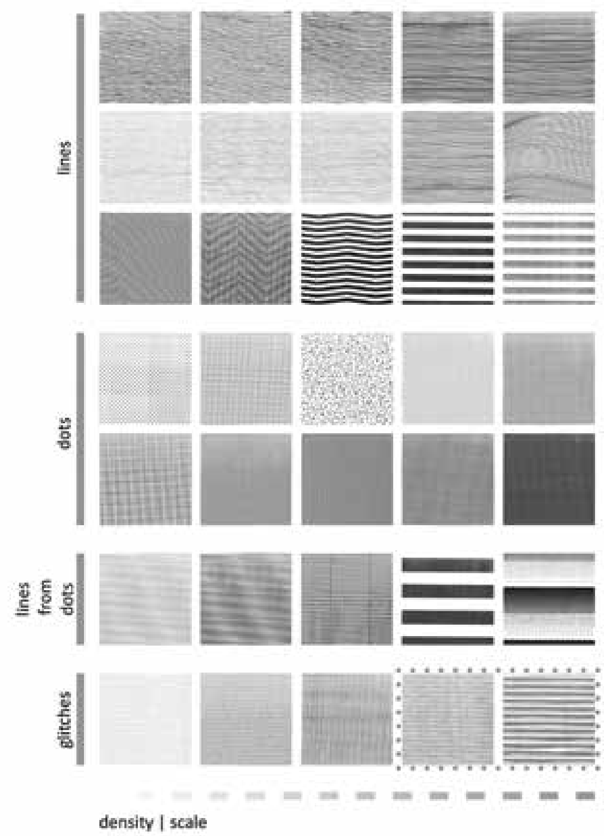


Figure 3: Various pattern-making methodologies and versions were explored to give a sense of depth to the bending panes of glass. With each operation a coverage count was calculated.

resembling sailcloth for a fabric-like effect (fig. 3). These were then digitized, but they quickly necessitated control of the graphic object's density, which could be achieved by implementing precisely controlled half-toning software. The half-tone screening software created in-house accomplished (pre-fabrication) the necessary gradation to create a smooth blend from the fully opaque spandrel to the fully transparent glass at eye height.

The use of raster data was ruled out because of the limitations for customization of the pattern given available software technology, and because the size of the panels at the resolution required would have far exceeded available computer power for processing, transmitting, and printing the data in raster form. AutoCAD was the platform of choice as it was the easiest to write a custom pattern generator for at the time. The custom pattern generator was written in AutoLISP, which uniquely calculated the location for each dot and laid the dots down as individual objects in the AutoCAD drawing file (fig. 4). A serendipitous "Bleed Test" aligned the circumference of each dot to the bleed of the silkscreen fabrication, making the dot size smaller in its production than in its final output. Several parameters were also established in this process to allow variation in the percentage of dot density and unique levels of gradation for each panel.

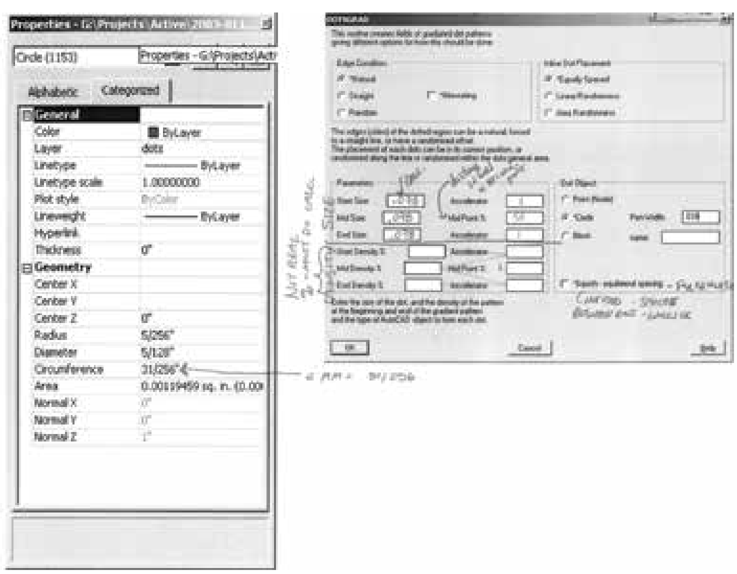
OPPORTUNE GLITCH

Maintaining the data in vector form for design production pushed the computers at Gehry Partners to their limits, and often exceeded them. This workflow was extremely processor-intensive and resulted in very long pattern generation times and very slow resultant files. So much so that, unexpectedly, alternative patterns (glitches) started appearing (fig. 5). In retrospect, these (re)configurations constitute a more complex and nuanced outcome worth readdressing for its irregularity, greater 3-dimensionality, and mapping of uncontrolled data. In hindsight, greater opacity coverage with a less clear graphic "dot" and banded condition to the exterior could have resulted from these glitches. For instance, this pattern provides a 95% coverage at its maximum, while the one used at the IAC provides a coverage of 75%. The serendipitous conversion of the original data into these patterns was assumed to be happening in the raster image processor (RIP) internal to the plotter; hence, in this case, the patterns were not under the control of the authors.

FOUND FILTERS VS. CONSTRUCTED FILTERS

The IAC case study above is an example of what constitutes a "found distortion filter" in architectural design. In this case, a bug in the internal RIP of the Oce plotter "incorrectly" processed the incoming vector data into a

Figure 4: (left) Bleed test settings to coincide with silkscreen fabrication, (right) DOTSGRAD script created to generate non-linear gradient pattern and dot size variation patterns.



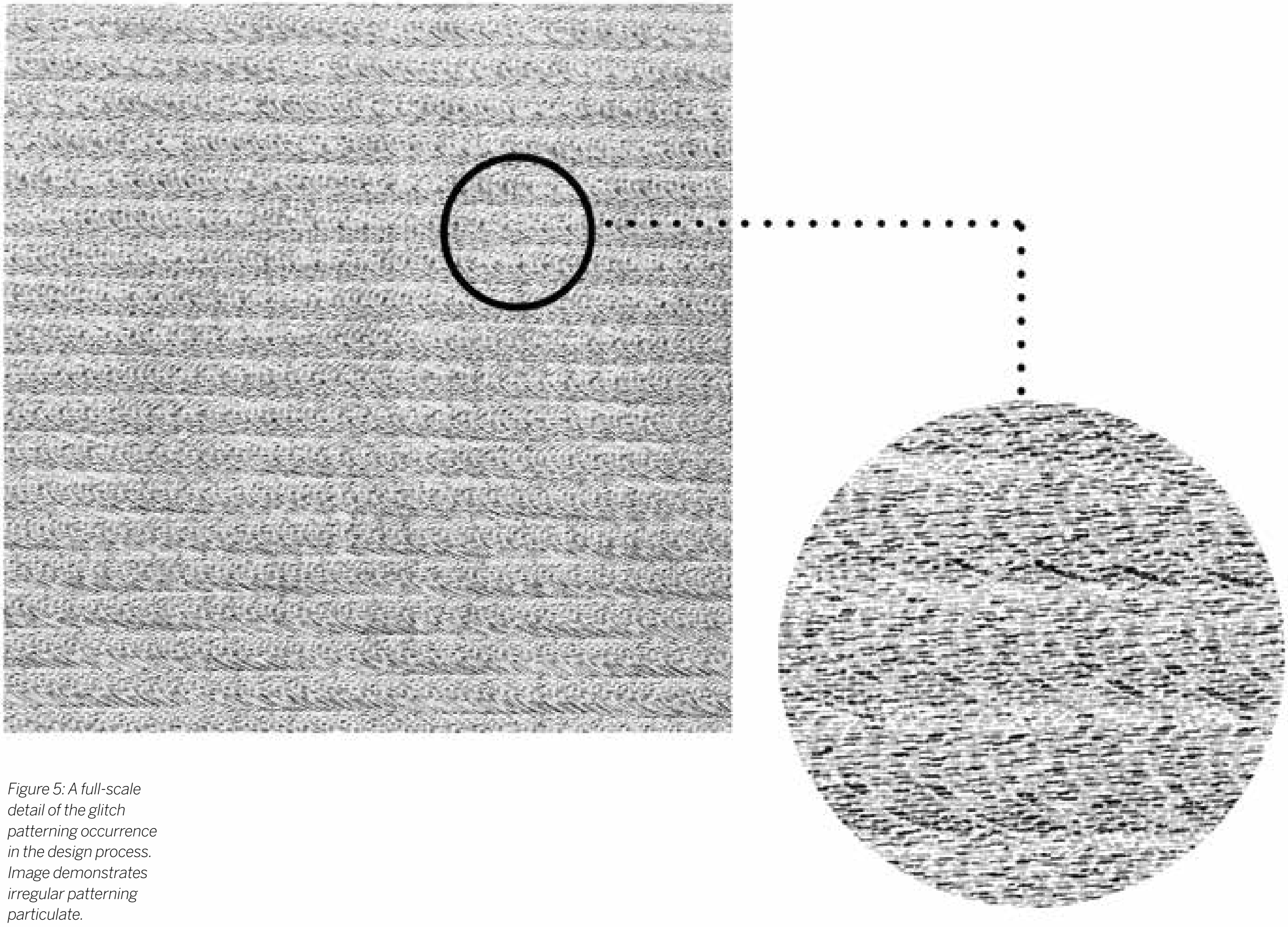


Figure 5: A full-scale detail of the glitch patterning occurrence in the design process. Image demonstrates irregular patterning particulate.

result that bears no resemblance to the original, but is remarkably beautiful for its depth and complexity and could not have been generated by the authors using conventional means. Being a found distortion filter, it was not directly controllable, but could have been indirectly controllable to some degree by varying the size, density, and arrangement of the dots in the input vector file.

The primary issue that a designer faces utilizing a found distortion filter is the capture of output data in a usable form. If the distortion happened to occur, for example, in the generation of the HPGL print file by AutoCAD, it may be possible to redirect the HPGL output to file and then re-ingest that data into AutoCAD for further processing and fabrication. If the distortion occurred in a RIP external to the plotter, even if that RIP did not allow for the redirection of the output to file, it may be possible to scrape the data transfer to the plotter off the wire using sniffing tools: "A packet analyzer (also known as a network analyzer, protocol analyzer or packet sniffer, or for particular types of networks, an Ethernet sniffer or wireless sniffer) is a computer program or a piece of computer hardware that can intercept and log traffic passing over a digital network or part of a network. ... The captured information is decoded from raw digital form into a human-readable format that permits users of the protocol analyzer to easily review the exchanged information."[3] If the distortion occurred in a RIP internal to the plotter (as was the case in the IAC example), it is almost certainly impossible to retrieve the output in digital form due to the internal complexity of the plotter hardware.

This can be contrasted with the idea of a "constructed distortion filter," which would be a process step (hardware or software) designed to introduce visual distortion. Designed controls would be provided to tune the distortion, allowing for a more formal distortion design. This distortion design could then allow for parametric control of necessary constraints like controlling solar heat gain and glare while providing privacy and views out, as was the case with IAC. The tool would then output the desired distorted data in a format suitable for further editing and, ultimately, fabrication.

INCORPORATING SERENDIPITY INTO DIGITAL DESIGN PROCESSES

Serendipity is, of course, ever present in design, and as a valid generative tool, it has long been debated in traditional design circles. Digital artists, however, often embrace serendipity and treat it as an artistic process (for example, complex layering of looped digital samples in music, like the work of Reggie Watts, who creates unpredictable performances on the spot using his voice and looping pedals[4]). The use of distortion can also be seen as a form of serendipity—while the choice of when to use distortion is controlled, and the general style and quantity of distortion is somewhat controlled, the distorted output is not controlled.

Upon discovery of a found distortion filter, the following generalized method can be employed to make the filter a productive part of the digital design process:

1. Research where in the chain of digital workflow the glitch occurred.
2. Isolate that process and establish its controls.
3. Capture the output from the distortion filter in a format that can be passed on to further design and fabrication steps.

In the IAC example discussed in this paper, the dot field in the AutoCAD file constituted the input data, and the plotted paper constituted the serendipitous distorted outcome. Workflow testing could have been performed to determine which step constituted the distortion filter, such as: viewing the HPGL file as generated by AutoCAD in a software viewer, printing through the same print server to a plotter configured differently, or printing to the same plotter through a print server configured differently. Once isolated, the input data could have been varied in a series of experiments to establish the range of controls available.

In order to be usable to the design and fabrication team, the output data from the found distortion filter would need to be captured in digital form. If the captured output was in vector form, it could be fed back into the vector workflow (that is, opened in AutoCAD and used as design data). If the captured output was in raster form, it would need to be opened in an image editor capable of handling very large raster files. Whether raster or vector is preferable would depend on the fabricator's process, but for most architectural applications, vector output would be required. This illustrates how the glitch pattern could be instrumental in defining a final frit configuration.

SUPPLEMENTARY PATTERNING TECHNIQUES

Further investigation is underway into methodologies for generating frit, capturing digital "glitches" and turning these patterns into "formal" aspects of the digital design process. Continuing research intends to determine potential viability of patterning techniques of distortion filters, such as using: a photograph as the driver of the pattern, attractor points, and agent-based

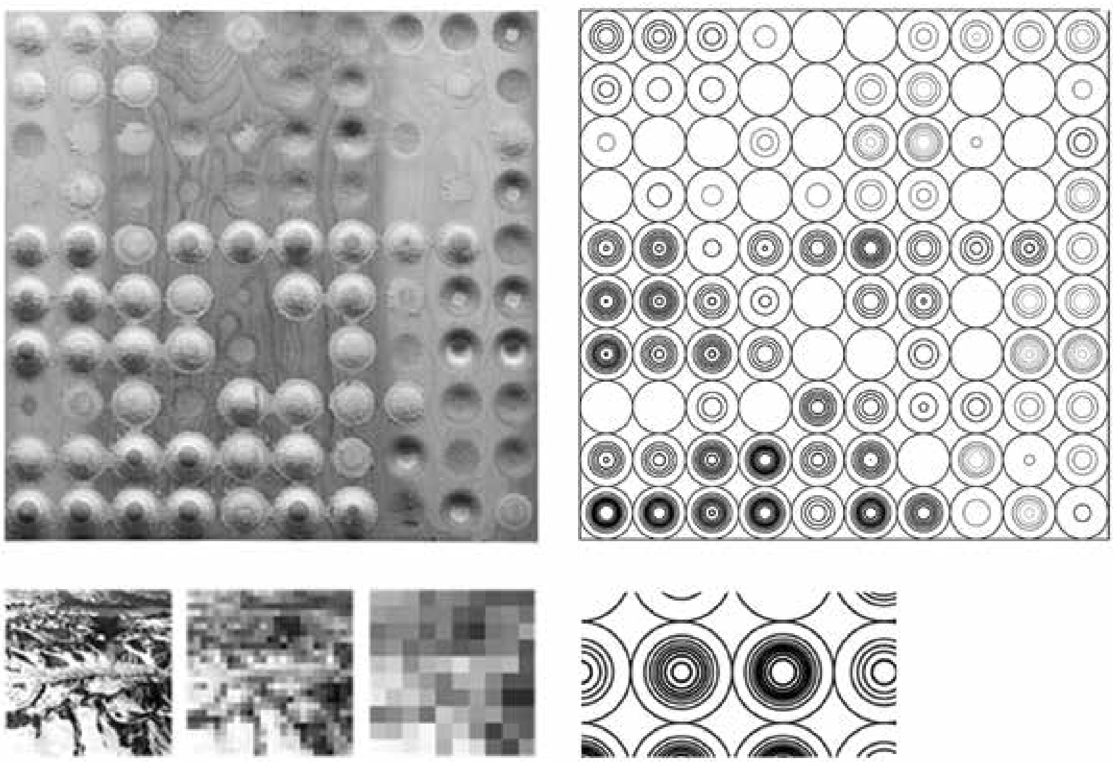


Figure 6: Example of bitmap pattern derivatives using BIM.

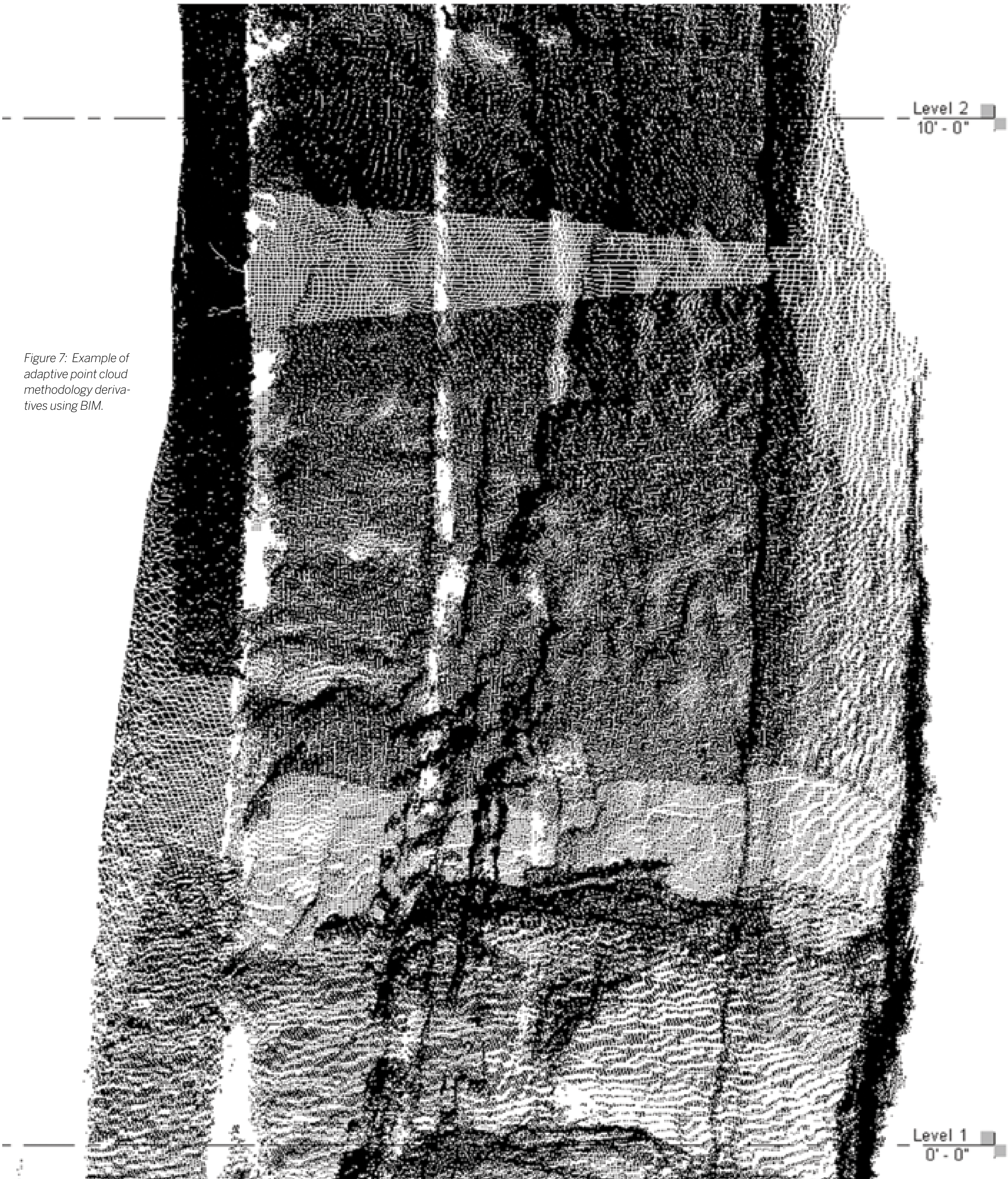


Figure 7: Example of adaptive point cloud methodology derivatives using BIM.

patterns within a pragmatic BIM platform. Alternatively, software like IGEO allows for open-source, agent-based distortion and generation.

BIM, generative exploration, and CNC fabrication demonstrate evidence of photography-driven pattern as a means of producing aesthetic effects through visual coding. Through the translation of an image-based parameter algorithm, a design process creates unique frit patterns with distortion embedded in the image resolution. This method has the added benefits of construction coordination as well as potential for a greater 3-dimensionality of the graphic controls. Glitch or serendipity in this sense comes from the adaptation of serendipitous imagery from pattern into low-tech material.

Point cloud data harvesting provides another means to investigate the applicability of serendipity in the generation and/or hosting of frit patterns and distortion filters with CAD and BIM platforms. This "block" reference allows frit to be more efficiently adaptive to given programmatic space, it acts parametrically for variability with ease of point cloud capture, and it adapts more readily to different space functionalities. Such a point cloud allocation of frit in IAC would have eliminated the overall coverage of the same applied frit pattern and, thus, the horizontal banding at each floor.

Continuing research intends to run tests to determine potential viability of these ideas:

- Recreate and test the limits of the original IAC AutoCAD script using modern computer capacity.
- Refine the limits encountered in embedding a frit pattern using distortion filters into contemporary software such as Rhino/Grasshopper and Revit.
- Refine supplementary patterning techniques with distortion filters.
- Explore constructed distortion filters (hardware and software) for application in architectural processes.

CONCLUSION

The research demonstrates a classic example of benign "hacking" or "repurposing of something physical or digital in a way not foreseen (benign hacking) or explicitly against (cracking) the original intentions of its designer."[5] If we agree that the parametric is a technique for the all-inclusive control and manipulation of design objects at all scales from part to whole, we must employ the algorithmic method of generation to produce complexity within an element as small as a particle or, in this case, a dot. To address the claim that parametricism today falls short of its potential to correlate multivalent processes or typological transformations, parallel meanings, complex functional requirements, site-specific problems, or collaborative networks,[6] this research intends to develop parametricism to control environmental data inputs at the truly granular scale.

ENDNOTES

1. Jordan Brandt, "The Death of Determinism," in *Persistent Modelling*, ed. Phil Ayres (New York: Routledge, 2012), 111-14.

2. Mildred Friedman, *Gehry Talks: Architecture + Process* (New York: Universe Publishing, 2002).

3. http://en.wikipedia.org/wiki/Packet_analyzer

4. http://www.ted.com/speakers/reggie_watts.html

5. http://www.adaptivebuildings.com/adaptive-fritting.html

6. Michael Meredith, " Never Enough (transform, repeat ad nausea)," in *From Control to Design* (New York: Actar, 2008), 98.

IMAGE CREDITS

Figure 1: Danelle Briscoe photo

Figure 2: Briscoe, Danelle (2002) IAC Project. Gehry Partners.

Figure 3: Danelle Briscoe research diagram

Figure 4: Prentice, Reg (2002) IAC Project. DOTSGRAD script notes

Figure 5: Briscoe, Danelle (2002) IAC Project. Gehry Partners.

Figure 6: Example of bitmap pattern derivatives using BIM. Submission by Chris Renke, BArch Candidate '12, University of Texas at Austin

Figure 7: Danelle Briscoe drawing and experimentation with Revit and point cloud

Bursting Margins [Involute Assemblies & Emergent Profiles]

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> *I showed my masterpiece to the grown-ups, and asked them whether the drawing frightened them. But they answered: Frighten? Why should anyone be frightened by a hat? My drawing was not a picture of a hat. It was a picture of a boa constrictor digesting an elephant. But since the grown-ups were not able to understand it, I made another drawing: I drew the inside of the boa constrictor, so that the grown-ups could see it clearly. They always need to have things explained…*
> *–Antoine de Saint-Exupéry, The Little Prince, 1943.*

Explorations on architectural envelopes have historically found their analogy in the anatomical or the biological body as models of both order and parthood. Cladding and structure have acquired in this way their conceptual status and alleged physiognomy through the analogy of skin and skeleton. The dialectic present in this binomial of skin and bones has instilled axiomatic assumptions of both spatial and material order: where the earlier maintains that one thing is simply inside the other, the latter is caught in the mutually exclusive role of the skin as either load-bearing and fully modulated with excessive engineering associations, or free from structural implications and subject to fetishized tectonic detailing or sculptural articulation.

This is not only a discussion about the functional (or even performative) role of the architectural envelope, but about the tense relationship existing between abstraction and materialism. While in the former, the architectural object is bound to remain ephemeral in order to favor representational purity, in the latter it accepts pure constructive determinism and dissipates its formal ambitions into a kit of multiple parts.

Speculating on an architectural object that assumes a more contested relationship with form and material, Bursting Margins adopts an alternate attitude towards enveloping. Bursting Margins argues for a more complex part-to-whole relationship. By virtue of perching robust modular frames within loose and tight flexible membranes, Bursting Margins pushes for changing material qualities supported by the introduction of live physics modeling software.

The approach not only forces the simultaneous consideration of rigid and soft materiality, but more importantly builds up a position for inchoate forms of material expression by exploring strong, yet transitory profiles—a byproduct of shrink-wrapping otherwise hefty frames. Can a mutant typology for the envelope be born out of the juncture between the rigid and the elastic, so that profiles become at times unmistakably visible, while in other moments mysteriously concealed?

To examine the design consequences of these issues, I will look at a number of design and fabrication aspects of a Textile Canopy project—a result of an intense, ongoing collaboration between my studio at Woodbury University and Semios by Fabric Images, our sponsoring company, the leading manufacturer in tensioned fabric architecture. The project is the perfect circumstance in which to push against the sedimented ways of thinking about the architectural envelope. In this analysis of the project I will not attempt to trouble disciplinary dualisms usually employed to talk about the architectural envelope (i.e.: skin and bones, modular and monolithic, inside and outside, etc.) but rather reveal and problematize the undecidables[1], that is, conditions that arise out of tense relationships amongst components and that cannot conform to either polarity of a dichotomy.

I will thus outline four criteria the project explores through contested relationships, conditions that allow the project to build on what Jeff Kipnis termed as one of his five important pillars. In his text "Toward a New Architecture," Kipnis denotes that "the properties of certain monolithic arrangements enable the architecture to enter into multiple and even contradictory relationships."[2] The proposed criteria is as follows: (i) Parthood & Wholeness – explores envelope ideas right at the juncture between aggregative modularity and unbounded spatial and material expansion; (ii) Rigidity & Elasticity – hypothesizes a material approach to structure and form while navigating through the boundaries of engineering elegance and fashionable shape; (iii) Pressing from Inside – mediates the traditional disciplinary categories of structure and cladding through the tectonics and representations of a puzzling bodily anatomy; and (iv) Modeling & Fabrication – discusses the tension arising out of the concurrent needs for digital interconnectivity of geometric conditions and autonomous material resolutions by regions as well as the challenges arising out of synchronizing, fabricating, and assembling the rigid and elastic components of the prototype.

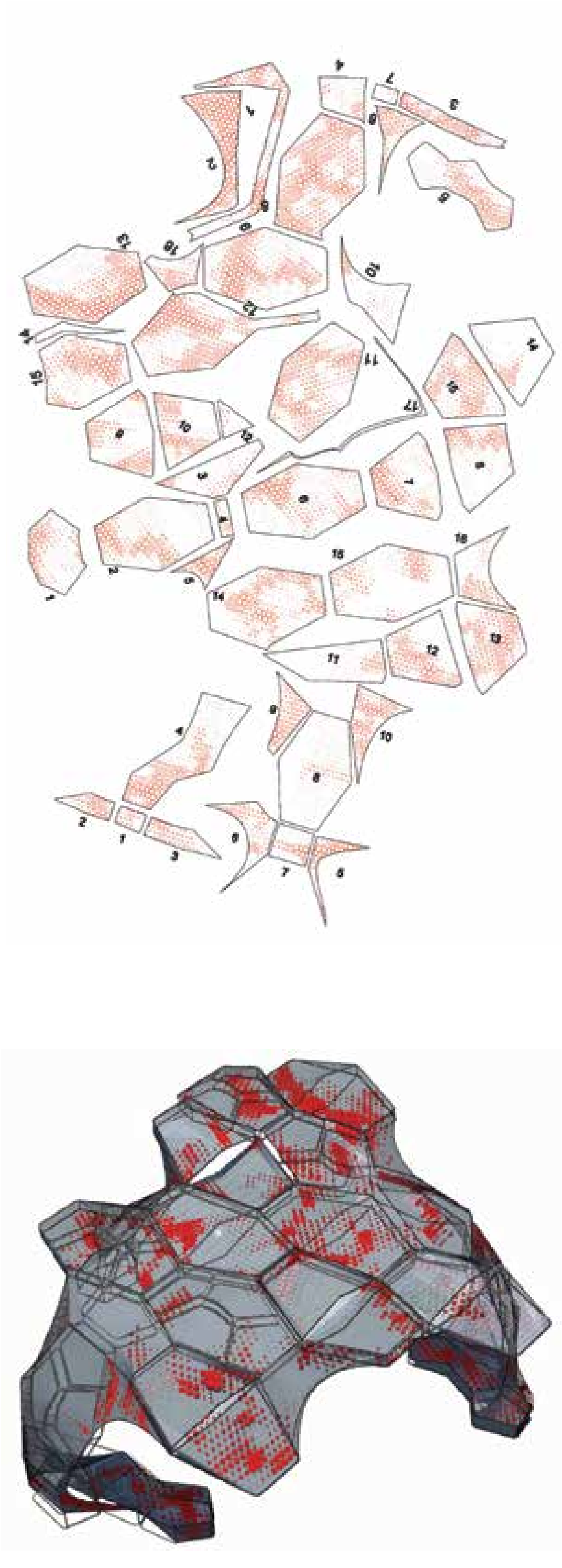

Figure 1: Birds-eye perspective of canopy structure and flat developed patches of membrane broken through seams

(I) PARTHOOD & WHOLENESS

One of the first undecidable aspects of the project is born out of its double role as light-weight product prototype for a shading structure as well as specific campus canopy project. While the latter demands clear spans, free plan, and flexibility of use, the earlier calls for multiple spatial (and therefore material) configurations. Thus, one of the first design intentions was to find a middle ground between the homogeneity of unlimited space and more precise notions of modulated space.

Precise Parthood: Nesting the Cairo Pentagon

The organization of the modular structure for the canopy follows a multiplication of a five-point geometry, commonly known as the 'Cairo Pentagon'[3]—due to its frequent use as a method of tiling in Egypt's capital. As it proliferates, this type of tiling creates the genesis for two flattened perpendicular hexagonal tiles, each of this composed of four nested pentagons. While these are equilateral pentagons, they are incongruent figures, as their angles differ slightly, thus creating a dual semi-regular tiling.

This capacity for nesting and alternating figural conditions (from five to six sided), orientation (the motif can be read indistinctly in either X or Y direction), as well as scale (hexagons are roughly four times larger than pentagons) proved a robust organizational logic for a project with both prototypical ambitions and novel formal agendas. For instance, the effect of gradually bending the structure at any of the three legs of the canopy is a product of the rotational capability as well as equilateral correspondence of the motif. In this way, ceiling becomes vaults and vaults become pillars by effortlessly folding the Cairo figures. This robust repetitive motif also allows the project to be systematically conceived as a prefabricated kit of multiple parts, achieving not only flexibility in assembly and efficiency in manufacture, but also a capacity for deconstruction, disassembly and reuse.

The repertoire of repetitive structure or form within architecture has often resulted in approaches that promote abusive serialization, resulting in a thoroughly articulated space. Steel construction has been the material vehicle for these Fordist models of mass-production, which celebrate endless repetition and regularity as well as spatial stratification. Parametricism as a form of additive versioning has introduced little to no exception in this practice: articulating the endless continuity of self-identical cellularity across an all-encompassing system all too often crystalizes into another top-down part-to-whole relationship and fixed logic, from a visual and spatial stance.[4] Thus, for a more undecidable formal and spatial envelope to exist, we required a balancing act between the hierarchies put forward by the Cairo close-packing system and some other notion of unbounded material definition.

Unbounded Jacket

A workable conceptual framework to approach this problem is from the perspective of mutable, even reversible, part-to-whole relationships capable of assimilating broader notions of spatial tactics. Materially, fabric promises physical versatility in its application as well as easiness of spatial extension, all produced with nimble plastic effects such as shrink-wrapping, stretching, pushing, draping, etc. Typologically, fabric offers the ability to work with mutant notions of the envelope,

Figure 2: Perspective section through canopy structure and existing auditorium

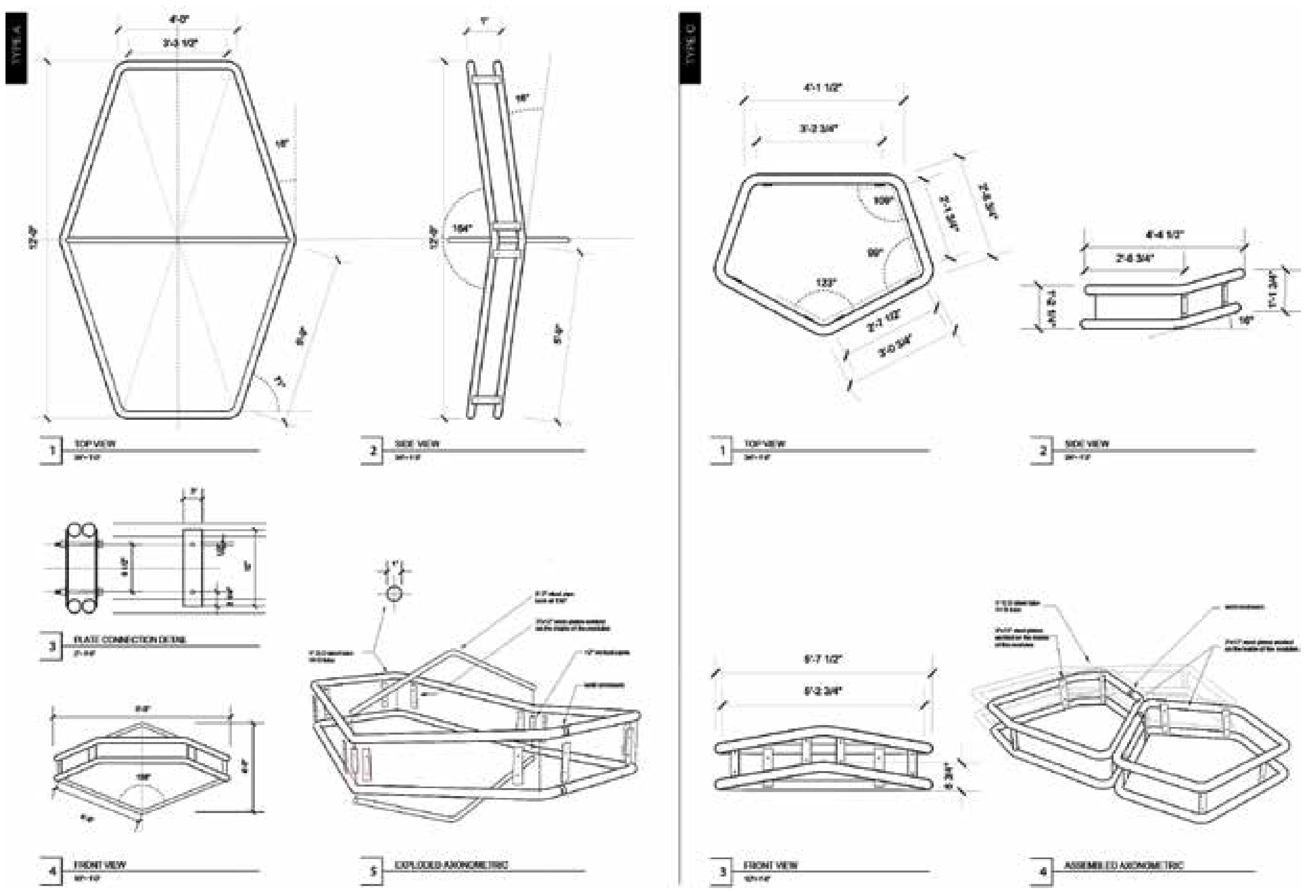

Figure 3: Shop drawings of bent aluminum tubes composing hexagonal or pentagonal structural modules

achieving hard and soft conditions as well as effects of looseness and tightness. Our renewed interest in fabric had to do as well with the degree by which new technologies—descriptions of which I will pursue in greater detail below—have pushed this polyfunctional material to behave ever more adaptively in order to achieve a wide range of building needs beyond mere passive sheltering.

Our preliminary material attitude towards fabric was to conceive of an architectural project within which a wide range of possibilities, mechanisms and procedures could work: from the immediate qualities and performances of the material—strength, durability, color, etc.—to the regulations and inflections that we as architects make on them.

Thus we pushed the textile to completely shrink-wrap the modular rigid frame, producing a range of loose and tight fits, which attach and detach to and from the structure. This range of fitting qualities reveals at times incongruences between the outer membrane and the internal frame in the form of skin excess, while in others the membrane performs much like a straightjacket. I will have occasion to elaborate on the issue of fitting below; however, I believe that the brief description above of the frictions between the modular inner structure and immensurable outer skin is where the undecidable aesthetics of the envelope rest. Moreover, by virtue of changing light conditions, the fabric produces substantial effects and visual readings, alternating transparencies and opacities; this condition makes the envelope's anatomy create several timely aliases, which at times reveal glimpses—or partial figures—of the modular Cairo spatial pattern, while in others conceal any notion of scale or order, giving way to a homogeneous, infinite, monolithic shell.

(II) RIGIDITY & ELASTICITY

Each one of the hexagonal figures that compose the Cairo pattern turns into a range of polyhedrons with varying profiles and related three-dimensional figures. The initial two-dimensional motif thus becomes more akin to a conglomeration of diamonds, imbuing the frame with crystalline or gemstone-like conditions. Each face or facet of these polyhedrons materializes into an irregular, closed 2-d figure or ring, which is manufactured with a round aluminum tube[5]; these would feed directly into the manufacturing line to be CNC bent.

Every piece of this gemstone puzzle is joined on their sides through a method called 'flat stock', involving steel plates at either side of each polyhedron that are later bolted together. Pentagons nested within hexagonal fig-

ures are selectively edited out in regions were the structure as a whole needs to reduce its weight; conversely, those modules positioned in sensible structural areas, such as the legs and their vicinity, are nested with pentagonal rings in order to prevent deformation.

Soft Gemstone

Since Frei Otto's experiments with soap bubbles (via Gaudi) informed his studies of membrane structures, elastic materiality has been associated with the tensile: materiality shaped under structural optimization through their natural gravitational flow. According to this principle, form-finding exercises galvanized most of the formal genres in elastic envelopes toward optimal draping simulations, often resulting in familiar, eidetic configurations. The engineering elegance that encompasses the formal lineage of surface structures relies on the principle of catenary curvature: is the natural curve that a cable or chain will adopt if suspended by its two ends. The resulting geometry is the corresponding ideal form for a cable resulting in uniform axial tension forces (or axial compression forces for an arch).[6]

Set apart from the historical envelope classifications of skeleton and skin, a surface structure's most important spatial and material characteristic is "the coincidence of the inner space and external form being almost identical; the form can be read from both inside and out."[7] The indexical nature of the structure from within and without precludes the irregular poché, as well as interstitial space or cavity. Under these assumptions, any thing constituting a disruption, break, or form of rupture disrupts a membranes' capacity for a pure structural reading. Geometrical simplicity, in structural principles based on natural laws, is essential.

Bursting Margins argues for a hybrid approach to structure, producing formal configurations that break a single ideal catenary path into many sub-segments. This results into a poly-curved shell, with fabric sagging into several curved surfaces following the principle of the catenary. What's stimulating about this approach is not only the ability of the poly-curved membrane to break spatially the scale of the sheltered area, but the textile ability to tighten the frame and force it to work under compression, much like a corset to the body. Fashion

Figure 4: Night view of canopy structure.

anachronism aside, the corset has a dual medical purpose, as people with spinal problems, such as scoliosis or internal injuries, may be fitted with a form of corset in order to immobilize or protect the torso.[8] In the same way, the ceiling and column moments of the canopy are held together by the membrane.

This is a clear alternative to the engineering elegance underlying natural shaping methods for structures utilized by Otto and others: a more aggressive shaping process that spreads the pressure onto the inner bones and holds the canopy figure erect through a precise, tailored fit. Imported from fashion, this model of elasticated yet stiffened architectural garment provided a more dynamic conceptual framework of mutual responsiveness between form and structure.

PRESSING FROM INSIDE

Bursting Margins positions the envelope as a kind of architectural hernia, where protrusions of organs (often internally contained by the cavities of the architectural body) re-surface, so that the anatomy of such a body is pressing from inside—or bursting. In trying to describe these sensibilities of his own work, British sculptor Henry Moore employs the allegory of "clenching your fist and seeing your knuckles pushing through the skin."[9] Moore went on to explain that this is not just another shaping force, but rather an overall sense that the vitality and strength of the sculptural body is given from inside.[10] Moore's admiration for the sense of pressure from within human figures, such as bones pushing through the surface, can be seen in many of his sculptures, alternating moments of fluidity with boney tautness.

The attraction for us is in the vanishing or dissolving qualities of emerging profiles, and the conceptual idea of a skeletal structure poking from the inside. This inside out approach to form is what guided our envelope studies. What's stimulating for us is not only the ability of the poly-curved shell to break spatially the scale of the sheltered area, but also the appearance of formal regions delimited by emerging—and dissappearing—profiles and fall-off silhouettes in the form of ridges, rims and creases. This is a direct product of the geometric motifs that compose the rigid frame pushing through the skin. These moments of rupture—or bursting!—play a pivotal, topological role: an interaction or friction of systems that would otherwise be kept separate.

It was the modern Italian architect Luigi Moretti who first underscored this condition of profiles in architecture in his 1951-2 essay "The Values of Profiles."[11] In his analysis of Moretti's work, Peter Eisenman argues that "the issue of profile is articulated through both hard edge and figured form."[12] Eisenman goes further and calls attention to the thematic quality of profile in Moretti's work and suggests that it "becomes more than just the edge of a three-dimensional volume and instead serves to question the clarity of boundaries between edge and volume,"[13] thus adopting a role as "marker of undecidable relationships."[14]

Figure 5: One-to-one scale prototype of rigid structure

For our canopy, profiles exist in one of two ways: as internal edges or as contours. Both of them mediate the intricacies of the 3-dimensionally manipulated Cairo pattern and relaxed fabric moments. Yet, internal edges exhibit vanishing qualities in the form of inchoate fall-offs, which at times partially expose figures of the inner frame, while in other ones peculiarly mask them. This reminds us of Eisenman's argument of the unstable boundary existing between edge and volume, and shall we add, between 2-d graphic features and 3-d modeling. Alternatively, contours possess mutant characteristics as well, but of a slightly different topological nature: they transform from straight-line traces of the firmly shrink-wrapped polyhedrons to the parabolic transitions fabric creates when it naturally flows in moments of detachment from the frame. The result is a series of compound curves full of turns, exhibiting both segmented and curvilinear geometric qualities. In sum, the elastic aspect of the canopy envelope becomes a site of augmentation and concealment of its modular inner skeleton, like collaged boney traces of an edged body about to burst.

(IV) MODELING & FABRICATION

From a digital modeling stance, the complexities of the poly-curved shell demanded digital modeling techniques that provide an easy access to topological change and disciplined relaxation—hardly possible with the simplistic and uniform constitution of NURBs surface logic. Instead, techniques in interactive simulation through Kangaroo Physics and other Subdivision Surface modeling techniques through T-Splines presented an effective alternative to conventional NURBs modeling as they allow for draping algorithms and overall digital continuity of surface conditions while at the same time inducing greater flexibility in the introduction of creases, wrinkles and other fashion-like detailing.

I have briefly referred above about the fabrication and assembly of the bent aluminum tubes that together compose the frame; I will deliberately avoid elaborating in depth about this component of the project as I believe the technology involved has been extensively documented in many tubular steel or aluminum structures. I will, however, dedicate this fourth section to discuss the material and assembly techniques involved in manufacturing the flexible membrane as well as attaching it to the aluminum structure, as I believe they are the ones that present the most complexity and challenge as well as produced the customized identity of the project.

The chosen exterior material is a polytetraflouroethylene (PTFE) membrane, which is able to provide shade during the day and a translucent figure at night, while the interior membrane will be made of softer linen-like fabric. Because PTFE is tough and hard to tension in long lengths, we faced the necessity of breaking the poly-curved membrane into several patches along predetermined seams that coincide with trajectories dictated by the Cairo motif (fig. 1). For the desired taut effect, these smaller patches would be laced tightly to the aluminum tubes via metal eyelets arrayed along the edges.[15] Through scaled analogue models we were able to understand that at this rate of connectivity between the membrane and frame, we would be able to maintain a degree of deflection in the fabric caused by the weight of the material.

The patches of fabric will be also outfitted with edge zippers in order to connect them together post tension. This assembly method was preferred due to its ability to exacerbate the seaming moments of the membrane, adding a new degree of hierarchy to the edges that exhibit boney tautness in the 3-d model. The zipper effect would thus add a garment-like quality to the membrane, yielding a higher level of design elegance while reinforcing some of the figural graphic trajectories that are fundamental to the project. Along the same line of thinking, LED Strips would occupy the space between the outer and inner membranes and copy some of these networked trajectories, allowing the hollow cavity to glow at night and project out the thick Cairo motif. By virtue of multiple projecting sources, structural patterns and seams would thus augment their intricate graphic presence and produce sophisticated atmospherics effects.

Figure 6: Interior view of shaded area looking towards auditorium

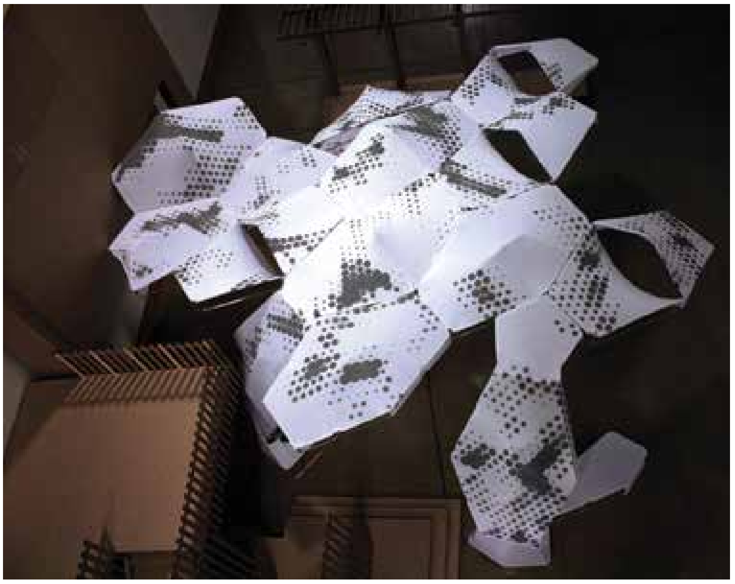

Figure 7: Aerial view of shading structure.

There is a reason, however, why the fabric of the project appears in pictures of the models up until a certain scale. At the one-to-one scale mockup that links one of the vertical and horizontal portions of the modular frame we encounter a few construction challenges when trying to attach the membrane onto it. Despite careful shop assembly of the many curved pipe elements[16], tolerances with the fabric skin require the use of a more advanced 3D survey technique unavailable to us at the moment in order to measure precise work-point locations on the frame, which was pre-assembled at the shop, disassembled for transport and reassembled on site. The complexity of design, with irregular shapes of patches, posed the difficult challenge of tensioning each of them into place through the lacing mechanism while simultaneously minimizing any wrinkling. Future mock-ups of the canopy project would inevitably necessitate a higher degree of synchronization amongst flexible and rigid components in order to yield a more precise level of correspondence that accounts as much for the attached, taut moments as for the semi-detached, looser ones.

CONCLUSION

There is always a mystifying element in elastic forms of growth. One possible explanation has to do with the fact that there is both maintenance and destabilization of the assumed corporeal aspects of the enveloping object or body, as much as there is restraint on an alleged second, enveloped object/body. A mutant typology, I've been arguing throughout the paper, is born out of this condition. However, the mutant not only embodies the ever changing boundaries between the distressed and the fluid; the discrete and the continuum; or the loose and the taut, but more remarkably between the different disciplines: in our case, architecture, fashion, and technology. The emerging associations between profiles and zipped seams, envelope and corset, structure and patterns, shape and tailored fit, etc., are just a few examples of those unstable disciplinary boundaries.

It seems paradoxical to argue that the strength of a project arises out of instabilities or incongruences. The late architectural critic Robin Evans reminds us, however, that "from the point of view of the architect seeking firmness and stability, the best geometry is surely a dead geometry"[17] as its elements "have been pretty well exhausted as subjects of geometrical enquiry."[18] Thus, the discourse of geometric representation requires, for Evans, some form of projection. In our canopy, it is in the passages between profile to surface or volume, or motif to relief where geometry has been activated, and where an alternative notion of envelope begins to unfold.

Projective representation is thus crucial to this discussion. It is particularly so at a time when a wide array of computational design practices seem to have rushed towards performance based optimization, unequivocally locking geometry from its inception. Take as an alternative example our canopy project: there is a tension between the measured side of the structure, with its marked sequence or rhythm, and the unquantifiable expanse of the membrane. We cannot completely see the internal structure in its full appearance, as some fragments are revealed while others recede into inscrutable depths. So in a sense what we see is part real part imagining of the form. In between we have to make a visual and conceptual leap of faith to interpret the spatial complexities of the whole. Throughout that process, whether you see a *hat* or a *boa constrictor digesting an elephant,* has more to do with driven aesthetic enquiry than with optical precision.

ENDNOTES

1. For a thorough explanation and theorization of undecidability in architecture, see Peter Eisenman, *Ten Canonical Buildings: 1950-2000*, ed. Ariane Lourie (New York: Rizzoli, 2008).

2. Jeffrey Kipnis, "Towards a New Architecture," in *AD: Folding in Architecture*, ed. Greg Lynn (London: Academy Press; Revised Edition, 2004) 59.

3. It is also called MacMahon's net after Percy Alexander MacMahon and his 1921 publication *New Mathematical Pastimes*. Alternatively, the British mathematician John Horton Conway refers to it as a '4-fold pentille'.

4. For an in-depth discussion on the issue of spatial and visual homogeneity/heterogeneity as it relates to parametricism, see my essay "Heterotopic Speciation [Theorizing an Alternative Parametric Syntax]" in *Proceedings of the 101st Annual ACSA Conference: New Constellations New Ecologies*, ed. Ila Berman and Edward Mitchell (2013) 443-52.

5. Aluminum was chosen as the structural material for the structure due to its high strength to weight ratio. The pictures shown of the current mock-up of the project, however, employ steel rather than aluminum due to the available manual craftsmanship involved at the time of its production.

6. Remo Pedreschi, "Form, Force and Structure", in *AD: Versatility and Vicissitude*, ed. Michael Hensel and Achim Menges (London: Wiley, 2008) 14.

7. Remo Pedreschi, "Form, Force and Structure," 13.

8. C. Willett Cunnington and Phillis Cunnington, *The History of Underclothes*, Dover Fashion and Costumes Series (New York: Dover Publications, 1992).

9. Dorothy Kosinski, ed. *Henry Moore: Sculpting the 20th Century*, ed (New Haven and London: Dallas Museum of Art/Yale University Press, 2001) 43-54.

10. Dorothy Kosinski, ed Henry Moore, 33-42.

11. Luigi Moretti, "Valori della Modanatura" in Spazio 6 (1951-2). Translated by Thomas Stevens as "The Values of Profiles," in *Oppositions 4: A Journal for Ideas and Criticism in Architecture*, eds. Peter Eisenmann, Kenneth Frampton, and Mario Gandelsonas (New York: The Institute For Architecture And Urban Studies, 1974) 109-39.

12. Eisenman explains that "Profile is the edge of a figure—in other words, how a surface in architecture meets space: the edge of a volume seen against the sky is a literal profile." Peter Eisenman, "Profiles of Text: Luigi Moretti, *Casa Il Girasole*, 1947-50" in *Ten Canonical Buildings*, 26-49.

13. Eisenman, "Profiles of Text," 26-49.

14. Eisenman, "Profiles of Text," 26-49.

15. The only exceptions to this are the boundary patches, which are directly zipped to the frame via pocket sleeves running along the edges.

16. At the moment of construction of the exhibited one-to-one scale mockup, only manual tube bending technology was available to us; thus the margin of error within the frame could have slightly increased the size of the framing and render the membrane patches tighter than they were originally planned to account for, thus demanding a larger force to tension them at the risk of tearing the fabric.

17. Robin Evans, *The Projective Cast: Architecture and its Three Geometries* (Cambridge and London: The MIT Press, 2000) xxvii.

18. Evans, *The Projective Cast*, xxvii.

PROJECT CREDITS

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Photos and Illustrations
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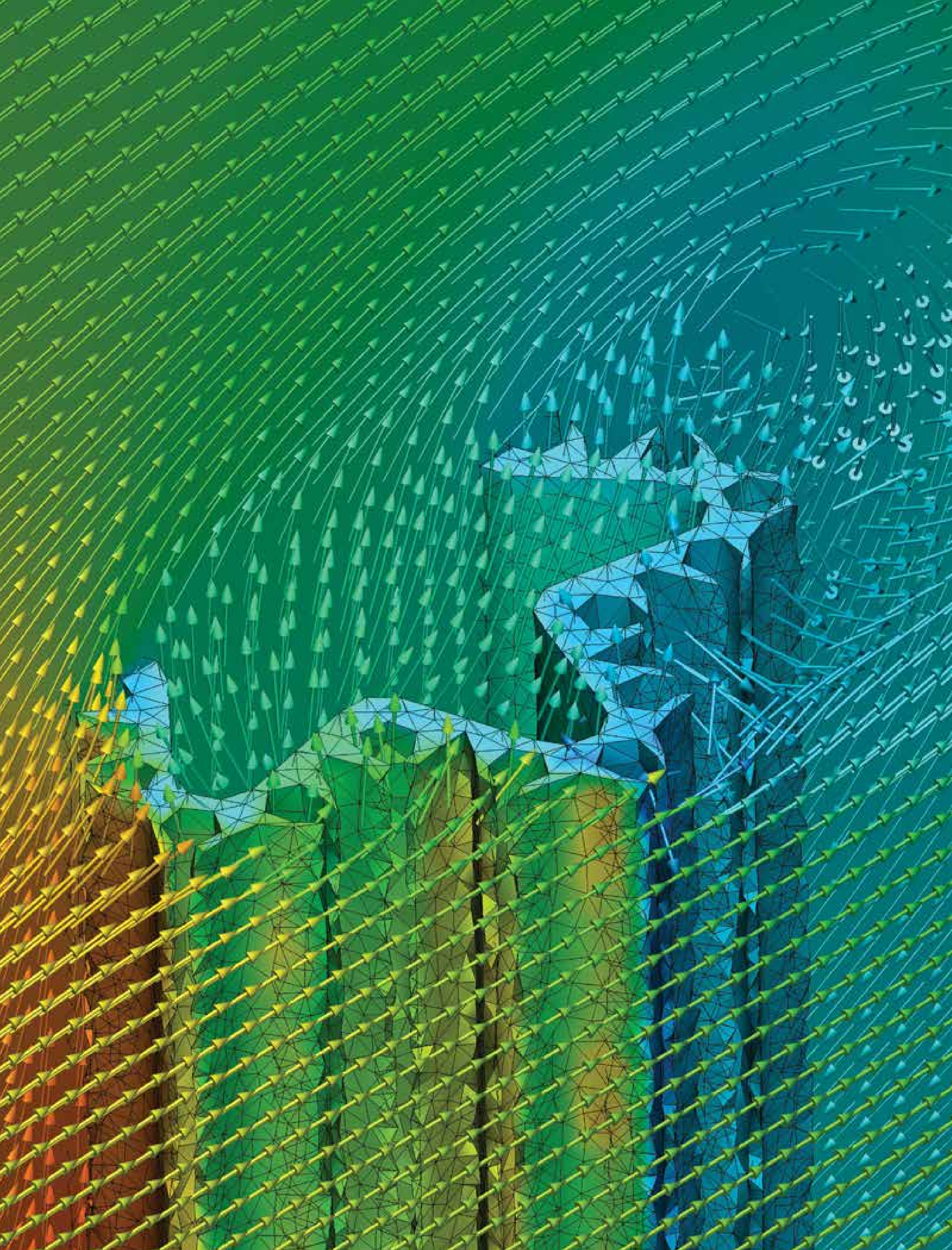

Thermal Form: Making Architecture Work

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WORK

Energy is a concept for equivalently relating many types of work to one another.[1] Alternately described as a *motion against an opposing force, or equivalent to the raising of a weight*,[2] this conceptual exchange of energy for work and vice-versa allows for a structural understanding and explanation of the various material machinations that occur between the *model* world and the physical world. Our obsession with conflating all types of work into the flattening signifier of *energy*, however, causes a variety of different systems, economies, and effects to essentially congeal into a single generic idea, simultaneously equivalent to everything, but expressive of nothing. Lacking basic material and spatial specificity, energy belies the rate at which something is done, *what* is being done, and how it is experienced, in contrast to 'work,' which is understood and monetized in radically different ways.

This anachronistic and pervasive mode of thinking has its roots in cybernetics and the perennial effects of post-war systems thinking[3], resulting in the translation of space and event into a persistent horizontal network of exchange, transfer, and transformation, allowing for the smooth flow of energy into multiple states, whether as a finite[4] resource, information, currency, or landscape. Systems-thinking numbs the qualitative sensory apparatus of the body, supplanting it with the metric of *comfort*, which becomes an indexical substitute for the body: a networked assemblage of stimuli and response quantitatively tracing the thermal states of air and water relative to metabolism and autonomic thermoregulation—sweating and shivering—of the human body.

Perhaps more problematic is the widespread adoption by the architectural profession of the relational concepts of energy and comfort as the primary guiding constraints that define building performance, effectively negating the difference between the varieties of thermal effect created by doing different types of work. Space is conditioned in a generic sense: heat is delivered; air is moved; and buildings are configured to accommodate infrastructure and optimized in the service of the demands posed by mechanical systems.

Though there are different types of work, the relative ambiguity of energy is only exacerbated by the established criteria for thermal comfort, emphasizing the absence of perceived thermal effect. Comfort is exclusive of pleasure, as it has historically been about managing

Figure 1: This composite view, generated in a CFD simulation, illustrates how the precise calibration of form can improve building performance. In this example, the exterior surface of an exhaust stack has been modified to redistribute air-pressure. The resulting change in air-velocity and direction eliminates the need for fan assistance in preventing back-flow.

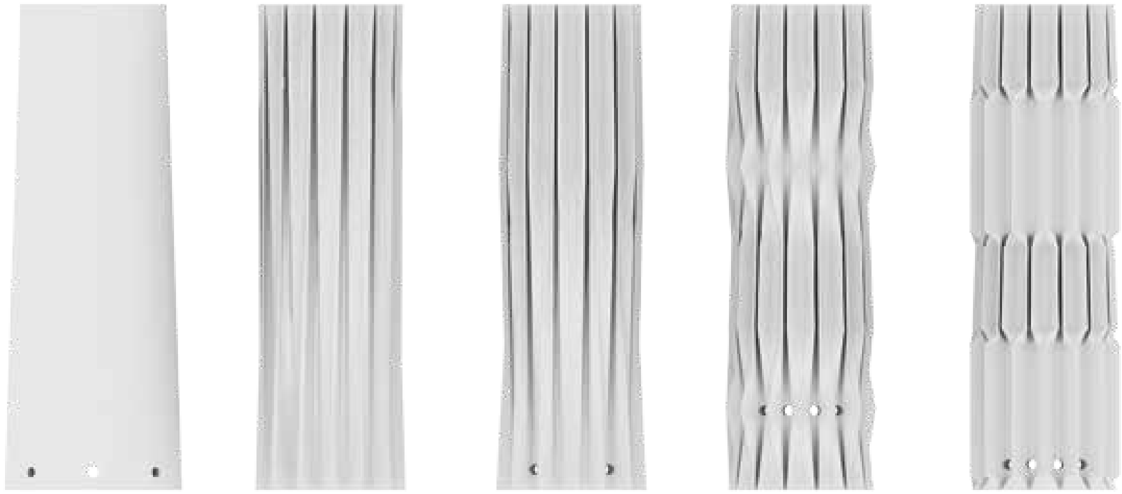


Figure 2 (left to right): Different surface fluting and profile configurations that investigate the ratio of surface area to cross-sectional volume and its impact on formation of vortices.

discomfort with an eye toward *maximizing the productive potential of the human body in a space*[5]. Energy savings, the *observance of limitedness in an economy of means within an industrial framework*[6], becomes the driving design motive, and comfort is reduced to serving as a referential metric which compares the cost of maintaining a space for human habitation relative to losses incurred in terms of human productivity if *comfort* is not maintained. Performance then is a comparative term, juxtaposing the cost of providing an atmosphere with the quantity and value of work performed by the occupant in that atmosphere[7]. A vague signifier that monetizes work, and a thermal criteria emphasizing absence, energy provides very few means of control and design agency for a discipline that specializes in the production of material configurations, spatial effects, habitation, and amusement. Through a perverse inversion, architecture has become the infrastructure for the infrastructure.

THE CAVE IS THE CAMPFIRE

Often cited when discussing issues related to architecture and climate, energy, sustainability and building mechanical systems, *The Architecture of the Well-Tempered Environment*, by Reyner Banham, established a historical narrative for the role of temperature in architecture, revealing the reciprocity between the organizational capacity of structure and its counterpart, the sustaining mechanical equipment. Central to this effort was classifying built and proposed precedents into categories. The Conservative, Selective, and Regenerative Modes are the terms Banham uses to approximately chart the evolution of thermal control strategies, ranging from pre-modern regional vernaculars to contemporary buildings, alternating between a linear developmental narrative—in which the conservative mode is inevitably supplanted by the manifest destiny of the regenerative mode—and a cyclical narrative, by which each of the three modes presents a potential opportunity for invention and development.

Building strategies with origins in Mediterranean vernaculars, emphasizing the configuration of structure and materials as the sole means for controlling interior thermal comfort, are classified as Conservative. The Selective mode refers to architectures that are modifications made to Conservative building types, required for situations in which the regional climate experiences large diurnal or seasonal shifts of temperature and humidity. These modifications are primarily material and structural, and would be described as passive in contemporary terms. They could also be dynamic—adjustable louvers, for example—allowing a building to adapt to changing conditions.

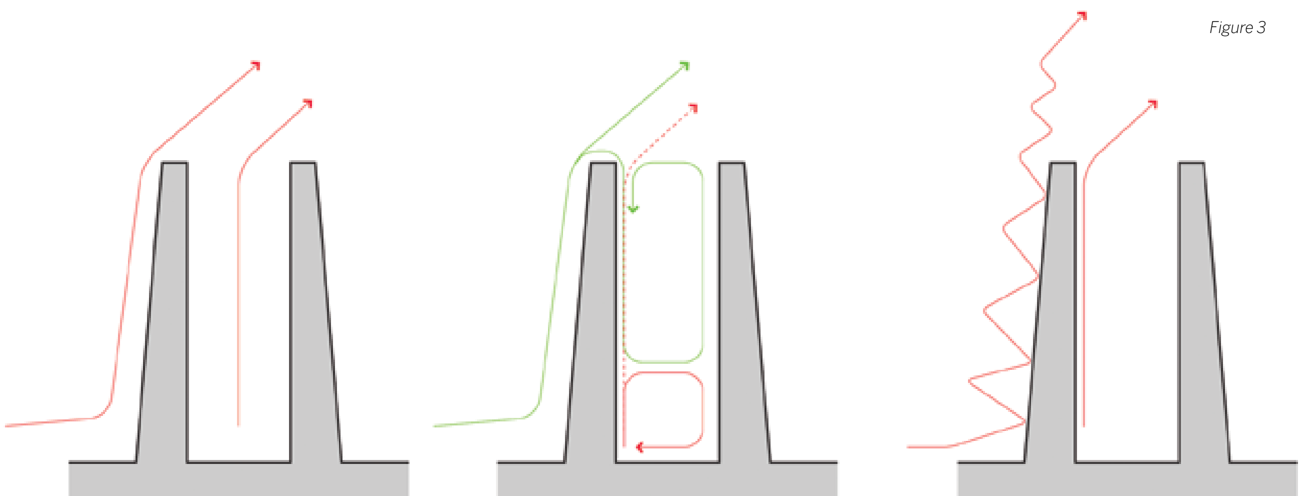
The Regenerative mode is defined by buildings that are tempered almost exclusively through the use of some form of combustion, challenging the historical dominance of structure and form as the primary strategy in managing internal climate. The Regenerative mode segregates structure from any relationship to temperature, other than as a passive scaffold, leading to a transformation of poche from a device that describes structural cross-section, surface profile, and thermal mass, to one that is characterized by its mimicking structural organization and use as a concealment strategy, dubbed: the new poche—the interstitial grey space of almost-habitable spaces comprised of: dropped ceilings; mechanical, electrical and utilities chases; plumbing; and more plumbing.

Active behind each of these categories is work. Though, while some form of work is done in the conservative and selective modes, it is the addition of heat to a system through combustion in the regenerative mode that *perceived* architectural agency—*moderni-*

ty—is achieved. Through the purposeful maintenance of an internal climate by the user, based on systems that separate form from power and structure from temperature—illustrated by the cave and campfire parable[8]—an unintentional bias is created against architectures that operate in the conservative/selective or traditionally passive modes. This is because stewardship of an internal climate and thermal effects provides a physical and conceptual connection between the occupant and the structure—it is a cultural sign of inhabitation and demonstration of the practice of ownership. Under these terms, *passive* structures—those building forms categorized as belonging to the conservative mode—are positioned as lesser in both their ability to provide comfort and their ability to satisfy the desire to inhabit. Additionally, the capacity of the *conservative* mode to do work in comparison to the regenerative mode is significantly diminished because conservative/selective structures maintain thermal comfort levels through the manipulation and mediation of external thermodynamic flows—their perceived level of performance is diminutive in comparison, less responsive, and less robust. This is an unnecessary bias stemming from the building and development boom in extreme climatic regions enabled by air-conditioning and rural electrification.

It is the inherent agency of the individual exhibited in the control over internal climate by the application of combustion, of work (as defined by Banham in the *regenerative* mode), that unwittingly forwards an image of architecture that is incapable of performing work without the support of mechanical systems, echoing the tyranny of aestheticized performance that Banham identified as one of the issues preceding, and ultimately leading to the failure of modernism in addressing climatic performance issues with any degree of expertise, relegating it instead to the domain of the heating and mechanical engineer. Architecture does not necessarily reach its technological apotheosis through the mechanization of energy. Instead, the application of information and energy to a form, transforming geometry in order to maximize its potential for engaging thermal flows, continuously surrounding and passing through it, representing a technological leap, and inverting Banham's three thermal categories. This means that the application of combustion and the production of heat is not necessarily a mechanical process but one that can be generated through the manipulation of form—the *application of radical intelligence and organized knowledge to the ancient craft of building*—though in a slightly different way than Banham may have envisioned. In this way, the structure and geometry of the cave *becomes* the campfire, moving beyond contemporary attempts at Building Integrated Energy Systems—the literal conflation of mechanical and structural systems—and instead entertains the possibility of a highly figured and intelligent surface that is unmoving only in structural terms, but highly dynamic and determined in its response to thermodynamic forces.

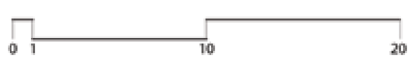
Figure 3



Exterior Air Velocity (X Vector and Z Vector at head) and Exhaust Velocity (Z Vector) are proportional to each other.

Exterior Air Velocity (sum of X-vector and Z-Vector) is greater than the Exhaust Air Velocity (Z Vector). Air pressure at the head drops due to cavitation, drawing air into the exhaust stack— i.e. Back Flow.

Air Vortex is generated by exterior surface, drawing air vertically past the line of the pressure head, preventing cavitation and back-flow.



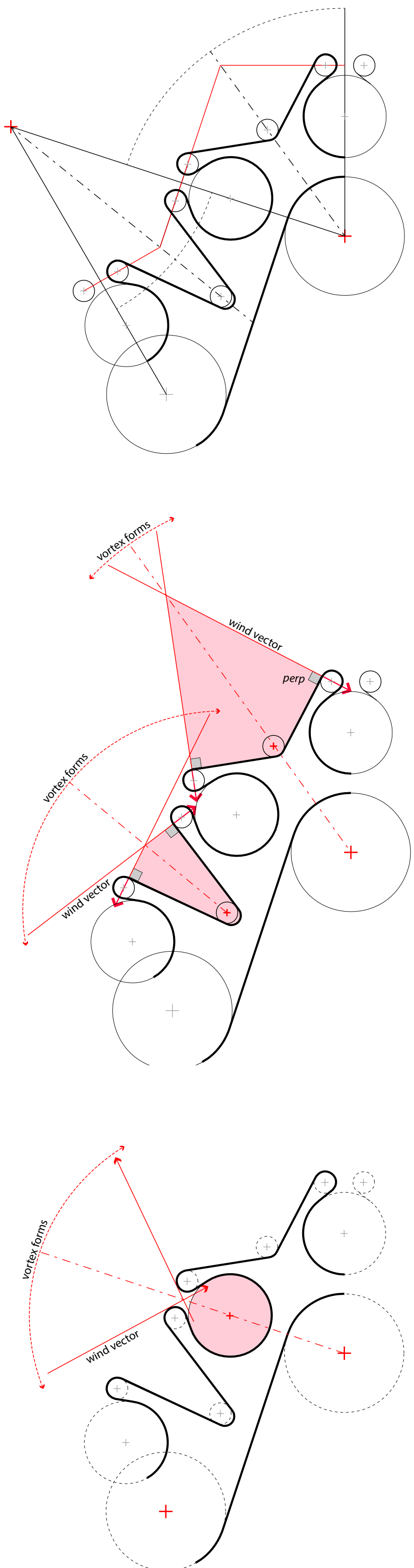


Figure 4

Interior surface curvature corresponds to external vertical surface channels. As radius varies the "length" across which air passes is reduced. This minimizes cavitation.

Angle between external air channels corresponds to vertical channels and interior curvature radius. The depth of these v-shaped grooves is based on negotiating between channel radii cross-section of the stack. A smaller cross-section increases the likelihood of cavitation; a larger cross-section results in turbulence at the pressure head, which negates the positive effects generated by the generated vortices.

THERMAL FORM

The thermal categories established by Reyner Banham are useful for identifying historical points at which structure is "liberated" from the task of being the *prime controller of the environment*[9] , as well as identifying the impact on design culture, which given the freedom to invest structure with a high degree of sculptural plasticity, exaggerated the disconnect between form and thermal performance, resulting in a situation in which form is inherently viewed as incapable of performing work equivalent to mechanical systems. This is a particular frame of logic that resonates with other disciplines as well. Until recently, it was believed that a sailboat could not move at a speed exceeding the velocity of the driving wind[10].

Thermal Form is architecture that does *work*. Or, it is the application of energy as information to architectural geometry, with the express purpose of using the resistance of structure against an opposing thermodynamic force, in order to manipulate and direct flows that exist in both the interior and along the exterior of a building. By examining the relationship between surface configuration, surface area, and type of energy transfer occurring, with a focus on the mechanism of transfer, thermal form strategies can be used to further optimize existing building typologies and environmental control system strategies, or to perform a more radical detouring of the atmosphere of a building.

It also represents a departure from the passive strategies typical of the *conservative mode* because the express goal is to replace high-performance mechanical systems with high-performance form, making architectural form and not the mechanical infrastructure do the *work*, enabling the conversion of the thermal flows attributable to any interior space to be harvested, transformed, and directed in ways that replicate or make unnecessary the various thermally regulating mechanisms used in contemporary building. This is a strategy that reduces the amount of power necessary to temper a building by reducing the amount and complexity of mechanical equipment needed to achieve the same level of interior comfort.

METHOD

If we are to set about constructing tools and methods for the discipline, emphasizing the polyvalent experiential qualities of work, in lieu of contemporary design protocols obsessed with energy and performance, a systematic investigation is required into the relationship between geometry and the various species of thermodynamic figure.[11] Thermal Form is a conjoining of disciplinary issues—representation and composition—juxtaposed with quantitative data analysis. A majority of previous analytical precedents exploring the relationship between geometry and environmental response have dealt with climate data analysis/visualization and the reciprocity between bioclimatic factors and the modification of building envelope—with the exception of projects that examine the adaptation of structure to environmental stresses.

Projects like the Vortex Generating Exhaust Stack[12] (fig. 1) follow a modified research trajectory, which has its roots in the late 19th-century efforts at developing performative systems for the maintenance of indoor air-quality. These systems employed a minimal external combustion source—the waste heat of the kitchen—in conjunction with the spatial and tectonic reorganization of the traditional building exhaust system: the flue[13].

The process for determining the primary developmental form began with a broad survey of existing thermodynamically performative geometries, with an emphasis on those that demonstrated a dynamic ability to direct energy across a specified distance—to perform the classical definition of work. There were several examples in which the surface geometry affected the behavior of thermodynamic flows through the transfer of heat energy. These processes were both fluid and based on the introduction of the specified geometry into an existing flow field at moments of greatest spatial or thermal difference. Two in particular were further investigated through morphological iteration, in which the geometric constraints were identified and manipulated to generate an index of a range of performative types. While the morphological index has come and gone as an aesthetic signifier of numerous contemporary projects, its utility in this case was in generating a constrained sample of forms, or panel, that would be used for Computational Fluid Dynamic simulations. In fixing certain variables, the effect of changes in geometry could be read in the progressive results.

Air Cavitation was chosen for development primarily because of the computing limitations associated with testing convection in relationship to humidity—processes associated with mass transfer. In both cases, classical compositional concepts, such as figure/ground and symmetry, often emerged as quantitative factors. Variations in stereotomic qualities—figuration and surface profile (fig. 2)—quickly became an ad hoc notational tool with which to visually inspect and speculate on the vortex generating potential of the numerous systems studied.

Through iterative parametric modeling and CFD testing, we arrived at a series of conical forms with fluted planometric profiles that generated high-pressure and low-velocity pockets of air in close proximity to the surface. As the velocity of the surrounding air is increased to a level at which back-flow would typically occur in a normative stack (of equivalent height, exhaust cross-sectional area and exhaust velocity) without surface figuration, the pockets of high-pressure air become entrained, forming vertical columns of rotating air—vortices—that prevent a negative velocity pressure to occur at the pressure head (fig. 3), and thus preventing back-flow. This geometry was further refined by examining the direction of the velocity vector relative to the surface normal (fig. 4).

The result is a passive exhaust stack of conservative height that operates under all conditions, from mild to extreme, without any significant change in the rate of building air exhaust. It eliminates the need for fans to mechanically assist in countering pressure changes at the head and in this way suggests an effective means of reducing the power use of buildings—by reducing the complexity or eliminating components of the environmental control system (fig.5).

CONCLUSION

The significance of this approach is that unlike existing contemporary precedents that use CFD visualization to reconfigure the relationship of interior spaces and programs under the rubric of "thermal cascades", Thermal Form directly targets the stuff behind the dropped ceiling—the architecturally latent grey area of mechanical poche space remains an untapped and unexplored zone of architectural invention. By changing our disciplinary definition of passive architecture, or, Banham's Conservative Mode, through the formal and experiential criteria of Work instead of Energy, we open the simultaneous possibility of continuing Banham's historical project and reinvesting the profession with a more comprehensive design agency.

Though the capacity for smart geometry to perform a mode of work is limited, this is due largely in part to the limitations of computation, or the constraints of making all potential thermodynamic criteria actionable in formal responses because of the absence of information. As consumer-grade CFD software becomes available—and increasingly powerful—the impact on modes of architectural representation will necessarily require a disciplinary adjustment of how architectural space is conceived, privileging a shift from a focus on energy and quantitative analysis of performance, to one emphasizing the thermodynamic figure, the capacity of architecture to due work through the manipulation of forms and realized as a new high-performance passive Architecture.

To speculate on the further application of Thermal Form, consider the impact on quality of life that the augmentation of form can achieve in areas in which either social, economic, or geographic conditions make the use of robust mechanical systems limited or impossible. In these regions, prefabricated and lightweight components could be easily deployed, or the formal configurations could be reproduced from locally available materials, delivering a level of performance in proportion to the amount of material and labor necessary exceeding that of traditional passive vernaculars.

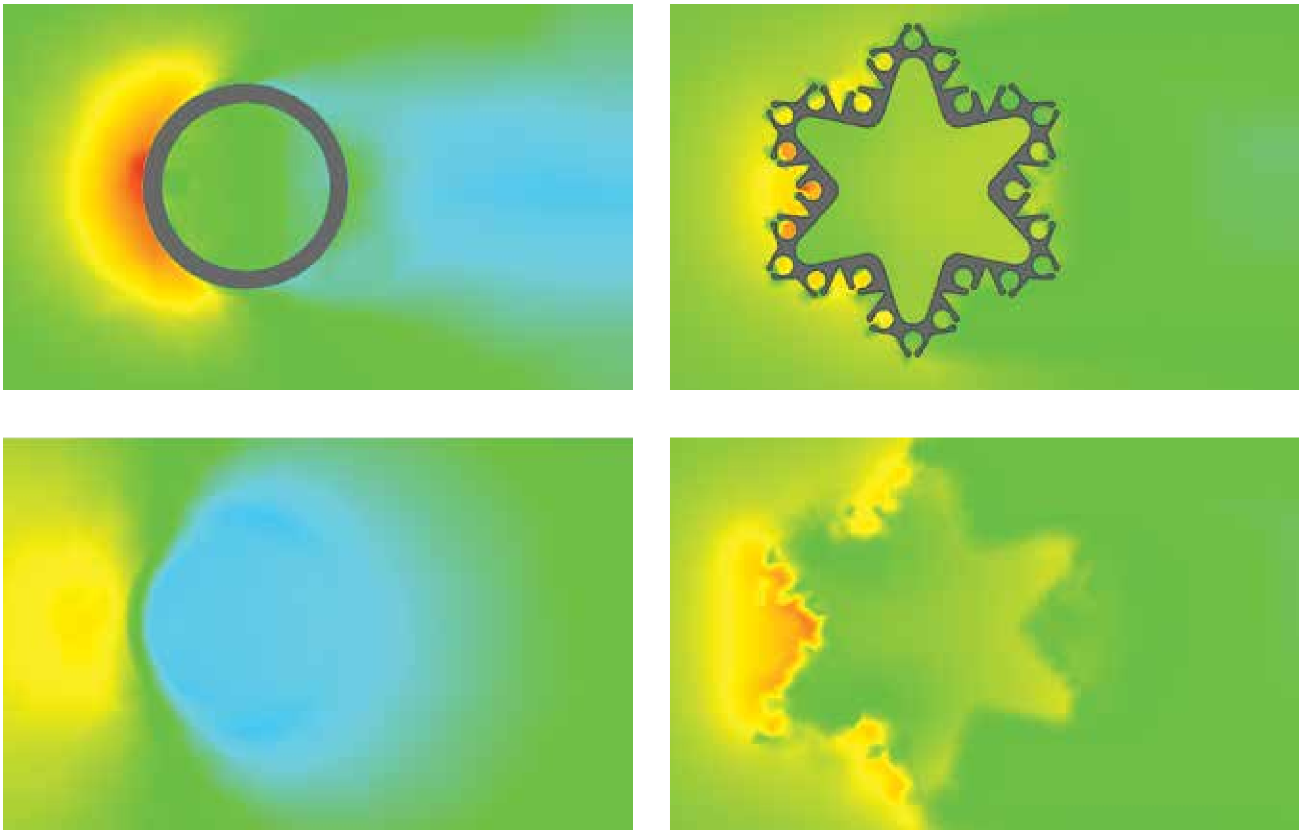


Figure 5: (Top left) As air comes into contact with the exhaust stack surface a high-pressure zone forms. In the images above we see that this high-pressure zone is relatively compact and localized. The distribution of air-pressure around the stack is as expected; air-pressure is highest on the windward side and an area of negative pressure forms on the leeward side (Bottom left) At a distance of 1 meter above the pressure-head/exhaust opening, the localized zone of high-pressure below, produces a negative-pressure as it passes over the stack, creating a back-flow condition. The use of fans and dampers is typically used to counter this effect. (Top right) In the proposed stack geometry, air-pressure is distributed across a larger cross-sectional area on the windward side and the negative-pressure zone on the leeward side is greatly reduced. (Bottom right) At a distance of 1 meter above the pressure head, we see that the high-pressure zone of distributed air across the cross-sectional area below has formed a high-pressure column of air above. This high-pressure zone forms a virtual barrier or wall of air around the pressure-head/exhaust opening and draws air out of the stack, thus preventing back-flow and reducing or eliminating the need for fan assistance.

ENDNOTES

1. Peter Atkins, "The First Law: The Conservation of Energy," in *The Laws of Thermodynamics* (Oxford: Oxford University Press, 2010) 16-17.

2. Atkins, *The Laws of Thermodynamics,* 17.

3. Reinhold Martin, "The Organizational Complex," in *The Organizational Complex: Architecture, Media, and Corporate Space* (Cambridge: MIT Press, 2005) 18-24.

4. Ivan Illich, *Energy and Equity (Ideas in Progress)* (London: Marion Boyers Publishers, 1974).For Illich, it is the monetization of the idea of energy that substantiates the rhetoric of an energy crisis. In the very real terms of thermodynamics, the availability of energy approaches infinity. Political and economic structures make energy scarce through transformation and control.

5. Le Corbusier, *Vers Une Architecture (Towards a New Architecture)* (London: Dover Publications, 1985).

6. Susannah Hagen, *Taking Shape: A New Contract Between Architecture and Nature* (Oxford: Architectural Press/Butterworth-Heineman, 2001). Hagen looks at the industrial transformation of labor and its correlation to the development of architectural systems that enabled energy-intensive forms of construction.

7. Michael Wang, "Into Thin Air: The Merging of Architecture and Environment," in *ART FORUM International* 49, no. 9 (2010).

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9. Banham, "The Environments of Large Buildings."

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11. Kiel Moe, "Thermodynamic Figures in Architecture," in *Thermally Active Surfaces in Architecture* (New York: Princeton Architectural Press, 2010) 120-24.

12. Patent Pending/January 31, 2014

13. Banham, "A Dark Satanic Century,"36-39. The "Doctor's" Houses, in particular the *Octagon* House by Dr. John Hayward, reconfigures the chimney flue to act as a passive stack ventilation system by running a vertical masonry partition through the flue and routing the return air adjacent to the kitchen, thereby decreasing the density of the air and increasing the pressure difference between inlet and pressure head.

COOPERATIVE FABRICATIONS

The SLO_Gen Table: Cultivating Industry/ Academic Partnerships

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IN COLLABORATION WITH

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Jim Doerfler, (formerly) Professor, Cal Poly, SLO
Kegan Flanderka, Cal Poly Architecture (2012)
Ben Hait, Cal Poly Architecture (2012)
Cory Walker, Cal Poly Architecture (2012)

The SLO_Gen Table is the physical outcome of a multi-threaded industry/academic partnership including Cal Poly Architecture, Gensler Los Angeles, Buro Happold Los Angeles, fabricator R.D. Wing Co., and material supplier LG Hausys. The table offers a dramatic and sensual introduction to the offices of Gensler LA amidst the visually and spatially stunning central atrium at the core of their new office (fig. 1). In addition to the physical outcome of the table itself, there are several less tangible outcomes in this one-year collaboration that cut across issues of curriculum, the role of digital fabrication and the academic design-build studio, and importantly, the collaborative enterprise at the core of this industry/ academic partnership. This paper unpacks the experience and design process developed from this ambitious project, while further articulating the opportunities and implications of these less tangible outcomes in the context of academic curricula.

Figure 1: The SLO_Gen Table.

The opportunity for this project developed after several years of successful academic co-ops with Cal Poly architecture students in Gensler's Los Angeles office. In these co-ops, students gain professional experience while also taking an academic studio led by practitioners, receiving academic credits in parallel with their professional internships. Shawn Gehle, Design Director for Gensler LA, had run several successful studios with Cal Poly students leveraging their energy and abilities toward urban research underway at Gensler[1]. During this time, Gensler LA was making plans for their new office in the core of downtown Los Angeles[2].

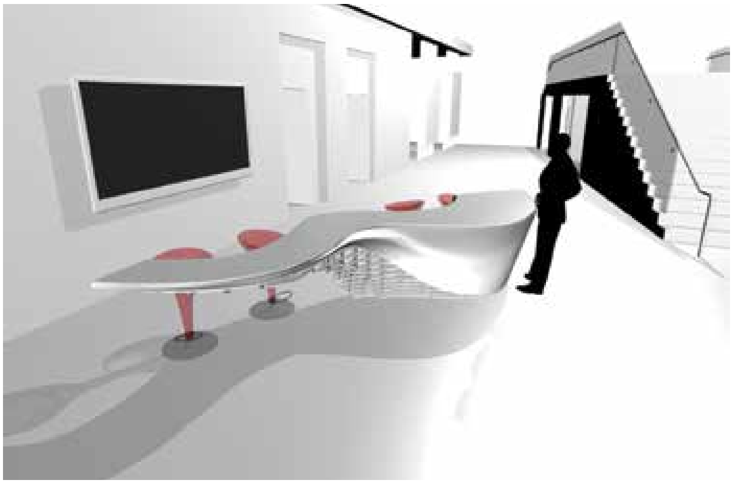


Figure 2: Student rendering at the end of June 2011. While key features of the final project are apparent, the geometry has yet to be tamed.

From Gehle's experience leading a professional co-op studio on urban issues, he saw the opportunity for a more hands-on material driven studio working with industry partners to fabricate a focal piece for the lobby of their new office.

With the office beginning construction, time was of the essence. However, professional project schedules rarely mesh with academic schedules. Fortunately, we[3] were able to assemble an ad-hoc crew of three students who had both the interest and the need for a Spring 2011 studio in their fourth year in our five-year Bachelor of Architecture program.[4] The intended schedule was for a Spring 2011 for-credit studio to develop schematic designs, with design development developing over the summer, and final fabrication in Fall 2011, in time for the projected office opening. In actuality, the SLO_Gen table took a full-year of dedicated effort from March 2011 to the installation in March 2012. As Gehle reflects in hindsight, this project was "something nobody knew what they were getting themselves into."

DESIGN PROCESS

Along with the considerable opportunity of this project came a very real aspect of risk for both Cal Poly faculty and Gensler alike. The opportunity for Cal Poly Architecture, and its Digital Fabrication Laboratory, or d[Fab]Lab, was significant, but with that came a unique pressure as a student-designed project. For Gensler the risk was particularly apparent, not simply in the monetary risk in funding the table, but in the potential of an empty lobby if the project were not to succeed. Gensler's optimism and positive student feedback in face-to-face as well as on-line reviews contributed a great deal to the success of this partnership[5]. With Gensler LA four hours apart from San Luis Obispo, we held frequent discussions and design reviews through GoToMeeting video conference calls. Although a technological detail, and now routine in global practice, this proved to be essential to this collaboration and paved the way for future industry academic partnerships.

The primary challenge at the beginning of the studio was the particular design brief was left flexible to test the students' potential. This included designing not only what became the table, but the reception desk as well as a casual sitting area. Each student's initial design proposals reflected his or her interests and abilities: one student was primarily interest in form-making; another student, who had the least digital skills, focused his energies on materiality; and the student with the most digital sophistication focused on techniques for variable components. Taken individually, each idea was out of control in its own way. However, as their different ideas were brought together, two different things happened. First, the brief began to take shape based on a common direction of what worked in the space, including its location and as a place to gather—anywhere from small one-on-one discussions to as many as 12 people. Second, the schematic design began to develop combinations of each of their interests combining form, material, and increasing precision and sophistication. Sparing much detail in the process, a rough, if crude, approximation of the final design did not surface until the end of June 2011 (fig. 2). While identifying some key features in the final table, the form was still out of control. After the students built a full-scale rough cardboard mock-up, they realized both how large and how much curvature they were introducing (fig. 3). This rough mock-up proved to be a significant project, if not pedagogical milestone, from which we had a quick but intense one-week design development phase to return with a refined design proposal (fig. 4).

Figure 3: Students complete a full-scale rough mock-up of the design in Figure 2. From this mock-up, they realized the size and curvature needed to be refined.

Figure 4: The refined final design after mock-up.

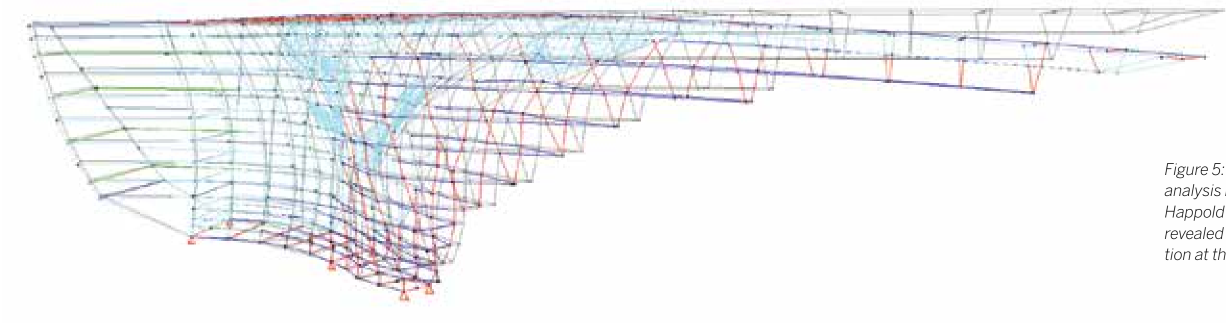


Figure 5: Egg-crate analysis by Buro Happold Los Angeles revealed 3" of deflection at the cantilever.

ENGINEERING

With this final design's considerable size at over 16' long with a 7' foot cantilever, Buro Happold Los Angeles was added to the mix of collaborative partners to provide engineering. The plywood egg-crate system was first analyzed independently from the HI-MACS shell, taking into account a range of joint fixity from fully fixed to introducing fabrication tolerances to set the rotation at each joint. This analysis resulted in 3" of deflection at the tip of the cantilever (fig. 5). While this was clearly not acceptable under any circumstance, it was compounded by the fact that any deflection from the egg-crate would transfer to the HI-MACS shell in which even minor deflection would result in cracking. To stiffen the cantilever, S-curved back-to-back angles running the length of the table with perimeter strapping beneath the surface were used to stiffen the egg-crate. The entire table, egg-crate system, support structure, and HI-MACS surface, was then analyzed as a composite system. As a composite system deflection was resolved, and stress analysis of the HI-MACS skin confirmed that any stress transferred to the skin was within panel specifications.

FABRICATION

Initial discussion began with a large architectural woodworking shop in Los Angeles, as we began to source local area thermo-forming fabricators for the HI-MACS surface. Ultimately, due to the demanding thermoforming required in this design, the HI-MACS material representative recommended R.D. Wing Co. in Seattle. With a background in fabrication for Aerospace in Fiber Reinforced Polymers (FRP), as well as being fully equipped with 3- and 5-axis CNC routers, it had both the experience and the tooling to execute the complex double curvature of the thermoformed shell. As a specialty fabricator with experience in architectural components as well, the company also had incentive in the project as a showpiece of its abilities. Due to the tight tolerances required between the egg-crate and the surface, R.D. Wing chose to fabricate both in-house (fig. 6).

The students' 3d Rhino model was the *only* design document transferred to R.D. Wing. We were able to provide an accurate estimate of the 12 sheets of plywood required for the egg-crate structure, but were not able to estimate the number of sheets required of composite panels as this was based on how the surface would be parted and molded. It is also here where the expertise of R.D. Wing was considerable. The s-shaped top panel was formed as a seamless flat top from four 30"x144" stock pieces—the only flat piece in the shell. The surface sides were panelized into five sections, with each section further subdivided into areas that would require a single slump mold, and areas of more intense curvature, such as the creases, that required a male and female mold to apply pressure from both sides to get the shape and detail desired (fig. 7). Molds were glued together in 4-6" stacks from large scraps of 15-20 lb polyurethane foam left over from other projects. A trim line was scribed into the molds at their parting lines. From 12 sheets of solid surface panels, individual pieces were formed and seamed to form the five sections (fig. 8). These sections were then bonded to the egg-crate with silicone to form one composite structure.

While the above describes the process of fabrica-

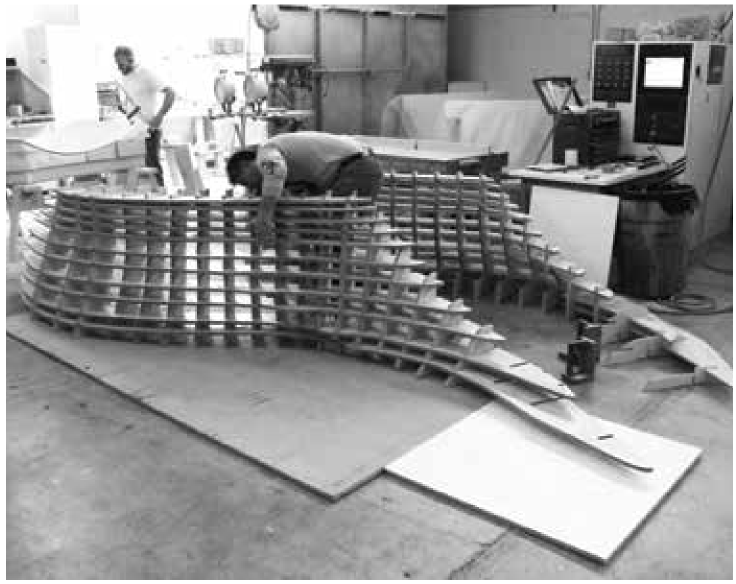


Figure 6: Two-part egg-crate under construction in the shop at R.D. Wing, Co. in Seattle.

Figure 7: Male and female mold required at areas of intense curvature, such as the creases.

Figure 8: Seaming of smaller sections to form a larger panel.

tion, the reality is this process required a great amount of precise hand trimming, providing support backing at corners with seam straps which required notching of the egg-crate structure to match, to say nothing of the hand polishing to provide a continuously smooth and seamless surface (fig. 9). As evidenced not only by the final product, but throughout the process of fabrication, R.D. Wing proved to be master craftsmen in working with FRP composite solid surfaces, which was as much digitally fabricated as it was hand-crafted (fig. 10).

FILE TO FABRICATION REFLECTIONS

Working closely with industry as a collaborative partner challenged some of the accepted academic approaches to digital fabrication and the academic design-build studio. This raises some questions about the role of the designer and the place of digital fabrication in this process. The term "file to factory" is more properly represented in this project as "model to factory". File to factory as a methodology incorporates cut files directly from the designer ready to be fabricated. This is what I had expected to deliver, at least in the case of the egg-crate, but in reality we exchanged no 2d files, no printed matter, just a single 3d Rhino file.

In multiple conversations with R.D. Wing, we agreed to simplify our model of the egg-crate with centerlines only to allow the fabricators to account for plywood thickness tolerances. This also meant that they were then responsible to model the egg-crate bridal joints, which proved to be a challenge for them working in MasterCAM. In consideration of the time constraints, I only learned after the fact that they hired an external consultant to develop the cut files. While this is something we could have developed through our parametric model, this is really a question of efficiency and cost, not a question of design. However, in making preliminary prototypes, the students understood that the egg-crate required a parting line to be able to assemble the pieces. While this was presented in the students' final design presentation, this information was not passed onto the fabricator nor was this parting line represented in the centerline digital model. As we were no longer involved during the fabrication process, nor did the consultant make this realization, the fabricators found out the hard way after cutting out each rib, requiring each individual piece to be cut by hand. While not onerous, but certainly tedious, this did affect craft albeit on largely hidden joints, but moreover points to a gap in the transfer of information.

While the egg-crate is the most conventional aspect of this project, and one that could be conveyed in the most conventional of information in the form of 2d cut files, the external surface had no underlying logic to be parted, apart from the flat top and two compound curved sides. Even the basic issue of how the seam would transition from flat at the top to the sides given the ¾" thickness was a complex issue due to the compound curvature, which was simplified on their end with a profile cut on their 5-axis router. Furthermore, although we worked closely with LG Hausys to find the maximum curvature radii for the HI-MACS surface, this information was for conventional single curved bends.

Consequently, we had no criteria to evaluate if the extreme curvature in the creases was possible beyond our initial design consultation with R.D. Wing and their confidence that they could indeed do it. While the egg-crate could have been conveyed in a file-to-factory approach, the experience with thermoforming solid surface material and the associated expertise in mold making was best left to the experts which includes how the complex curved surface would be parted, and thus the transfer of a 3d single surface model was most appropriate.

DESIGN-BUILD IN THE CONTEXT OF EXPERT FABRICATORS

Working with expert fabricators also challenged the expected level of fabrication in the academic design-build studio. While initially I expected this to be a much more hands-on project, in the end the absence of full-scale production helped to identify the critical moments that prototyping is significant. Rather than refined digitally fabricated prototypes, the rough cardboard full-scale prototype had the most significant impact on the students design development. In other words, rather than being a refined prototype, it helped them to refine the design. Similarly, the students constructed just enough of the egg-crate model to realize it could not be assembled, and through this, formed an alternate approach with a center parting line. Finally, a vacu-formed small-scale model of a section of the table was created for the final presentation, but like all presentation models, was used to sell the design more so than to refine the design. While in no way do I wish to down play the important pedagogical role of hands-on full-scale construction, it is revealing that the most significant prototype in the design development was not the refined one, but the quick and dirty full-scale cardboard prototype. Working with expert fabricators, rather than trying to be one, focused the expertise of the designer on understanding scale and proportion that requires a different degree of prototype with different purposes.

INDUSTRY/ACADEMIC PARTNERSHIPS AS R&D

The success of the SLO_Gen table goes beyond the table itself, opening up new applications and opportunities for Gensler LA and Cal Poly alike. As a focal point in Gensler's Los Angeles office, it sparks conversation and interest and has also become a site of further design innovation becoming the surface for a multi surface experience using the HI-MACS white surface as a touch interface for the display screen in the background[6]. From this demonstrated innovation of FRP thermo-forming, Gensler has further explored the application of thermo-formed FRP cladding systems. For Cal Poly, the publicity through numerous design blogs and industry case studies offers exposure to the program in non-academic venues.

Figure 9: Hand polishing of HI-MACS to buff out all seams into a single surface.

Figure 10: Final detail with egg-crate and compound curvature of the shell.

However, the primary intent is not that this is a one-off project, but points to a much more ambitious curricular development to continue to sustain and cultivate the relationships formed in this academic/industry partnership, which requires the continued cultivation of talent and opportunity. As academic teaching schedules are often planned a year in advance, and as industry opportunities rarely come with such advance notice, the ad-hoc collection of students and overload teaching that the SLO_Gen table required is not a sustainable long-term solution for such academic industry partnerships. The SLO_Gen table provides a visible example of the phenomenal outcomes of such partnerships, but a larger curricular structure to cultivate these relationships as well as student talent is needed.

CULTIVATING TALENT: THE MATERIAL INNOVATION LAB (MIL)

Parallel to the design development of the SLO_Gen table, I was in the process of developing a new multi-course curriculum in digital fabrication at Cal Poly, San Luis Obispo. All too often in any tool-based course, such as a seminar in digital fabrication, once the students develop their skills sufficiently enough to pursue more innovative applied research, the course is over. As Cal Poly is on a 10-week quarter schedule this is even more pronounced. And yet, this shorter course duration became an asset in developing two new courses, Arch 461_Computer Aided Fabrication which is the pre-requisite for Arch 471_the Material Innovation Lab (MiL). This two-course sequence follows established theories of cognitive behavior, particularly in regards to learning new tools and technologies. Learning a new tool or technology creates a focal awareness in which intentionality becomes about that tool[7]. Furthermore, when something goes wrong, or something "breaksdown," this only returns attention to the tool-at-hand. In other words, a transparency of use has not yet been achieved, placing emphasis on the technology. This can readily be seen in any technology seminar or studio in which the discussion is more about software than it is architecture. A broader, more sustained cognitive model would include this functional use of learning tools, but then connects this to a wider disciplinary network, to then allow focused investigation into architectural applications. While the first course introduces tools and techniques, the second course engages a wider network of industry partners enabling the Material Innovation Lab to operate as an innovative applied research lab.

Intermediate to advanced students interested in digital fabrication at Cal Poly are able to take Arch 461 exposing them to parametric design and digital fabrication through the lens of material constraints and opportunities[8]. As a prerequisite, this provides fertile ground for the Material Innovation Lab. It is important to note that these courses are intentionally not offered sequentially, but at minimum a quarter if not an entire year apart such that students initially exposed to new tools and techniques have time to develop their abilities through their design studios. Consequently, students come back to the Material Innovation Lab often with more experience than from the course alone. Furthermore, the Material Innovation Lab, in both name and course description, dispenses with any mention of the word "digital". As a self-selected cohort of students, we know that digital fabrication is part of the background of their experience, and consequently the course fully employs parametric design and digital fabrication but as tools at the periphery of the discussion enabling rapid fabrication of prototypes, molds etc, as a fully integrated digital / physical learning environment. This enables the Material Innovation Lab to operate as an applied and innovative research lab developing full-scale prototypes with industry partners. As a recurring course in our curriculum, it allows us to continue to cultivate talent, maintain professional contacts and form new ones, such that we can connect talent with opportunity as it arises.

This has enabled us to pursue new collaborations testing the limits of FRP Unitized façade systems with Gensler LA, Kreysler and Associates, and ENCLOS as well as receive significant funding from the Concrete Masonry Association of California and Nevada (CMACN) to design and develop new innovative CMU approaches through advances in mold-making afforded through digital fabrication.

Like the SLO_Gen process, if not inspired by it, the Material Innovation Lab offers a horizontal model of student and faculty engagement. The course is conceived as a "think-tank" in which all members of the class—faculty, students, and collaborators alike—are equally engaged in the development of a common problem, typically driven around a particular material. Ideas are neither individual nor proprietary (at least not so far), faculty are not necessarily the experts, and students are further "taught" through live feeds with industry collaborators sharing their experiences and ambitions.

ENDNOTES

1. Each studio culminated in a video that can be found here: http://vimeo.com/65184582 and here http://vimeo.com/52642730.

2. While contemporary practice has largely proven more agile to integrate digital tools out of necessity, in academia on five-year curricular cycles, integration has been much slower and a long time coming, and yet this new generation is in turn influencing practice. For example, the role of digital fabrication for the waterjet cut screens behind the table is a case in point. Developed in part with the help of Tam Tran, now a Gensler employee, but at the time, one of the fourth-year co-op students. As a second year architecture student, Tham crashed a one-day parametric seminar I taught on "Explicit History" (before it was named Grasshopper) and ran with it, creating digitaltoolbox.info with his second-year colleague Scott Leinweber. While I was only reminded of this when writing this essay, I have included this as an endnote to exemplify the shift from an ad-hoc to a more fixed and stable curricular approach that concludes this essay.

3. Former colleague Jim Doerfler, who coordinated the Cal Poly co-op students, as well as former co-director with me in our Digital Fabrication Laboratory (d[Fab] Lab), invited me to join the project.

4. With the majority of our students in our fourth-year curriculum off-campus, it was a stroke of luck that these three students were available and a great fit for the studio. Similarly to Endnote 1 above, this points to the need for a larger curricular framework to support such industry/academic partnerships.

5. In addition to Shawn Gehle's constant support throughout the project, the support of Gensler architects Sabu Song and Richard Hammond in supporting the students is greatly appreciated.

6. See http://vimeo.com/72684794

7. Terry Winograd and Fernando Flores, *Understanding Computers and Cognition: A New Foundation for Design* (Reading, MA: Addison-Wesley Professional, 1987).

8. Jeff Ponitz, Mark Cabrinha, Clare Olsen, and Carmen Trudell. "Project-Based and Procedural Pedagogy in Digital Fabrication," in NCBDS 29: *Actions: Making of Place – Proceedings of the 29th National Conference on the Beginning Design Student* (Philadelphia, PA: Temple University 2013).

IMAGE CREDITS

Figure 1: © Gensler Los Angeles

Figure 2: Student rendering by Cory Walker.

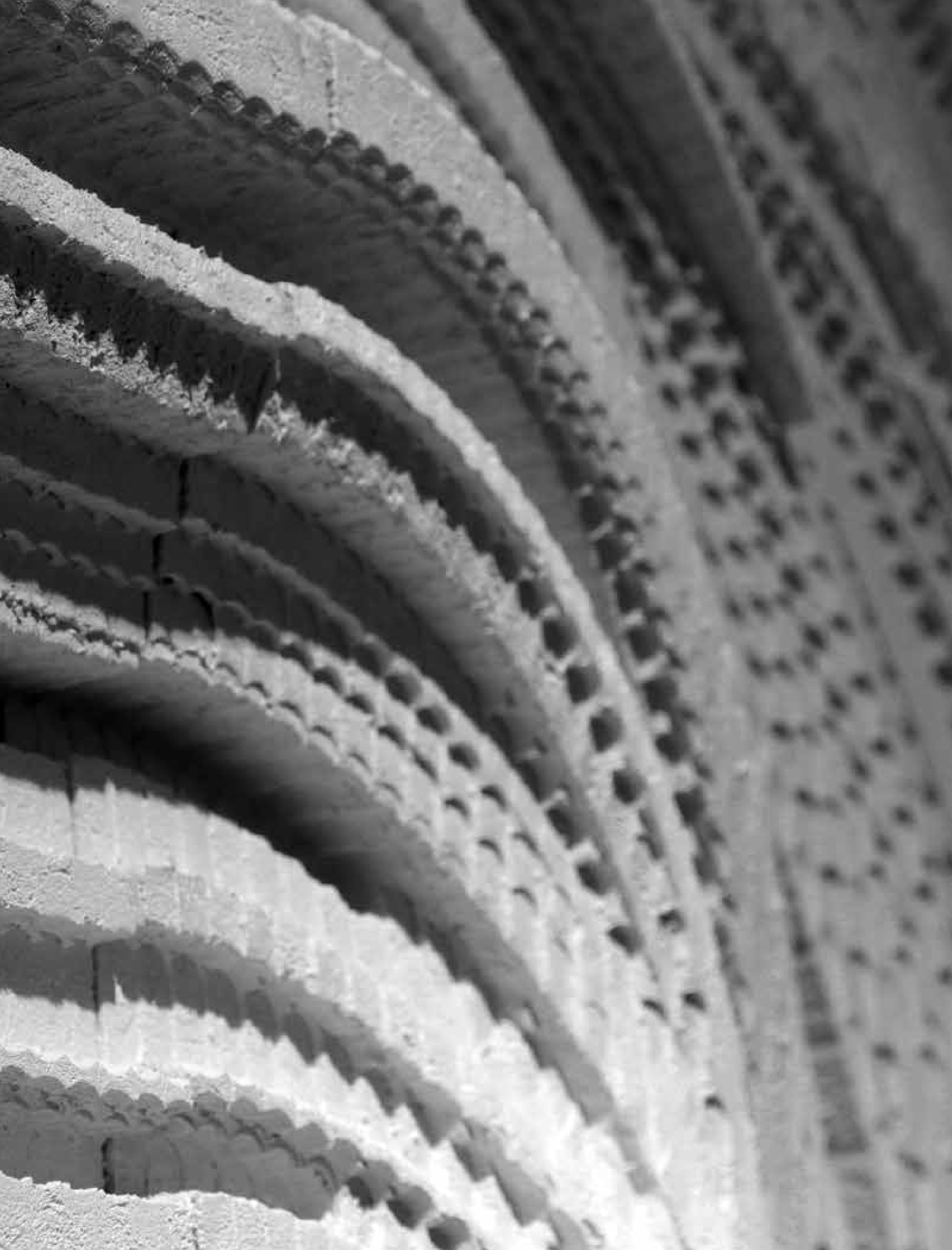
Figure 3: Photograph by Cory Walker.

Figure 4: Student rendering by Cory Walker.

Figure 5: Image courtesy of Buro Happold, Los Angeles.

Figures 6-9: Images courtesy of R.D. Wing Co., Inc.

Figure 10: © Gensler Los Angeles



Synthetic Manufacturing

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1. INTRODUCTION

This paper will discuss three scaled prototypes that utilized the idea of how repurposed waste materi-als are sourced within the field of architecture, and the developmental nature of the design utility based on the parameters of repurposing within the underlying theme of "synthetic manufacturing." The basic use of these prototypes ranges from 1) an architectural modular developed as an attempt to address the issue of construction waste produced by demolished project sites for unskilled workers within developing countries; 2) an art installation piece that addresses overstocked and over-ordered materials and EPS foam, originally used for insulation, by contractors for an existing institutional construction project in Houston, Texas; and 3) an academic design-research project that was further pursued as an art installation sculpture, made for the HKSZ (Hong Kong Shen Zhen) Biennale, which uses localized wood materials, pre-fabricated through CNC and tried-and-tested to be constructed offsite to limit the onsite production, delivery, and man-power.

Each of these projects investigates the range of developing processes of computational design-research and the parallel intentions of diversion within the construction, repurpose, and demolition processes inherent to the production of architectural design. All three case studies utilize and appro-priate construction waste and consider the repercussions of the construction waste within a novel form of fabrication and processing for the built environment. Incorporating the three Rs (reduce, reuse, and recycle) into construction, renovation, and demolition waste management creates a closed-loop manu-facturing and purchasing cycle. This significantly reduces the need to extract raw materials, reduces the amount of materials going to landfill sites, and reduces the life-cycle costs of buildings and build-ing materials.

2. BASIS OF DEVELOPMENT

According to the United States Environmental Protection Agency for Region 8, the qualifying basis of construction and demolition materials is as follows:

> *Construction and demolition (C&D) materials consist of the debris generated during the construc-tion, renovation, and demolition of buildings, roads, and bridges. C&D materials often contain bulky, heavy materials,*

such as concrete, wood, metals, glass, and salvaged building components. Reducing and recycling C&D materials conserves natural resources and landfill space, reduces the environmental impact of producing new materials, creates jobs, and can reduce overall build-ing project expenses through avoided purchase/disposal costs.

In recent years, numerous efforts have been underway to reduce the environmental impacts of con-struction and demolition projects. EPA Region 8 helps promote and facilitate the recycling and re-use of these materials by providing useful information and grants, tools, and resources.

Given the basis of the classification of what materials qualify as construction and demolition materi-als, the following projects were researched and developed according to the nature of the use and need. Most importantly, each prototype and design-research project dived into the computational aspects, in both high-tech and low-tech opportunities, and investigated the fundamental requirements, computa-tional rigour, and intrinsic opportunistic possibilities of computational tooling in both analogue and digital testing as a means of understanding the material opportunity provided as a CRD material, while looking upon the use of the material as a hybridized retainer for the larger development of the premise.

3. RESILIENT MODULAR SYSTEMS V.1

Resilient Modular System (RMS) is a continued collaborative academic project that is working to-ward a regional grant approval. RMS is a multidisciplinary research proposal to forge the synergy and efforts between three different colleges/departments within the University of Houston: the College of Architecture, Department of Industrial Engineering, and Department of Material Studies and Engi-neering. The topics and fields of research will include, but will not be limited to: Architecture/Design, Industrial Engineering and Prototyping (Digital/Analogue), Patents, and the Material Sciences. Within the larger understanding of the design-research, all conducted research will require a high level of computational science and bioengineering support. Each collaborator/faculty member is a key asset to the development of this project and is an expert within his or her respective field.

The division of research and development included the following: Professor Wendy W. Fok (Archi-tecture/Design/Prototyping), two graduate students assistants, Jose Aguilar and Megan Hartensteiner (Prototyping), Professor Ali Kamrani (Patent/Industrial Engineering/Modular design aspects for form and fit analysis), and Professor Ramanan Krishnamoorti (Material Sciences/Bio-related engi-neering). The developmental nature of RMS was to conduct design-research into a modular system that could be applied as an urban intervention within the context of temporary and permanent settings.

Using both eco-intelligent architectural design objectives, the knowledge and technique of manipulat-ing sustainable materials ultimately pursues a positive impact on the planet as a growth opportunity and engenders a focus on enhancing benefits (not only reducing costs) through its decision-making and actions—taking an approach of optimization rather than minimization. This project can under-stand the perspective of "people, planet and profit" as expansionist and enabling leadership through the achievement of advanced success metrics. For example, the concept of effective design of prod-ucts and services should move beyond typical measures of quality—cost, performance, and aes-

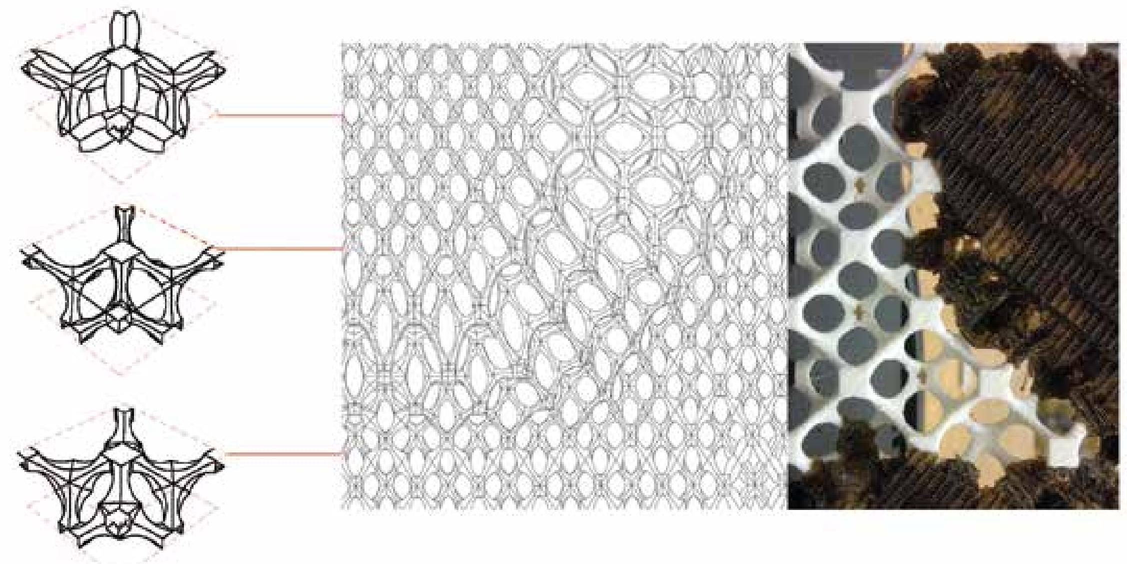

Figure 1: Scale, iteration, and tessellation of the RMS Modular

thet-ics—to integrate and apply additional objectives addressing the environment and social responsibility.

Through both digital and analogue (physical) prototyping in both architectural and design scales, and migrating the opportunity of a full-cycle cradle-to-cradle design process into a Design-Fabrication project—with real-world contextual testing and use of both repurposed construction waste and biode-gradable materials (specifically, biodegradable soy-based polyurethanes, ceramic fillers, and compo-site plastics)—RMS (temporal + structural) is to find a dualistic opportunity into sourcing ecological solutions of constructing temporary structures within the built environment in locations of need.

The idea of the RMS (temporal) is the ability of it to become an ecological and resilient modular con-struct for the built environment that could be subsequently dissolved, yet, in an effort of full-cycle de-sign, also contribute to nourishing the natural landscape.

The temporary proposal is that one of these structures could be possibly constructed as a retaining wall system similar to the ones that are seen along the side of the highway or a landslide retention wall. The composite within the mixture of this will consist of ceramic filler, broken-down glass, and biodegradable plastic as the main composite material. The process of this works as follows: 1) A landslide retaining wall is constructed with the RMS module; 2) due to exposure and UV-tested breakdown, the biodegradable plastic comes to the end-life; and 3) the plastic degrades and dissolves. Since the plastic is made with a mixture of ceramic filler, when the plastic dissolves, 4) the ceramic filler will be left, and since the ceramic filler itself retains moisture, 5) when the ceramic filler is de-posited into the soil, it will provide itself as a form of nourishment for plantation and development for agricultural growth.

The primary material research for the RMS (temporal) ephemeral structure will be based on agricul-tural or soy-based biodegradable polymers that have been in research since the late 90s and have been improved, bought out, and carried forward by some of the world's largest companies, like food and agricultural giant Cargill, who in 2008 spent over $22 million USD on developing a method to re-search and use polyols that can replace petroleum-based chemicals. The most effective method is to blend soy protein plastic with biodegradable polymer to form soy protein-based biodegradable plastic, and forming the material with the method of extrusion and injection-molding to form useable pieces of plastic. Therefore, using the same traditional methods of constructing plastics, the same design fab-ricated parts would be used for applying similar 'thermoforming' or 'vacuum'-forming techniques in-to constructing the prototypes.

While the secondary research for the RMS (structural) will be research for repurposing construction waste as a mixture for the remediation of the structural testing

Figure 2: Dualistic research approach of RMS

and joint detailing, the same modular structure will be utilized to further innovate on studying the structural form/fix/analysis of the RMS (structural) modular.

4. GEO-COGNITION

GEO-COGNITION is based on the geometric concepts of projective geometry (duality principal) and the convergence theory, and the fusion of the four main geographic locations that had the most signif-icant impact within the artist's career and life. The supervening confluences, which occur through transitional developments between the cities, are formalized by utilizing a form of projective geome-try and attach themselves within an underlying cognitive geometrics theory.

The confluences of the cities, through its linearity and dynamics, are representations of both duration-al and formal natures of the transitions. These factors are carefully developed and linked to the artist's respective influences and the relative time spent within the period of that city, resulting in the dynam-ic effects which transition between the axioms of the different skylines and planes. Formally speak-ing, the different skylines merge (converge) from one into another, creating a morphogenesis between the planes.

Projective Geometry is the branch of geometry dealing with the properties and invariants of geometric figures under projection. In older literature, projective geometry is sometimes called "higher geome-try," "geometry of position," or "descriptive geometry" (Cremona 1960, v-vi). The most amazing re-sult arising in projective geometry is the duality principle, which states that a duality exists between theorems such as Pascal's

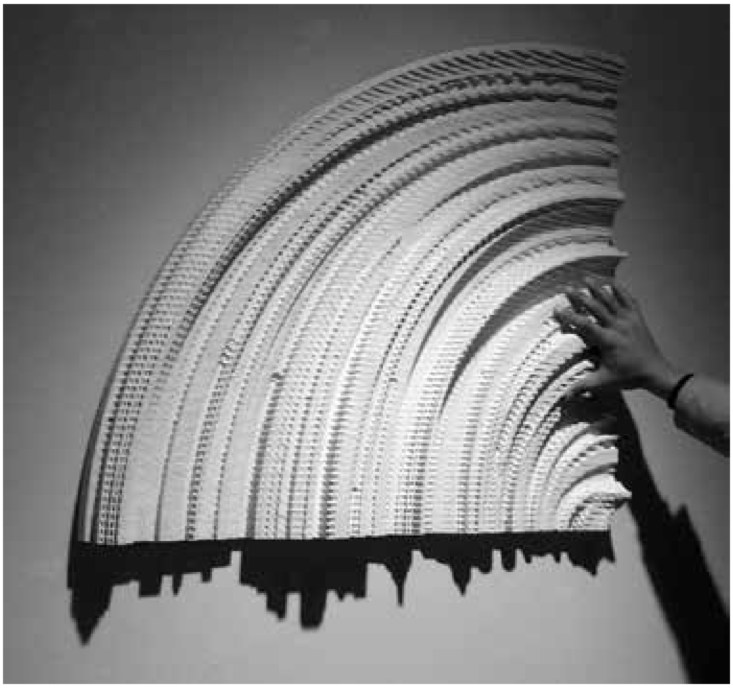

Figure 3: Singular modular example of the GEO-COGNITION installation
**Note: Shadows produce Cityscape*

theorem and Brianchon's theorem which allows one to be instantly trans-formed into the other. More generally, all the propositions in projective geometry occur in dual pairs, which have the property that, starting from either proposition of a pair, the other can be immediately inferred by interchanging the parts played by the words "point" and "line."

The material exploration of GEO-COGNITION was made possible by utilizing the by-product of an architectural construction site. Facts show that most U.S. construction sites and construction managers overstock on more than 30% of building materials for construction. Over 70 million tonnes (155 000 million pounds) of waste is produced in the construction industry each year. This amounts to 55 lbs. per week for every person, about four times the rate of household waste production.

The EPS DOW insulation foam used to CNC mill, produce, and fabricate GEO-COGNITION was made possible through donations from an actual construction site (a commercial building on the cam-pus of the University of Houston), whereby the site manager offered us the overstocked material.

Through reusing the overstocked insulation material, it provided us (the artist) complimentary materi-als for production, while also lessening the waste creation and dumping cost for the contractor. This type of cradle-to-cradle/grave approach to design allows an innovation of creation, and amalgamation between art and architecture. Different material explorations, including the use of HIPS and MDF, and several prototypes, were made before finalising on the EPS DOW insulation.

5. TETRA V2

Tetra V2 is an urban sculptural installation created for the HKSZ (Hong Kong Shen Zhen) Biennale 2012 that provided evidence of offsite production (four days of CNC and production work), and less than eight (five) hours of on-site installation, with the assistance of three workers.

The intention of the Tetra V2 computational process was developed through Rhino as an overall pro-cedure to expedite the installation process by devising an offsite pre-fabrication, manufactured, and construction system, using localised and repurposed MDF materials within the region of Hong Kong. The installation was developed as an academic project at the Chinese University of Hong Kong for a summer 2011 studio, which was subsequently furthered as an installation commission for the Hong Kong Shen Zhen Biennale. The larger intention of the piece was to understand the load bearing mate-rials of repurposed wood materials, and understanding the manufacturing process of the CNC for offsite assembly. The design of the efficiency for offsite transportability and onsite construction, therefore, became a key asset into the umbrella premise of designing the sculpture itself.

Given the minimal budget and constraints of the design itself, the continuous production of utilizing the CNC in an innovative flat-cut 2-axis process, rather than the typical 3-axis production, made this structure an assembly project rather than an innovation of the tooling itself. Each arm of the tetra-pod is composed of two pieces of 2-axis flat-cut MDF, whereby each tetra-pod itself is composed of six arms, and each pod is comprised of twelve pieces. The ability to construct a three-dimensional struc-ture is therefore played into both the computational tooling of the piece, and the innovation of the as-sembly.

The construction and demolition of the piece was, therefore, an innovation of repurposed materials; however, the hybridized approach of offsite assembly and onsite installation also expedited the de-installation of the structure. It also led to the ease of transportability of the piece, which later became part of the permanent collection of the BGCA Foundation in Sai Kung, Hong Kong.

6. PERFORMATIVE CRITERIA

The goal of these prototypes and design-research projects is to deliver a performative criteria and in-centive for continued effort into generating material appreciation, and a conscious approach to the continued discussion of generated waste production and management within the construction industry. While a large part of the debate is to better fulfil full-cycle design and cradle-to-cradle full loop de-velopment, in the case of the RMS, the larger discussion is to provide a model of research that allows the cradle-to-end result of construction waste being repurposed rather than disposed. All three in-stanc-

Figure 4: Onsite installation of the Tetra V2 at the HKSZ Biennale

es functionally outsource to the utilitarian approach to further the results of the architectural state of the material, and transpose the traditional expectations of the end-result of the produced product or design—by creating a viable and creative method to the end product.

The current environmental crisis and diminished natural resources have challenged the practice of ar-chitecture to rethink its outdated processes of design and construction. New processes that act as full regenerative cycle systems are replacing existing wasteful construction models. The scope of this work focuses on the understanding and development of minimal surfaces, specifically of those that are triply periodic (i.e., periodic in three directions) as an efficient modular building component fabri-cated out of high-content recycle/salvaged construction solid waste. Each building component will be designed utilizing computational generative strategies to find the most optimal performance. Rapid prototyping and digital fabrication methods will be utilized in order to find efficient and economical modular structure systems that perform at three levels: structurally, environmentally, and socio-economically.

7. CONCLUSION

The diversion of construction, renovation, and demolition (CRD) waste from landfill sites is an issue that has been gaining attention within both the public and private sectors. Surveys have indicated that as much as one third of the 20 million tonnes of solid waste from municipal waste streams is generat-ed by construction, renovation, and demolition activities. Many of our landfill sites are reaching ca-pacity. In addition, CRD waste is sometimes illegally dumped or burned, causing land, air and water pollution. The increasing costs of disposal are ultimately reflected in project costs, as contractors must incorporate anticipated disposal costs in their bid costing. Realities such as these emphasize the need for initiatives that focus on reducing and diverting as much waste as possible from CRD activities.

With the rise of computer-aided technology, the vast amount of rapid prototyping tools prompts de-signers to question how our visions of objectivity diverge into the tendency to push and understand the limits of different material properties to further the development of architectural design. The premise of this research proposal is to achieve speculative studies within a project framework, which will be presented through a quad-fold process of design-research, fabrication-construction, exhibition-publication, and international distribution (including patents).

Design—the larger function of the term inclusive of Research and Development of Applied Sciences, Engineering, Technology and Architecture—today could perhaps be described as the relational equa-tions mediated by digital techniques assisted with production and knowledge of fabrication. Like many fields in the modern culture, it strives to be truly integrated wherein the designer can move seamlessly from concept to production in a single, contained process.

The much larger discussion is less about how the demolition technique is developed, however; it is about the greater control of the material that is processed, where demolished materials are reused. Part of the problematic debate within the construction, renovation, and demolition argument originates from the structural integrity of reused materials, and the incentives provided by the localised govern-ments for the repurposing of the materials. Whether computational techniques are required as a means to further the research, computation should, however, be viewed as a means to test and further the po-tential for opportunistic developments, rather than purely as a means to digitize the technique of building.

According to the United States Environmental Protection Agency, a large part of the initiatives for re-purposing materials within the field of construction are dedicated to reduction and reuse. Rather than looking into the means of solely researching with the ongoing problems that end-materials produce, perhaps the larger research and development goal should be to look into potential re-establishment of the materials into cradle-to-end results, which produce a larger effect—whether cultural, social, or economical—on the societies, which architecture and construction place an importance on.

ENDNOTE

Reduction

Techniques for reducing the amount of material used in construction without any harmful consequences to the structure are still being developed. One of the best debris reduction techniques, Advanced Framing, can greatly reduce the amount of lumber used in wood framing for houses.

Reducing the amount of C&D materials disposed of in landfills or combustion facilities provides numerous benefits.

- Less waste can lead to fewer disposal facilities, potentially reducing associated environmental issues including me-thane gas emissions which contribute to global climate change.
- Reducing, reusing, and recycling C&D materials offsets the need to extract and consume virgin resources, which also reduces greenhouse gas emissions.
- Deconstruction and selective demolition methods divert large amounts of materials from disposal and provide business opportunities within the local community.
- Recovered materials can be donated to qualified 501(c)(3) charities, resulting in a tax benefit.

Source: United States Environmental Protection Agency

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IMAGE CREDITS

All photos and illustrations by Wendy W. Fok – WE-DESIGNS.

Fabricating Play

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INTRODUCTION

Experimental architecture during the 90s was transitioning out of and reacting to the previous phase of architectural experimentation, which displayed traits of fragmentation, as exemplified by the deconstructivists or perhaps the later phase of postmodernism in architecture aiming to communicate meaning or narrative through historical references and formal juxtapositions. The influence of the computer began to inspire a new type of formal exploration that sought smoothing, both formally and spatially in the immaterial world of cyberspace. With the rise of the implementation of digital tools in the process of architectural design, it became possible to accelerate and consider not only new modes of representation, but also new methods of fabrication and new formal typologies. Initial "paperless" architecture of the 1990s, such as the *Virtual House* by Peter Eisenman, de-emphasized the production of the material object as it explored the realm of the virtual.

The introduction of more complex animation software such as Alias Wavefront and Maya to the architectural design process allowed designers to move beyond traditional methods of formal composition utilizing static grids, intersecting masses and volumes, and folding of angular planes to the use and articulation of surface derived geometries. Greg Lynn's book *Animate Form* (1999) outlines theories in support of topological explorations of architectural form that is not considered

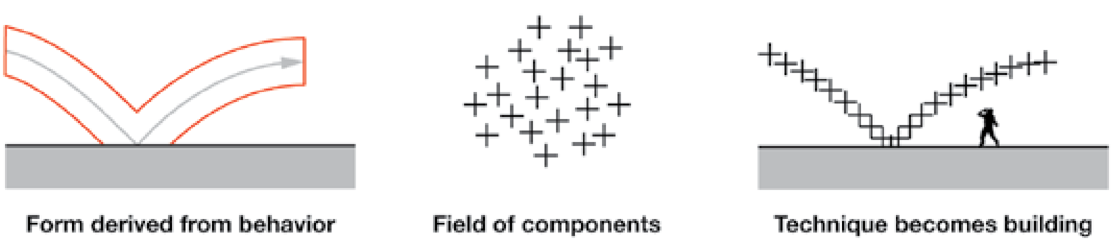

Figure 1: Form derived from behavior, fields, and techniques.

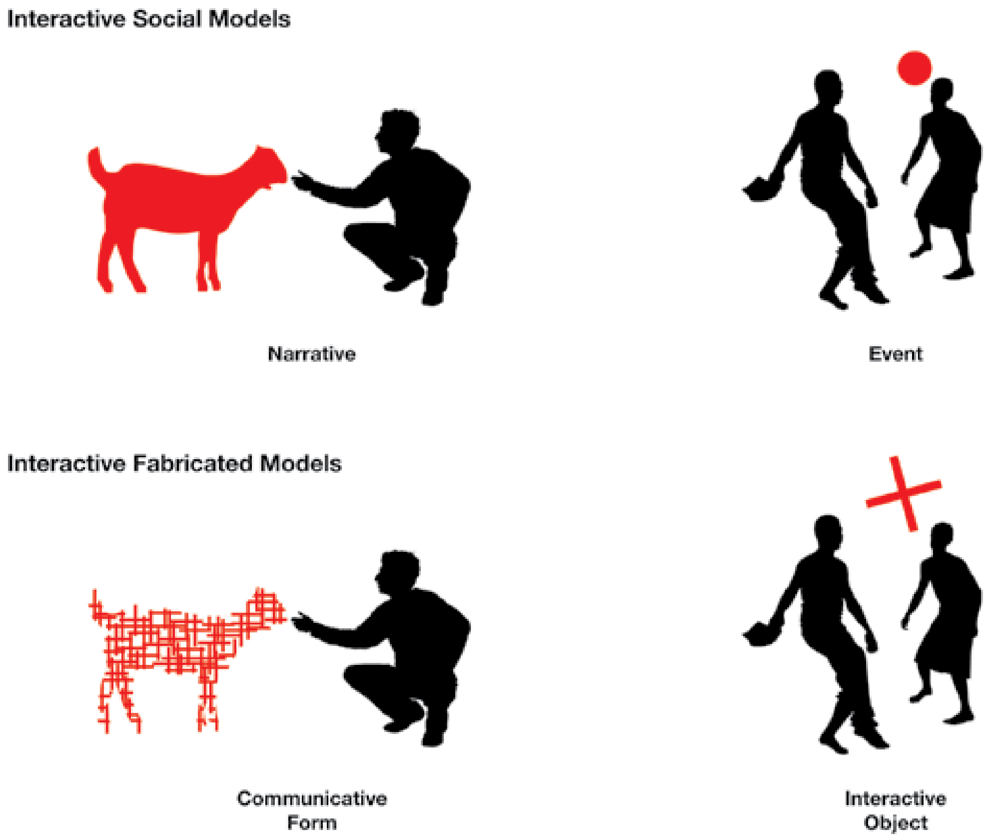

Figure 2: Communicative form and interactive fabrications.

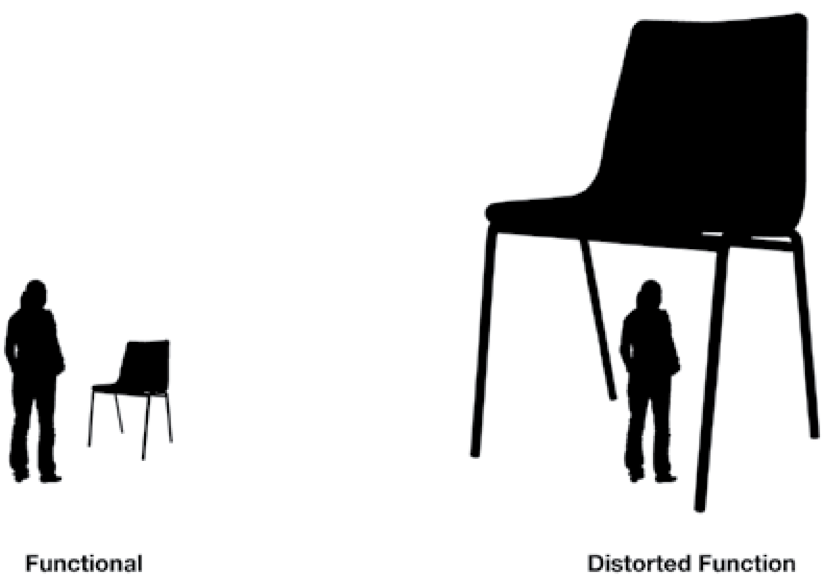

Figure 3: Distorted function.

static, but rather behavioral, in which the vectors or paths of "geometric particles that change their position and shape according to the influence of forces"[1] become the final project form.

Digital fabrication tools such as the CNC router, laser cutter, and 3D printer became more readily available; designers began to experiment with the production of mass component fabrications. Stan Allen's essay "*Field Conditions*" (1999) theorizes models for architecture described as "bottom-up phenomena, defined not by overarching geometrical schemas, but by intricate local connections. Interval, repetition, and seriality are key concepts. Form matters, but not so much the forms of things as the forms *between* things."[2] Moving through the first decade of the 21st century, the gap between digital design and physical production shrank, and many projects began to rely heavily on simple techniques to organize part-and-whole aggregations. These techniques in many cases became the signature of the resulting project, as demonstrated in Aranda and Lasch's Pamphlet *Architecture 27: Tooling* with project headings such as "*Spiraling, Packing, Weaving, Blending, Cracking, Flocking, and Tiling*."[3] These projects exemplify a synthesis of bringing together the years of implementation of the forms derived from behavior of calculus based forms and component distributions as described in Lynn and Allen's texts respectively (fig. 1). In the wake of the adaption of these tools to implementation in general architectural practice through utilization of commercialized Building Information Modeling (BIM) software, there still remains some ground to tread in terms of formal exploration based on the traits of digitally developed forms as our technologies evolve, but perhaps the infatuation with technique and the possibility of limitless formal results can be set aside in favor of new (or perhaps previous) conceptual models to drive the architectural projects such as narrative and event. With this in mind, there opens up a possibility to consider the use of the systematic processes of computation in design to be directed towards the development of the architectural object that not only considers the operations embedded in the development of form, but how the resulting objects may activate user participation through communicative form and interactive fabrications (fig. 2).

METHOD

Scaled models or renderings may represent these interactive models, but they would not allow real interaction. Furniture provides a useful size for testing limits of fabrication, material, and performance at full scale. While not building, furniture may act as a prototype to implement methodologies and employ thinking through systems at different scales. Just as a chair is not a building at a smaller scale, these constructs cannot be scaled directly to become architecture (fig. 3). However their attitude and relationships between space, structure, and material can be scaled directly. The two design-fabrication research projects I will present here explore these issues at this scale. Both projects investigate part to whole assemblies of mass-produced and mass customized units seeking economy in the simplicity of the unit and system of connection to produce variety, but ultimately seek to engage and alter behavior in public space. The first project is the *Massimals* series, an ongoing design investigation that began in 2010 with Akari Takebayashi within our collaborative research practice, Design Office Takebayashi Scroggin (DOTS). *Massimals* explores the fabrication systems packaged in the narrative construct of a petting zoo. The second project, *The Play Lounge*, is the result of an elective course I taught in Spring 2013 entitled *Tectonics, Typology, and Distribution* exploring these issues through research, discussion, and fabrication (fig. 4). The course begins with an analysis of a set of simple toys in order to extract concepts of "play" to use as a model to develop a series of big interactive furniture.

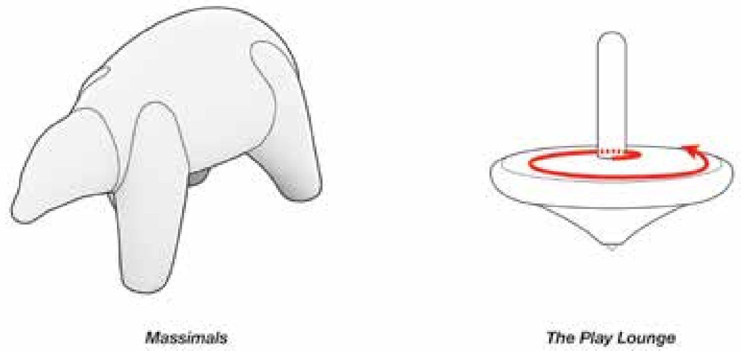

Figure 4: Massimals and The Play Lounge (Spinning Top drawn by Edward Madden)

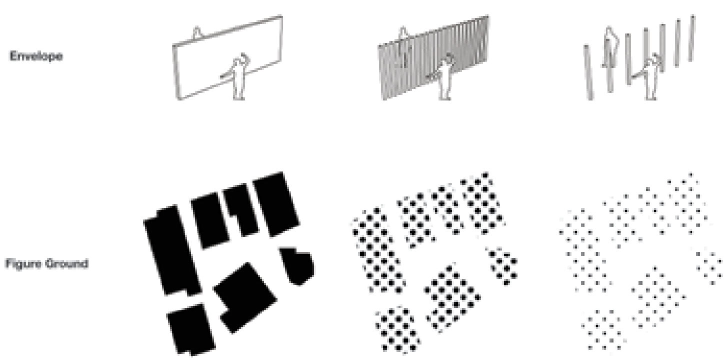

Figure 5: Dissolving surface and mass.

MASSIMALS

Building envelopes no longer constrained to traditional hierarchies of primary structure and infill have become dynamic fields able to express nuances of structural forces or content though gradations of porosity leading to the dissolution of the monolithic. What if we consider this model in relation to mass? Figure ground relationships could be broken down into spatial networks defined by series of masses or volumes distributed in close proximities (fig. 5). The *Massimals* project considers this by the arrangement of a series of lumbering polar bear forms (fig. 6). These fabrication prototypes are developed to consider the possibility of new relationships between assembly processes and the volumetric envelope to examine how physical form can engage the public realm.

These design objects are abstractions of animal forms built in the manner of massing studies produced in an architectural design practice. Like massing models, they are volumetric, devoid of details, and fabricated from one material such as chipboard, polystyrene foam, and foam core utilizing conventional assembly techniques such as contour models, egg-crate structures, pixilated massing, and folded plate (fig. 7). The suggestive forms and their specific arrangement imply docile behavior similar to animals in a petting zoo augmenting the way visitors approach and engage built form.

Rather than porous field configurations developed from bottom up phenomena or amorphous forms derived from behavioral techniques or adaptive envelopes, *Massimals* are top down, determined forms defined by mass and overall shape. The material system gives each variation on the massing typology it its unique character (fig. 8). Resolution of the application of these material and assembly systems played an important role in determining the degree of abstraction of the shape. In most cases, material sheet thickness will decide this, but in the case of the tessellated model, we could be more selective. We chose the iteration situated just before it lost stability and began to look more like an aardvark.

The *Massimals* project seeks to expand the possibilities of built form and potentially how we interact with buildings. Though abstracted by the techniques of fabrication, the object's recognizable affinity towards the

Figure 6: Massimals, at Land of Tomorrow Gallery (LOT), Lexington, KY and figure-ground plan.

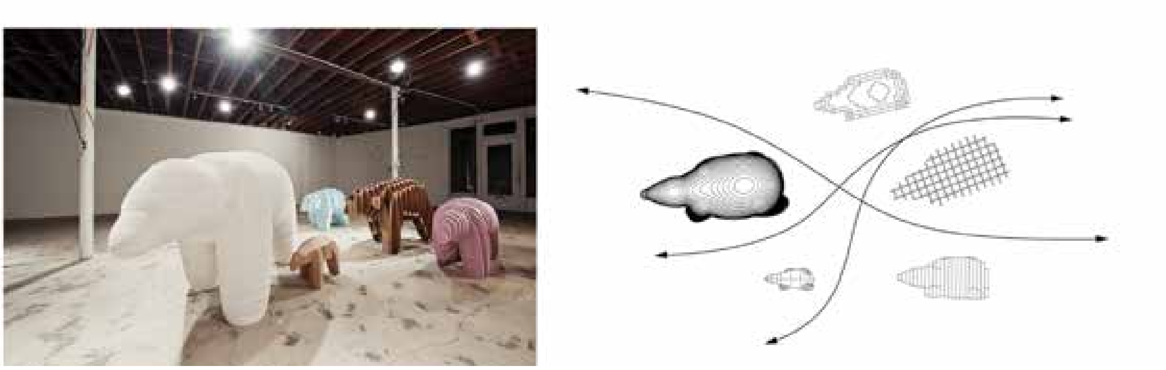

Figure 7: Assembly techniques.

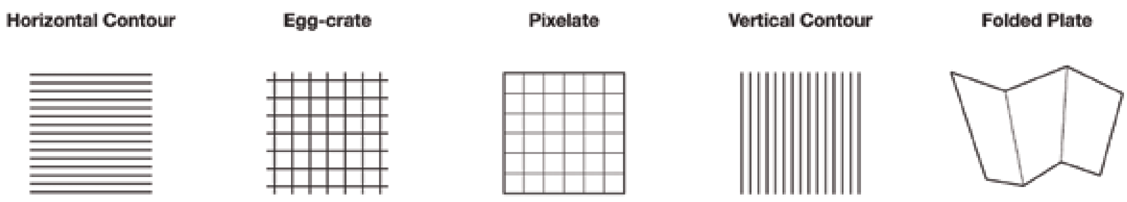

Figure 8: Massimals and material cut-sheets.

Figure 9: Massimals "petting zoo."

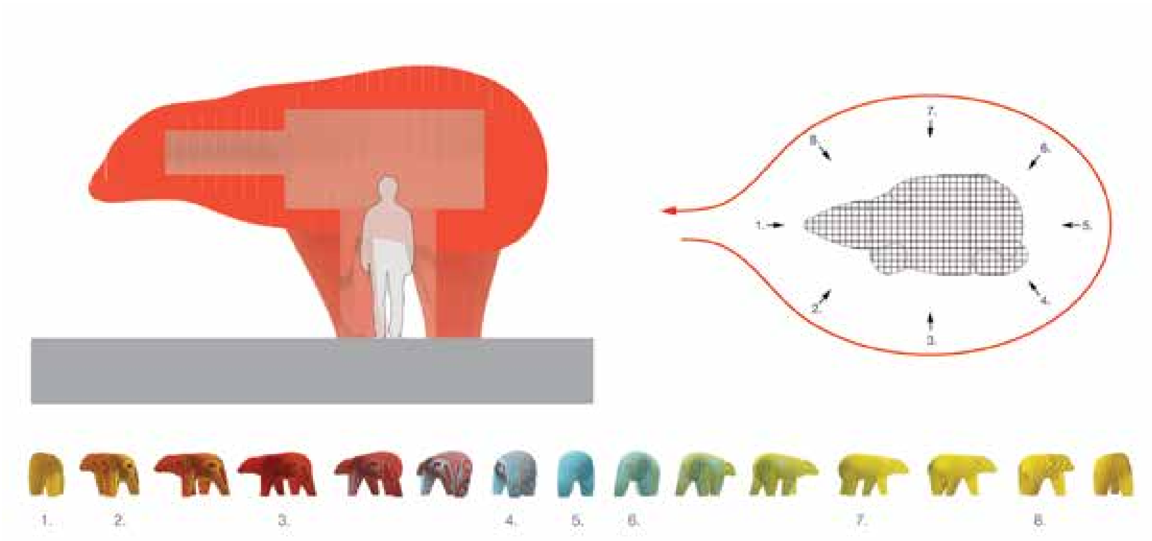

Figure 10: Rainbow Massimal, section and path with color transformation frames.

shape of polar bear and its arrangement in the narrative of a traveling herd or a petting zoo brought curiosity and playful interaction from the viewers. It is architectural design research, but not a model representation of something other than itself. Each Massimal expresses a familiar character in negotiation with material, construction, site specificity, and contextual parameters as an opportunity to drive design experimentation and while simultaneously engaging users within their proximity. While the recognizable forms within the herd prompted playful interaction and the arrangement of the volumes produced a passive mingling, we wondered how this could become more active and perhaps develop a kind of feedback loop (fig. 9).

RAINBOW MASSIMAL

When DOTS was later commissioned to add another Massimal to the series, we used the opportunity to make it large enough to inhabit its belly. This big Massimal was presented at the annual Beaux Arts Ball held in Lexington, Kentucky, in 2012. In the sprit of the ball, a costume party, we gave a larger version of the *Egg-crate Massimal*

Figure 11: Rainbow Massimal, elevations.

a "costume" by assigning each elevation a unique color. Due to the gradual transformation of the profiles of the egg-crate technique, a continuous and dynamic visual transformation emerges as you moved around the exterior; thus, we named it the *Rainbow Massimal* (figs. 10 and 11).

THE PLAY LOUNGE

The explorations and discoveries of the *Massimals* projects provided the foundation for my elective, *Tectonics, Typology, and Distribution*, which again considered the relationship between these systematic assemblies and user participation. The projects emerged through discussion and making over the course of fourteen weeks exploring issues of form, scale, material, seriality, and mass production.

As a research exercise we investigated a series of simple, non-electronic toys of no particular distinction, to understand what activities inspire interaction with the user. The *Rainbow Massimal* presented an example of how interactivity can scale up (fig. 12). It presents a simple relation between an object and user movement to present an effect. At a smaller scale, the zoetrope, a precursor to the motion picture projector, presents an animation as the object spins to present a succession of frames within its rotating cylinder. For the *Rainbow Massimal*, this relationship between object and viewer is inverted as we shifted the movement from the rotation of the object viewed to the viewer in order for the effect to work (fig. 13). In the course, we consider this how we could scale the interactivity of the toys to the size of big furniture pieces or BIG toys.

The interactivity of each toy was analyzed to foreground the activities they facilitated were charted. As with the *Massimal*, we selected one simple shape to move forward: the spinning top. The assembly method would also employ systematic processes of aggregation and connection of simple units. Off the shelf components were tested for potential interactions between soft and hard materials. The final material unit selections—rubber ball, foam noodle, and vinyl tubing—would dictate the organization of their deployment. The linear foam noodles were arrayed as profiles to produce a soft donut; rubber balls were aggregated into a cluster; and the vinyl tubing woven though a frame producing concentric rings became the elastic skin of a rocking and spinning top (fig. 14). Each of these off-the-shelf materials could be adjusted for comfort by tightening profiles and density of the noodles, deflating the balls from their initial rigidity, and gauging the tension on the tubing to allow relaxed seating (fig. 15). What was tested with one unit would be applied to all within that piece. Each toy had a simple, repetitive connection logic that allowed the final constructions to be manufactured fast and cheap (fig. 16).

Figure 12: Toy interaction chart by Derek Taylor.

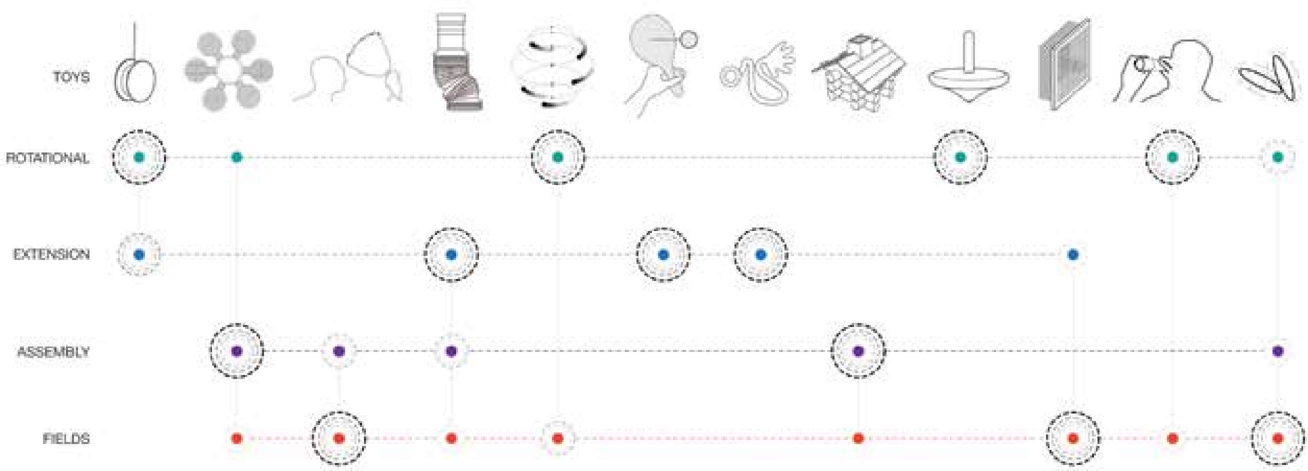

Figure 13: Zoetrope.

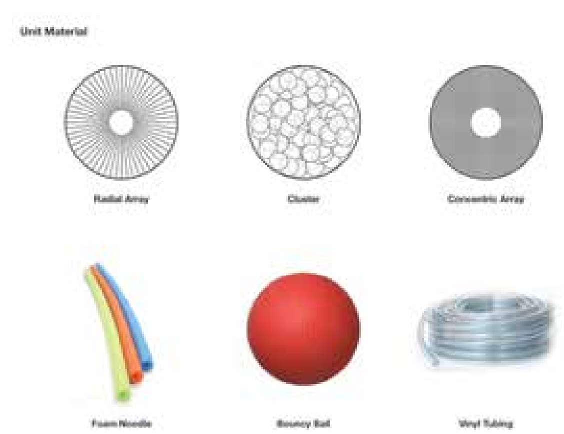

Figure 14: Unit aggregation and material.

Figure 15: Adjusting unit material.

Figure 16: The Play Lounge, assembly.

Figure 17: The Bubble Bunch, from above.

Figure 18: The Rocker

Figure 19: The Foam Donut at the 2013 Beaux Arts Ball (photographs by the author).

Figure 20: The Bubble Bunch, scale shift.

Each toy became activated by physical engagement and encouraged a variety of playful behaviors. *The Bubble Bunch* deviated from the formal typology through making its engagement in the form of a 3D puzzle that could become enclosure or a set of distributed elements (fig. 17). *The Rocker* necessitated at least two people for balance and could take up to 6 people to generate the rocking and rotating movement (fig. 18). Its mirror-clad exterior of *The Rocker* gave the effect of a disco ball when in motion. *The Foam Donut*'s durability is open to a variety of interpretations about how to interact with this massive soft shape (fig. 19).

POSSIBLE FUTURES

While these objects from *Fabricating Play* are currently residing in a state of furniture or furniture-like constructions, the interactivity they suggest could potentially translate to a larger scale (fig. 20). Could we have reconfigurable environments? Buildings? Cities? The contribution of the investigation suggests that we may consider place as not solely defined by built form, but rather by engagement with active bodies (fig. 21).

ENDNOTES

1. Greg Lynn, Animate Form (New York: Princeton Architectural Press, 1999) 103.

2. Stan Allen, Points + Lines: Diagrams and Projects for the City (New York: Princeton Architectural Press 1999) 92.

3. Benjamin Aranda and Chris Lasch, Tooling (New York: Princeton Architectural Press 2006

IMAGE CREDITS

Photographs by GLINTstudios unless otherwise noted.

Figure 21: The Bubble Bunch, at Lexington PARK(ing) Day (photographs by the author).

PROJECT CREDITS

Massimals

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The Play Lounge

Design and Fabrication Team: Ryan Bashore, Adam Eaton, Jeffrey Guiducci, Ye Jin, Jamie Lam, Edward Madden, Joseph O'Toole, Brian Richter, Kevin Setser, Eric Stephens, Derek Taylor, Cynthia Trefilek, Caroline Wahl, Breana Woodville
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Compete to Fabricate – TEX-FAB: A New Model For Computational Design Research

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INTRODUCTION

A brief survey of major public and civic works of architecture over the past 250 years will undoubtedly reveal the role of the international competition in shaping some of the most influential buildings in our cities around the world. From Charles Jean Louis Garnier's Paris Opera House in 1874 to Richard Rogers and Renzo Piano's Georges Pompidou National Center of Art and Culture in Paris nearly 100 years later, it is possible to see within one city how the competition has facilitated the evolution and discourse about public space and ornament. Or, in the case of the Chicago Tribune Competition in 1922, won by John Mead Howells and Raymond M. Hood, the collection of entries comprised a pivotal moment in the development of the skyscraper and also illustrated how a competition could serve as a vehicle for public education and discourse on architecture. It can also easily be said that some architects have started their practice on the basis of winning a significant international competition. From Rafael Viñoly's Tokyo International Forum to Bernard Tschumi Parc la Villette, their winning commissions led to international prominence and continued design opportunities. From the quintessential public space of Olmstead's Central Park in 1858 to the iconic presence of the Gateway Arch by Eero Saarinen in St. Louis, Missouri, in 1946, the competition has also provided other significant aspects of what defines our urban experience.[1]

Regardless of the typology, context, or scale, the design competition functions best when it facilitates innovation and excellence in design outcome. A competition has the potential to synthesize a zeitgeist out of which a community can generate a compelling and significant

Figure 1: Yokohama Port Terminal by Foreign Office Architects, winner of the international design competition.

dialogue. In the case of the Yokohama Port Terminal in 1994 (fig. 1), Alejandro Zaera-Polo summarizes this as *"...the opportunity to crystallise a type of investigation that I believe involved a whole generation of architects, and to test it with reality. The hybridisation of infrastructure, landscape and architecture, the integration of computer-aided design into the practice of architecture, and maybe the exploration of a global practice were tested through this project into a real building."*[2] While the words of Zaera-Polo strike an ambitious trajectory, the project as completed by the Foreign Office Architects team did establish a new benchmark for a generation of young architects seeking examples that personified the interplay between the digital, the infrastructural, and the urban landscape. It is the capacity for a competition to engender such moments that set up a powerful dialogue with not just the competitors, or eventually the built commission, but ultimately those seeking footholds in what will push the architectural discussion forward for generations to come.

Figure 2: Map of participant location for the REPEAT competition.

TEX-FAB BACKGROUND

TEX-FAB started as a nonprofit between professors Andrew Vrana at the University of Houston, Kevin Patrick McClellan at The University of Texas at San Antonio, and Brad Bell at The University of Texas at Arlington. The organization was initiated as a platform for the gathering and dissemination of information pertaining to computational design and fabrication. At the time of inception, in 2009, there was growing intelligence within the sectors of the AEC profession, academia, and the manufacturing industry, but very few mechanisms for facilitating a more robust dialogue between these groups. TEX-FAB intentionally stepped into this space and did so with the goal of interconnecting regional and global communities. To this end, TEX-FAB has established three primary modalities for creating a platform to facilitate dialogue between disparate sectors around issues of computational design and fabrication. The first of these tenets is *Theoria* (Lectures/Exhibitions), wherein the regional community is engaged with presentations of work. The second is *Poiesis* (Workshops), which, in a practical sense, centers on active learning and sharing of knowledge with hands-on activities. Finally, *Praxis* (Competitions/Commissions) opens up

Figure 3: "Minimal Complexity" final installation. College of Architecture, University of Houston, February 2011.

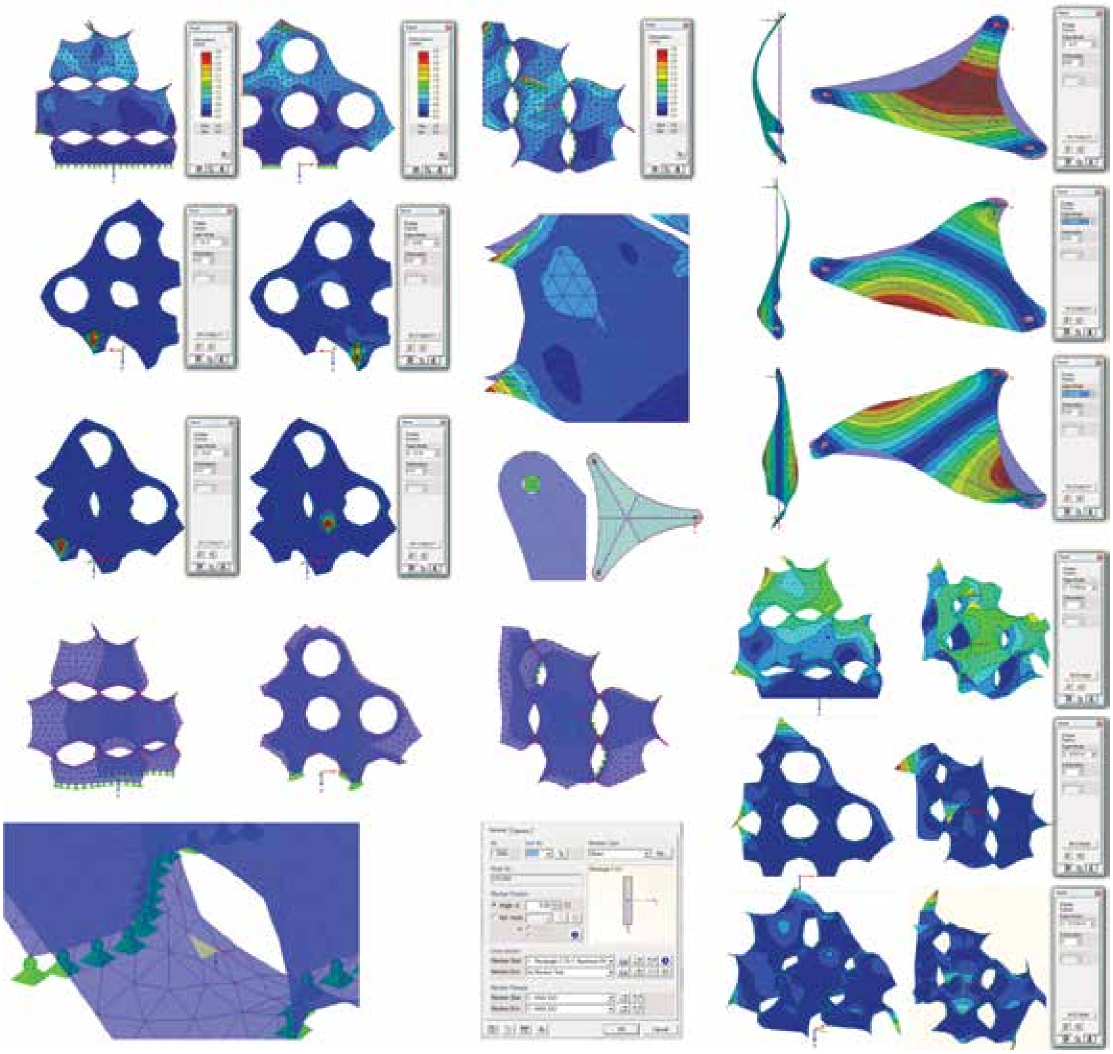


Figure 4: Structural analysis of Minimal Complexity, performed by Buro Happold of New York.

the discourse to a global network and allows TEX-FAB to apply itself as a catalyst for exploration. Each of the three areas has a particular scope and duration, thus integrating into the platform for dialogue in a very intentional manner. The organization has grown now to include The University of Texas at Austin (2013) and will add additional universities in 2014. With five conferences, three international competitions, and five exhibitions, the organization has grown to reach deeply into the context of the region while broadening a discourse with an international audience from around the world.

TEX-FAB: PRAXIS

"Ideas and things, the materialism that is so often invoked by the last and most hysterical of the theory avant-garde, should itself become part of a constantly transforming design in which design is never understood as a static object but is always a dynamic movement. This kind of design approach is perhaps best seen today in the emerging world of rapid-prototyping where the search for 'new' prototypes that solve specific problems has been replaced by prototypes which are focused on binding together teams that innovate." Michael Speaks[3]

For Speaks, the role of the prototype and its inherent connection to a more articulated research agenda looks to a new and repositioned role of the emerging practice that is not preoccupied with stylistic impulses or even moral ones. The prototype is a manifestation of a research process that, when linked with a more robust digital toolset capable of enhanced simulation, can create data points for feedback loops into an objective and rigorous design process. This is the mark of a new generation of practitioners who are not situated solely inside of academia, the profession, or manufacturing, but who are navigating across these boundaries and who are traversing this landscape in a manner that sees research not just as a vehicle for obtaining specificity within a design process, but ultimately as the way to achieve innovation.

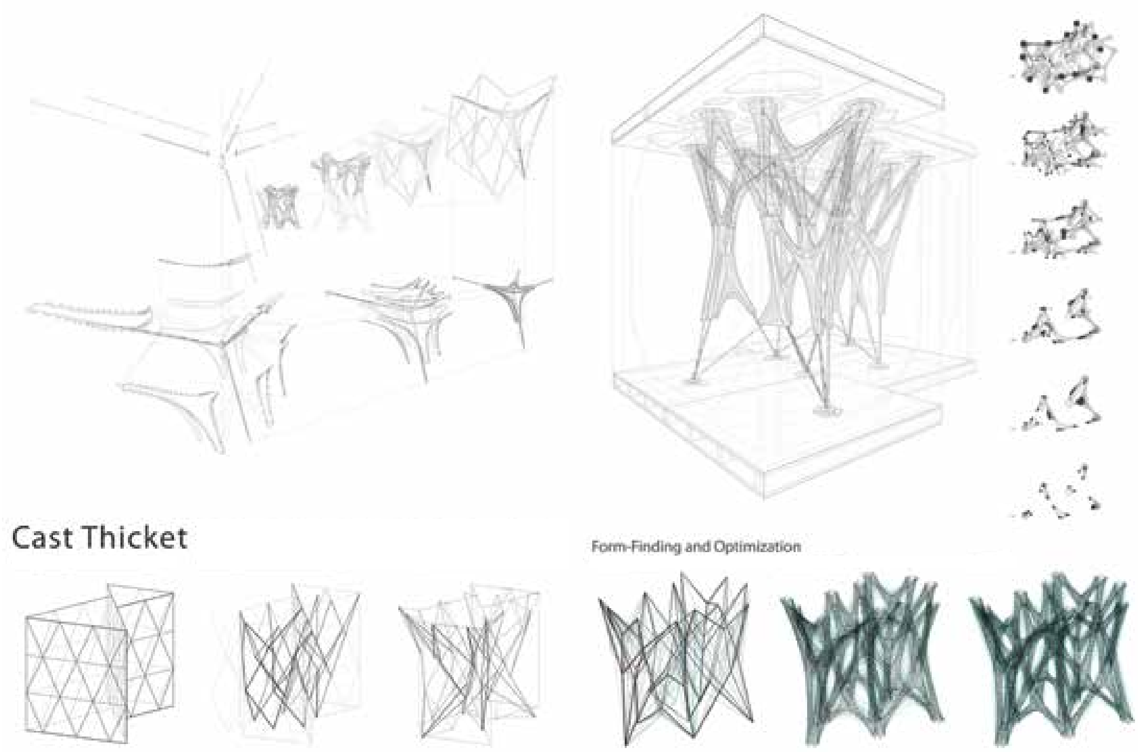


Figure 5: "Cast Thicket" boards for the APPLIED exhibition illustrat.

It is based on emergence of research-based design practices that TEX-FAB now recognizes that the regional and global networks can speak most conclusively. In response to this broader context, the third modality of Praxis has been developed as the most far-reaching and the most intimate. The competition, which, as conducted by TEX-FAB, results in a commission, is a platform for a very diverse set of designers to explore the potential of parametric modeling. Unique to the mission, however, is a desire to see the competition result in a built commission leveraging the resources and relationships of the professional offices and fabricators cultivated through the TEX-FAB network. So to this end, TEX-FAB sees the process of implementation coming out of the competition to be one that can leverage the network and utilize its inherent values to provide a robust support system for fabrication, installation, and construction. The past three competitions have drawn participation from around the world, (fig. 2) and the winners have all then gone on to demonstrate a unique capacity to sharpen their research and methodology through the platform of the commissioned work. This partnership of working with young designers to assist in furthering research trajectories and collaborate in bringing larger proposals into existence is one area that most clearly demonstrates the unique position of an organization like TEX-FAB. The commissioned pieces are the nexus of the various intersections of academic, industry, and profession; they are the extension of a theoretical research agenda; and, they are the physical testing ground for the integration of new working methodologies.

REPEAT

In June of 2010, the REPEAT competition launched, asking entrants to look first at the connection and then, through repetition, define the whole. By reevaluating the design process and looking at it from the connection, what might emerge? We encouraged the generation of cutting-edge design proposals for a structure, and the only caveats were that it be generated and conceived digitally, incorporate repetitive elements, be optimized for relocation and transportation, and be produced through fabrication technologies available in Houston, Texas. These four 'programmatic' parameters served to be very open-ended and broad, while another constraint was included to delimit the work: a budget. No more than $10,000 could be used in the competition proposal's production costs. The role of Houston as context was also significant and provided the perfect backdrop for the objective put forth by the competition. Within cities with atomized light manufacturing capabilities, such as Houston, there exists a potential for designers to engage fabrication via connection with so-called "job shops" that are open to small run projects and customization due to their association with the energy industry. Harnessing the network of fabricators already affiliated with TEX-FAB, we established the means and methods of production for the winning entry and ensured that production costs were not exceeded.

The jury, comprised of Patrik Schumacher, Marc Fornes, Lisa Iwamoto, Chris Lasch, and Blair Satterfield, selected Minimal Complexity for its aesthetic beauty, technical superiority, and elegance of detailing (fig. 3). It employed structural robustness, material efficiency, and an inherent logic of assembly embodying the principals of the competition brief to the highest degree. The competition was predicated on the ability to utilize resources for materials and fabrication partners in the greater Houston area. To that end, very early on in the process of developing the project for construction, Crow Corporations, which is a metal fabrication company located in Houston and a digital fabrication partner with TEX-FAB, was brought in to help resolve technical issues for laser cutting aluminum. Once TEX-FAB, Vlad, and Crow Corporation established that 14-gauge aluminum was the desired thickness for the several thousand pieces that needed to be cut, the next step was to check for structural soundness of the design, material properties, and connection detail. For this, Buro Happold in New York was enlisted to coordinate a detailed structural analysis. The Finite Element Analysis model was run on the geometry as both a shell and beam structure. The Global Shell Model, using iso-parametric finite shell elements, indicated to be very sound under the dead load of the piece overall (fig. 4). The final structure is composed of 148 basic quad sections of the Schwarz's P Surface, with each section being made out of 16 parts, resulting in 2,368 total pieces. The true strength of the design is found in the simplicity of repeating the same 16 parts throughout the entire surface. When each of the basic quad regions is set up for assembly, the double-curvature of the surface is introduced through the alignment of the 16 parts with fasteners.

Figure 6: "Cast Thicket" final installation. School of Architecture, The University of Texas at Arlington, February 2013.

TEX-FAB took control of the means and methods of final assembly by employing a series of templates, base plates, ballasts, shoring, scaffolds, and hoists to manage the vertical development of this self-organizing structure. The process of building the system up into 16-part quads led the planning and construction of larger subassemblies or sections of the structure that could be built on the ground and then positioned correctly and bolted in. The choice of 14 gauge laser cut aluminum with ¼" holes proved to be ideal for workability and joining with a variety of fasteners that served to align the parts progressively. A pattern of tightening and loosening the fasteners at adjacent components was learned by the assembly team in order to allow for hole alignment before final bolting was accomplished. The structure's progressive rigidity as the fasteners became fully engaged was further proof

Figure 7: "Cast Thicket" fabrication sequence.

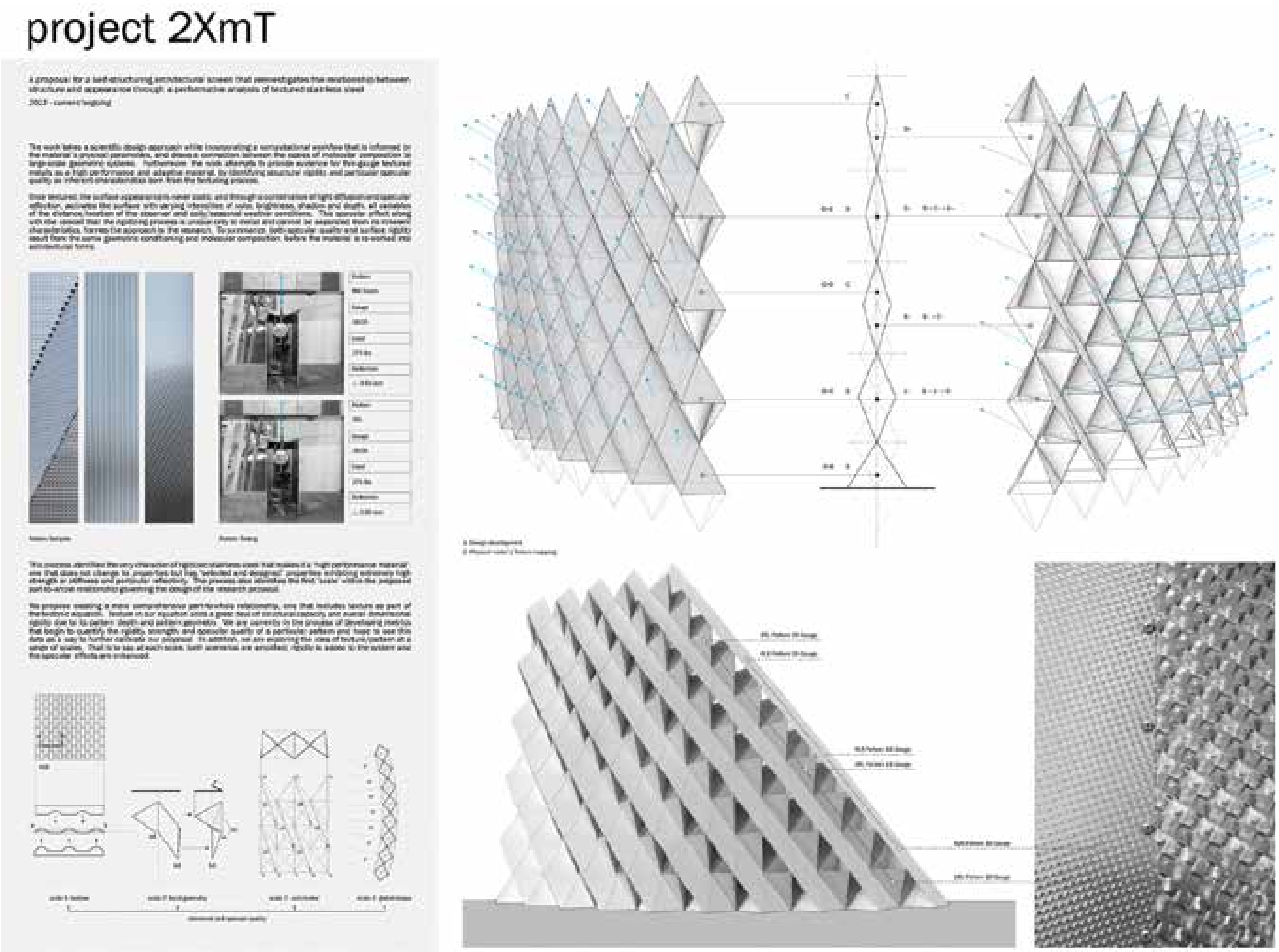


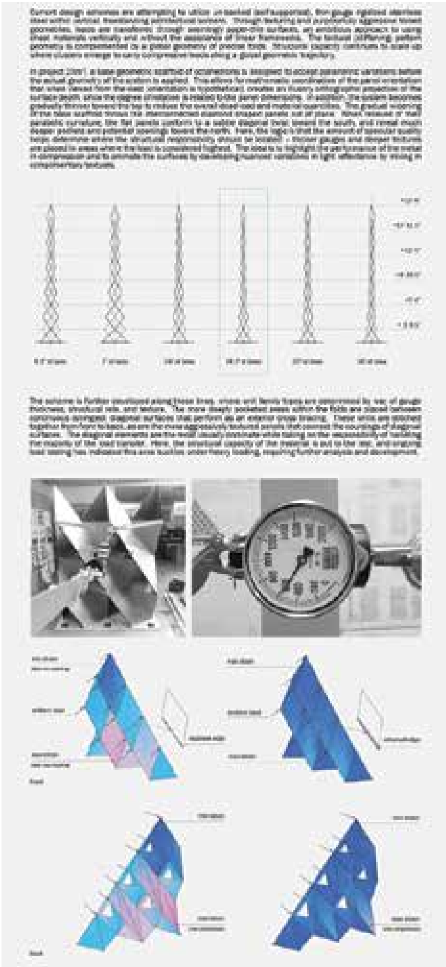
Figure 8: Final boards showing the integration of the tetrahedron and octahedron geometry to the global geometry of the facade.

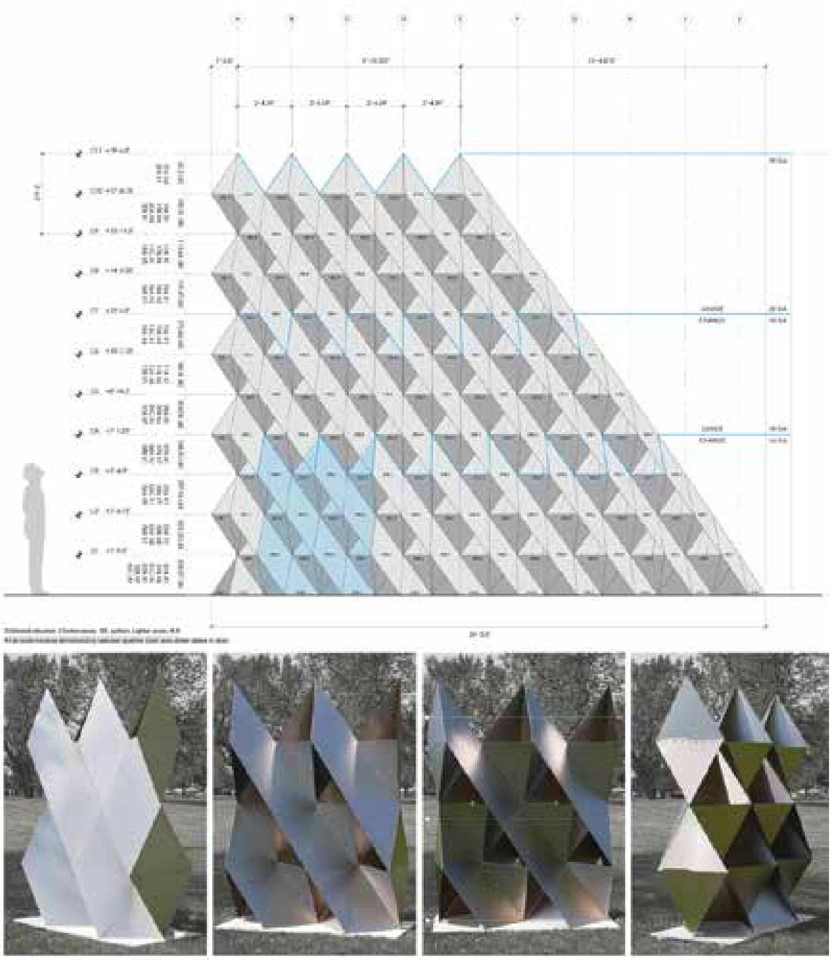
of the designer's concept, the engineers FEA analysis, and TEX-FAB's expertise as fabrication and logistical consultants. The main assembly took approximately 20 hours with a team of four.

APPLIED: RESEARCH THROUGH FABRICATION

Following the REPEAT competition, the TEX-FAB directors organized a competition in 2012 that intentionally started with the position of applied research. The call invited participants to leverage existing or even proposed research agendas onto the TEX-FAB network and find a useful and productive conduit for advancement. In October of 2012, a jury composed of Andrew Kudless, Branko Kolarevic, Vlad Tenu, and Nadar Tehrani, convened and selected Cast Thicket by yo-cy (fig. 5). Led by Christine Yogiaman and Ken Tracy, yo-cy is a young design firm working through a variety of methodologies to research the material logic's implication on the design process. Specifically, the Cast Thicket proposal examines tensile concrete molds through the use of plastic formwork and a layered structural network. For this production, Buro Happold and Crow Corporation were once again used as the structural and metal fabricators, respectively. TOPOCAST Lab provided fabricating and casting services, with yo-cy coordinating with the TEX-FAB team to provide production details and project development.

Cast Thicket builds off of an existing trajectory of tensile formwork dating back to the turn of the 19th century that has gained more traction with the work of practitioners like Miguel Fisak and more recently, with the work of Mark West. The current work of Cast Thicket differs from some of the past precedents using fabric formwork on several levels. First, the use of .03" polypropylene sheets in small patches with integrally fabricated seam connections puts increased emphasis on the seams, both formally and logistically. Second, the overall organization uses a tensile network of struts and nodes to distribute load and create space. These combined strategies allow for a series of discrete mold patches to make interconnected struts





from a single pour (fig. 6).

The formwork is stitched and laced up throughout a larger scaffolding that provides an overall tensioning and rigidity to the piece prior to casting (fig. 7). The polypropylene parts, which have all been custom cut on the CNC, are formed around the structural steel. The steel is a series of 3/16th plate stock parts that have been cut to a specific length and profile on a metal laser cutter in order to lock into pipe nodes throughout the entire system. The steel then floats internally of the polypropylene to provide the space for the concrete to be poured. The concrete is a custom-formulated mix of high-strength, low-viscosity, white concrete. With a series of admixtures that provide controlled set-time, flowability, weight, and color, the yo-cy and TOPOCAST team arrived at a composition that ensured that the pouring of the highly-intricate forms could be accomplished given the mixing and delivery method of the concrete.

One of the key factors in the APPLIED competition was to establish a case study for how specific research knowledge could be transferred to a different working group. In this regard, the procedural approaches of both material testing and digital tool implementation had to be closely documented and specifically communicated. This was tested through a series of prototypes done by TOPOCAST Lab prior to initiation of the large cast, to ensure a higher probability of success and to formulate best practices as well as continued research development in mix composition. In addition, all production and development between yo-cy, TOPOCAST, Buro Happold, and Crow Corporation was conducted through a common digital database and parametric model. This approach further solidified a growing belief within the manufacturing/design paradigm that the use of a 2D drawing is no longer relevant. At no point in the process of production were 2D drawings needed or used. While it might be premature to abandon this completely, the discussion on this issue has evolved significantly over the past decade, and within this research context, it was valuable to evaluate the effectiveness of this working methodology for the purpose of research collaboration.

SKIN: PERFORMATIVE FACADES

In February of 2013, TEX-FAB launched the SKIN: Performative Facades Competition with the intention of leveraging parametric and fabrication research methodology towards a targeted building component. The building envelope represents the most complex and fundamentally linguistic element of architecture today. Its formal development and performative capacity is foundational to its purpose and presents a dialogue the building has with itself and that of its context.

Once again, an internationally recognized panel of experts judged the competition. Neil Denari, James Carpenter, Mic Patterson, Bill Zahner, Skyler Tibbits, Randy Stratman, Gregg Pasquarelli, and Maria Mingallon evaluated entries from around the world from a diverse set of competitors. The jury selected Nicholas Bruscia and Christopher Romano's proposal, 2xMT, for its rigor and clarity. The team is able to leverage a technical elegance out of the material capacity of a self-structuring architectural screen using textured stainless steel. By focusing on the relationship between the structural and the specular qualities of the surface, their research explores a unique territory that relies on the methodological implications of rolled thin-gauge metal. After the metal has been processed with the appropriate texture for both strength and specular qualities, it is then precisely folded into either tetrahedron or octahedron configurations. Once clustered, the surface begins to take on self-structuring capabilities and leads to a freestanding wall. To further refine the scheme, the team coordinates gauge thickness, module geometry, and texture relative to location within the global system to implement specificity into the facade.

The 2xMT team evolved into the 3xLP team for the prototype for the TEX-FAB 5 exhibition. The nomenclature reflects an associated shorthand used to describe the texture and module in each prototype (fig. 8). The 3xLP team, assisted by Phil Gusmano and Dan Vrana, has a longstanding research relationship with Ridgidized Metals Corporation. The company is located in Buffalo, which has allowed Nicholas and Christopher an opportunity to cultivate a critical relationship with the manufacturer of the material and leverage the research capacity of the University of Buffalo SUNY where they both teach in the Department of Architecture. It is

Figure 9: 3xLP, winner of the SKIN: Performative Facades Competition, by Nicholas Bruscia and Christopher Romano. SKIN: Digital Assemblies Exhibition, The Mebane Gallery, UT Austin School of Architecture, 2014.

precisely the discovery of these types of relationships that the TEX-FAB platform is set up to further cultivate and promote. As part of the sponsorship as well as the larger mission of TEX-FAB, the A. Zahner Company was secured as a fabrication and technical sponsor for the competition. This meant the execution of the 3xLP project was a collaborative effort between the team from the University of Buffalo, Ridgidized Metals, Zahner, and TEX-FAB, all working together to produce the prototype. The final piece of the team was the inclusion of ARUP as the engineering consultant, providing FEA analysis. All production took place in Kansas City at the main Zahner facility and was shipped to Austin in mid-February in time for installation by the 3xLP team (fig. 9).

This working process marks a new turning point in the competition model. With sponsors providing not just technical advice or financial support but also taking over complete production, there is a more rigorous integration between the design research and fabrication research. The overlay of industry methodologies introduces procedural techniques that must either be accepted or modified in order to make something. It is at this intersection that the desire to innovate becomes the sharpest within the architectural component.

CONCLUSION

In Finland, it is customary to hold a competition for almost every public and civic work of architecture that is constructed in the country. It is embedded into the DNA of the design culture and is oftentimes the launching point for many young Finnish design firms. The history of this goes back to the Eliel Saarinen's winning proposal in 1904 for the Helsinki Railway Station. Nearly 100 years later, Steven Holl's Kiasma, resulting from an invited international competition, stands next door as the first significant cultural work done by a U.S. architect in Finland. The government has actively and consistently pushed for new ideas in architecture. In this regard, it is an agent for innovation and opportunity that is equally as important as any of the buildings being brought forward through this process. However, all this can only happen because culturally, there is a collective value placed on design. This reciprocity facilitates interest matching opportunity and vice-versa.

TEX-FAB is not a cultural agent, but it is an organization that is leveraging the competition to connect a growing interest in design research with computational design and fabrication. Specifically, TEX-FAB is doing this in a way that is providing a novel space for young designers to collaborate with technical, professional, and manufacturing experts to advance their research agendas. The TEX-FAB competitions are a new collaborative model for how local and global networks can blur boundaries and find greater opportunity in the knowledge base of many versus just a few.

ENDNOTES

1. A brief history of major global design competitions over the past 250 years can be found in Paul D. Sprieiregen, *Design Competitions* (New York: McGraw-Hill, 1979).

2. http://www.think-space.org/en/competitions/past_forward_competitions/yokohama/

3. http://www.archilab.org/public/2000/catalog/speaksen.htm

IMAGE CREDITS

Figure 1: Forgemind ArchiMedia

Figure 2: Brad Bell

Figure 3: Kevin Patrick McClellan

Figure 4: Erik Verboon, courtesy of Buro Happold New York

Figure 5: yo-cy: Christine Yogiaman & Ken Tracy

Figure 6: Kevin Patrick McClellan

Figure 7: Brad Bell

Figure 8: Christopher Romano & Nicholas Bruscia

Figure 9: Andrew Vrana

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