1-1-2011

Energanic prototypes in the [post]-digital terrain

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ENERGANIC PROTOTYPES
IN THE [POST]-DIGITAL TERRAIN

by

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Bachelor of Architectural Science, Ryerson University, Toronto, 2005

A design thesis|project

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Architecture

in the Program of Architecture

Toronto, Canada, 2011

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Master of Architecture Degree, 2011

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Abstract

Although the direction of contemporary architectural thinking is heavily influenced by its critical engagement with energy usage, this relationship remains largely unexplored imaginatively. This thesis investigates an energy-centric approach to design that is enabled by the digital workspace. By injecting energy transactions and modulations into otherwise abstract digital geometry while using analysis tools to examine their effects, the work is intended to speculate what this relationship with energy could be. For too long the application of emerging computer–based technologies in architecture have resisted critical agendas beyond idealist shape-making and form. At the same time the role of energy in the design process has been subsidiary and weak. Both fields of knowledge and their relationship to architecture are examined in a necessary marriage of mission and means. The research portion of this document concludes with a series of speculations that illustrate possible outcomes of the proposed energetic agenda.

Acknowledgements

I would like to thank my family and friends for their constant support and encouragement throughout this process which has been severely delayed by life’s character-building circumstances.

Above all, I would like to thank my advisor, John Cirka, for taking me on as a student. His patience, passion, knowledge, feedback , and encouragement was invaluable. I’d like to also thank Dr. Kendra Schank Smith and John Schnier for participating in my thesis reviews and for providing constructive input.

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1 Introduction: Beginning at The End

1.1 . Preface

Certainly the terrain we currently operate in today is a post-digital one. It is necessary to stress that the definition of "post-digital" does not mean the absence of digital components. Indeed it represents an architecture that is very much a synthesis between the virtual, the actual, the biological, the artificial, and other hybrids. We know that it is impossible to speak of "digital architecture" as if it were some kind of opposition to normal real world architecture, yet this is what often happens. Although the term "digital" as a prefix for architecture should soon become fully extinct, it yet remains throughout the presented work for reasons of clarity.

As expected, in order to speak of the post-digital, the journey had to travel through the digital to get there. The thesis begins by addressing the power of the tools and techniques we have access to and the information they are able to quantify. It then proceeds from an analysis of practice, experimentation, and critical commentary, to realize that this fascination with technique has become a powerful belief system in its own right. In a world full of unease and concern we need ideas far more than techniques. Thus, the thesis reformulates itself and creates an agenda that is empowered and mobilized by ideas. The entire thesis, from start to finish, reflects what architecture typical of this generation needs to do: transition from the dogma of technique to the possibilities of the post-digital.

1.2 . Energanic Architecture

Although we live in an increasingly energy conscious society, non-renewable resources are still readily available and are relatively cheap to extract, process, and consume. Our built environment is a direct reflection of this process and its future seems to be plodding along in a familiar, linear fashion. The economic forces of mass production and industry continue to fuel this perception of readily available energy, producing sweeping environments that are for the most part similar, generic, and value-free. It appears to be business as usual; a world that is complacent and detached from consequence.

This is an attitude that transcends cultural differences and pervades developed countries. Architecture, and its devices, has enthusiastically and uncritically embraced the late capitalist model. It has become driven by ideal and abstract formal agendas, which are enabled by the ‘shape-making’ potential of computer-based design tools and funded by speculative finance. Although we have adopted the mantras of social and environmental responsibility (‘sustainability’ and ‘green’), we would be deceiving ourselves if we argued that these are much more than an extension of the speculative investment model. While having value, they are far too simplistic and too reductive, and must be incorporated into a much larger vision.

If we stand back and seriously critique the current picture, we see an extremely thin veneer for a planet in distress. One need not look any further than the resources that are currently essential to our way of life. A good number of them are either non-renewable, too expensive, or bordering on extinction. This fact alone is so heavy and charged that it causes consternation for those who try to grasp its implications. Yet this problem is a key ingredient that initiates the work presented here.

The work is not about providing a thorough analysis about the state of our resources and it certainly does not approach the subject matter in an apocalyptic way. Nor does it attempt to provide any specific solutions that could even begin to solve problems of such scope. It simply wishes to imaginatively engage architecture’s critical conflict with energy usage and speculate about the possibilities with a conceptual lens that arises from the process. Rethinking the energy issue and establishing it as a critical agenda should produce new and perhaps even unsettling results.

In order to fully appreciate the author’s position, the reader is asked here in the beginning to imagine a few scenarios that will certainly face us in the future. First, imagine that our brute-force solutions to everyday problems are no longer smart enough. Picture a situation where the window on our continual supply of cheap raw materials is closing while at the same time our current renewable resources struggle to keep up with the demand of development. We find ourselves in a situation where resources are too valuable to squander; where the development of new materials and methods are a necessity. The value of intellectual energy will skyrocket and a high capital cost/low maintenance mentality will replace the current one which is exactly the opposite. Structures, materials, and methods will lose their familiarity. They will become sensitive, lighter, and wilder. Such a future has been described in part by Sanford Kwinter, who has continually promoted the dynamics of natural phenomena:

> “Design today must find ways to approximate ecological forces and structures. To tap, approximate, burrow, and transform morphogenetic processes from all aspects of wild nature, to invent artificial means of creating living artificial environments” (Kwinter, 1995)

The world we live in is not running out of energy. Just as the natural world has learned to adapt and thrive with the available energy found in our atmosphere, so too can we. Adopting this attitude will compel energy to become the creative material of design that it deserves; one that moves from the background to the foreground. This will demand a design environment that cannot remain in abstract or neutral states but one that applies new vocabularies of energetic transactions and modulations into its ever-expanding repertoire. Sean Lally gives us a few examples of some possibilities:

> “We must engage energy as something generative or explorative: to appropriate, mutate and bastardise temperature gradients, air masses, luminosity, plant physiology, scent and humidity indexes” (Lally, 2009)

An architecture of energy that is inspired by natural phenomena and explores real-world forces is suggested; whose visible form and structure reflects the materialization of energy management. This is certainly not a new territory or manner of thinking, but because of our global situation, it is one that should rise to the top of the list to be revisited and extended. With theoretical underpinnings linked to the work of such thinkers as Thompson, Otto, Deleuze, Kwinter, and Frazer, it has a rich and varied discourse that continues to inspire design today.

In order to achieve its aims, the research work has been separated into two distinct categories. The early research portion reflects a practical understanding of emerging computer-based design tools and their role in architecture. This is fundamental to the work because it allows us to see how these tools have been utilized and the types of directions that architectural thinking has been led into. It provides us enough information to form a critical analysis of the current body of work and it is this part of the journey that has led the thesis to a new paradigm. It has also been important to develop a competency with digital processes because the thesis relies on the ability to translate and exercise the link that marries a mission with its means. It was not until extensive work with digital processes were performed and discussed that a critical agenda of this nature was developed.

The second body of research explores matter as a system of energy transactions. This was an instinctive element evident in the work as it progressed and helped to direct the thesis forward. The premise is that energy driven form as a creative and imaginative design methodology will stimulate the types of responses that may begin to address our environmental anxieties–this of course facilitated by digital processes. Thus we have a marriage of the necessary parts into what is deemed a worthwhile and timely agenda for architecture: energanic.

2 Part 1: Emerging Technologies and Architecture

2.1 . Broad Overview

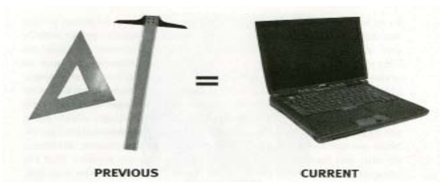


Figure 2.1.1 - The Digital Revolution

Figure 2.1.2 - The evolution of tools

Figure 2.1.3 - The Digital Temple

New computing technologies have transformed many relationships in society. During the early 1980s, the transition from analog devices to digital systems affected our lifestyles and professions in many ways. For architecture, the transition from the drafting table to the computer was a significant change but since the underlying coordinate system essentially remained the same, it was not an overly dramatic event at first. When new software and hardware began giving designers access to more complex geometries and methods of prototyping, then a dramatic transformation indeed was underway. Computer-aided drawing tools were embraced and the profession began to imagine ways to contribute to a digital society and a digital future. Creative work and texts emerged and formed a critical practice that is described as digital architecture. It was an exciting time. Yet after such a rapid and exciting beginning, “digital” architecture has struggled to sustain its early potential, leaving us to seek a fresh context in which we may re-engage with an energy conscious ethical agenda.

Architecture, as a profession, has been much slower to respond to the digital revolution in comparison to other industries. The impact of digital technology is only beginning to emerge in a significant way. Almost all architecture firms have invested heavily in computing infrastructure, software, and training and require competence in computer technology as a prerequisite for securing a job. However, this does not mean that these practices are operating much differently than in the past. Philip Bernstein states that one could argue that the digital revolution's greatest contribution to the construction portion of the industry is our ability to create crisp plotted output that can be easily reduced in size and carried into the field (Bernstein, 2001). However, the use of computer-based design tools in contemporary architectural practice has progressed rapidly in recent years, taking the profession well beyond the perception of these being merely used for production and simply replacing traditional techniques. Certainly digital technology has transformed the forms and spaces of what we design, but Christopher Hight makes the important observation that what remains less examined is its transformative potential for forms of design practice and spaces of knowledge (Hight, 2006). It is this transformative potential that is of interest. How can these emerging tools be fully taken advantage of and how might they support new trajectories for us to explore?


Figure 2.1.4 - Large scale prefabrication

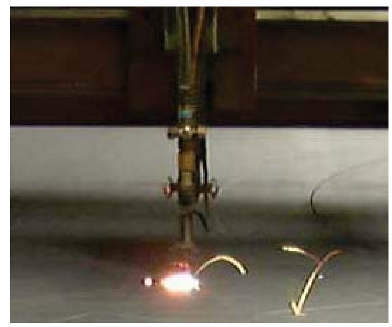


Figure 2.1.5 - A CNC plasma cutter

Over the last century architecture has slowly evolved from construction based on the creation of architecture by tradesmen utilizing hand tools to a process in which the majority of the construction is based on on-site assembly of mass produced or custom built components by skilled craftsmen. Quality, efficiency and performance benefits of factory based production environments have encouraged this evolution. The current situation is yet predominantly based on mass production techniques developed in the early part of the twentieth century. These techniques have slowly evolved to enable a limited degree of cost effective component variation. The concepts of digital fabrication and mass customization have emerged in the last several decades promising


Figure 2.1.6 - The diversity of digital fabrication

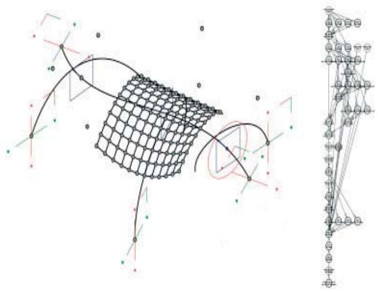


Figure 2.1.7 - Associative geometry


Figure 2.1.8 - Blast-forming


Figure 2.1.9 - Digital control and accuracy

to offer unique advantages of variation and flexibility in building components compared to mass production. In the next several decades it is likely that digital fabrication will continue its integration into accepted building practices. However, due to the advantages of mass production and the inherent limitations of mass customization, it is unlikely that in the near future buildings will be constructed using digital fabrication of mass customized components as the only method. More likely, mass customization within architecture is likely to work together with mass production techniques providing a more versatile and hybridized manufacturing environment. Already component assemblies ranging from small to remarkably large sizes are being fabricated in off-site facilities using both mass production and evolving mass customization technologies. The levels of quality control, efficiency and precision in these parts and assemblies are unprecedented, encouraging a slow but inevitable shift into off-site prefabricated components manufactured at ever increasing assembly sizes.

The cutting edge of current methods is the digital fabrication of architectural components driven by computer modeling of building components and fabricated using advanced CNC machining processes. Architects are increasingly using these new technologies in order to realize complex geometries previously unfeasible, adding to the diversity of the built environment. There appears to be a shift away from mass production and standardization to differentiated building elements and systems (Schodek et al., 2005). This shift challenges conventional roles and responsibilities within the building and construction industry and brings new uncertainties and opportunities into the mix. Architectural practices with sophisticated digital infrastructures and capabilities are well equipped to take advantage of this developing cultural change because of their ability to directly transfer complex design information to digital fabrication equipment. Branko Kolarevic argues that this convergence of representation and production processes represents the most important opportunity for a profound transformation of architecture as a profession, and with it, the entire building industry (Kolarevic, 2003). He also observes the unintended outcome of new digital processes of production–that it has the potential to reestablish the close relationship that once existed between construction and architecture. It allows architects to position themselves in the immediate interaction between design and making through new areas of fabrication research. Practitioners who understand and have adopted the use of these techniques have achieved wide recognition but the same techniques have been slow to be adopted in the profession as a whole. (Schodek et al.)

2.1.1 . Fabrication Research

The area of fabrication research is expanding with the increased complexity of built forms. This research is about describing how to “make” things–to take complex design information and realize it through fabrication machinery and modeling software. Branko Kolarevic explains that critical to this process has been the ability to augment assembly with digital technology after components have been digitally fabricated (Kolarevic, 2003). John Thornton, formerly of ARUP, reconsiders the notion of fabrication research as an embedded aspect of architectural practice. The practical benefits of fabrication research cannot be overlooked. Fabrication research increases knowledge and provides stimulus for creativity (Thornton, 2006). The intuitive knowledge of materials and sensitivity to the flow of forces that a craftsman understands when working with a particular material has not been traditionally a part of the designer’s realm. This type of intimate relationship with the materials that are specified and detailed in a given project may significantly improve how and what materials we might decide to use. It also brings to light the possible difficulty of constructing what we have drawn or modeled and the effect that small changes have on how something is made. Often, when we research one problem, it helps us solve another. Thornton argues that understanding how things are made is transposed into understanding the capabilities of

Figure 2.1.1.1 - Fabrication research

computing systems and manufacturing processes (Thornton, 2006). This is a critical observation for a type of understanding that is so underdeveloped in architectural practice today. Fabrication research forces us to interact between design and making–an activity that has disappeared from conventional architectural practice.

2.1.2 . Changing Roles

The integration of design, analysis, manufacturing, and the assembly of products or buildings is beginning to redefine the role of the architect in the process. It is allowing the potential for design to embed itself deeper into the process of construction and the possibility for architects to once again become central to the process of building (Shelden, 2006). Primarily, it has to do with the flows of information and the linking of all inherent processes. How exactly does this affect the role of the architect? The construction industry? Are the hierarchically structured organizational models of conventional practice applicable any longer? Is the "master-controller" position proposed by Kieran Timberlake in any way relevant (Kieran, Timberlake, 2003)? Or is more appropriate what Branko Kolarevic describes as a "digital collaborative enterprise"; the seamless integration of the separate realms of architecture, engineering, and construction? (Kolarevic, 2003)

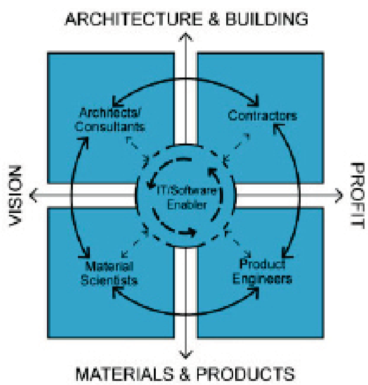


Figure 2.1.2.1 - Digital "Master Controller"

2.1.3 . Digital Production

In order to better understand the potential advantages of current production technology, a brief overview of the fundamental processes at the heart of the subject is worthwhile. As new techniques of digital design, representation, and fabrication are developed, these new processes have the potential to cause significant changes in the way that the profession operates.

Computer-aided manufacturing (CAM) is certainly not a recent technological development. The first computer-controlled automation began in the 1950's and has progressed significantly to accommodate a wide range of materials, scales, and new processes and robotic devices. Fabrication technologies can be grouped into four main categories: cutting, subtractive, additive, and formative. Most of these technologies fall under the generic title of Computer Numerically Controlled (CNC) fabrication, and use information directly from digital models to fabricate designs from a variety of materials at full scale. The most common CNC technique is two-dimensional fabrication. In this process powerful cutting tools such as plasma-arcs, laser-beams or water-jets cut sheet materials based on movement of either the cutting head or the bed that holds the material. The thickness of materials that can be cut becomes the primary limitation and often requires additional CNC processes. Subtractive fabrication involves the removal of a specified volume of material from a solid with the milling being constrained to an axis, surface, or volume. This process allows for deeper cutting depths and removal of material in three dimensions. Some machines offer up to six axes of movement and the ability to twist and turn a part as it is being cut can allow for increased complexity while simplifying the overall process. Additive fabrication uses the layering of material to build up shapes in many different ways. For example, in one process a laser melts intermediate metal layers in order to fuse the layers into a solid form. Rapid prototyping machines often use layers of plastic that use heat to fuse the layers together. Every year new types of computer controlled fabrication machines are developed, expanding options and enabling new design opportunities. As fabrication technology continues to evolve and become more mainstream and cost effective, change in architectural production will be inevitable and it is critical to understand digital production as a strategic aspect of the design process rather than a merely facilitative activity (Menges, 2006). These processes have the potential to redefine many fundamental understandings within the

Figure 2.1.3.1 - Computers and robots

Figure 2.1.3.2 - Large scale mock-ups

fabrication and construction of architecture. Successful projects make it clear that CAM can truly be cost effective through innovative means of digital production supported by advanced digital design approaches, but the relationship between existing skills and tools with new techniques and technologies becomes a much more difficult consideration. Exploring these processes allows us not only to see what is possible to construct today, but they may also help us develop an insight into the tectonic possibilities in architectural design for the future.

2.1.4 . Mass Customization

One can argue that on a fundamental level some aspects of architectural design are about customization, site-specificity, self-expression and the celebration of individuality, even status, yet it is more often than not rationalized and value engineered to the point where the identity of the conceptual ideas have been diluted to such an extent that they all but disappear. Stan Davis first coined the term ‘mass customization’ in 1987 in his book *Future Perfect*. Mass customization is loosely described as the use of flexible computer-aided manufacturing systems to produce custom output, and is perhaps the most revolutionary concept that has emerged in manufacturing since the mass production paradigm.

Figure 2.1.4.1 - Mass Production vs. Mass Customization

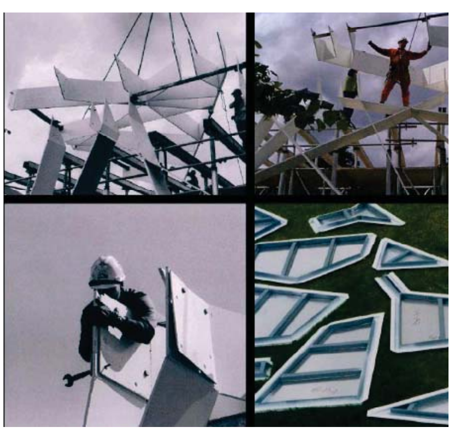


Figure 2.1.4.2 - Mass customization

A classic example of mass customization outside of architecture is the renowned Dell “build-to-order” model of purchasing computers that allowed for Dell’s domination of the PC market. Yet when the Dell model is scrutinized, it poses some challenges to the definition of mass customization. All of the components selected by the consumer for their “customized” Dell are mass-produced and offer only a limited number of options. The consumer cannot select outside of these options which begs the question of whether this is truly a case of mass customization. If this were compared to contemporary architectural construction, it could be argued that mass customization already exists in the building industry. In housing for example, consumers are likewise provided with a range of different models and upgrades to choose from. This, however, is not mass customization of the actual underlying construction processes, which would allow for true customization as the definition above implies. The production process itself has to be flexible.

If the future were one where mass customized production processes using digital fabrication could be used to make unique buildings and components in a manner as cost effective as those produced by mass production, what could happen? It seems that only the limitations of our imaginations would hinder us from pursuing the types of energy-related solutions and ideas that we so desperately need.

2.1.5 . Design Through Making

The relationship between design and making is a recurring question in architecture. Historically, architects were trained as apprentices to become “master builders.” Their education was based on the immediate experience of hands-on knowledge of materials and construction methods. They would “make” architecture. Ever since architects established themselves as a profession and devoted their efforts to an exclusive body of knowledge and learning, this relationship with construction has grown weaker and weaker over time. Many practices today exist only in the digital realm. I have worked at three practices since 2005 and not one of them incorporated the physical realm of models and mock-ups within their design process. What does the architect still have to gain from the realm of the physical and the process of making? The onset of CAD/CAM interfaces poses an interesting inversion. Many emerging practices are recovering creative control by developing expertise with production processes and new technologies. They have begun to renew the age-old relationship with construction by making it their business to investigate materials, details, innovative construction methodologies, structures and systems. In the age of mass information and design data, the quest to make concepts buildable has to lead to the renewal of architects developing sound understanding and experience of ‘making’,

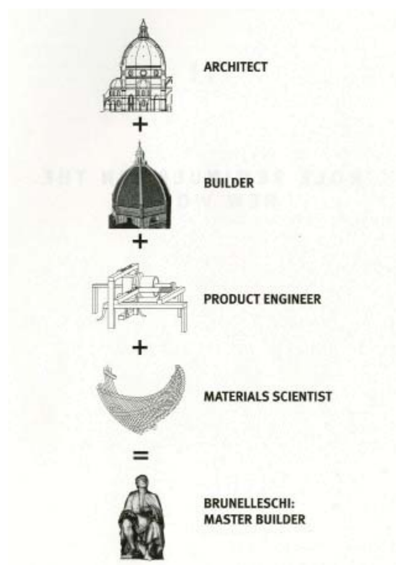


Figure 2.1.5.1 - Medieval Master Builder

the skilled construction of built projects. New tools, new means of construction, and new ways of understanding form have initiated a new vocabulary of making. Effective and relatively inexpensive fabrication and prototyping technologies have brought the physical back into the design process. Many emerging practices have realized that digital experimentation alone is not enough.

2.2 . Computer Aided Design and Manufacturing

Computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies are established practices in the aerospace, automotive, and shipbuilding industries. These technologies have inspired much interest in architecture and building yet their applications are only beginning to emerge on varying levels. There appears to be no clear agreement as to how or even why CAD/CAM practices should be utilized in the design and construction of the built environment. The following sections provide a brief overview of the topics inherent in this debate.

2.2.1 . Applications of CAD/CAM in Other Industries

CAD/CAM technologies were initially developed for industries other than the design and construction of buildings. It is therefore worthwhile to examine what capabilities currently exist in other fields, keeping in mind that many of these technologies might not be particularly useful to design and build buildings. The construction industry can potentially have a lot to learn from these other fields, which have a long history of research and development and have seen great gains in productivity and innovation. Many of these applications have similarities in terms of complexity of organization and construction. Their inherent efficiencies and seductive forms also inspire us. Andre Chaszar, in his book *Blurring the Lines*, has put together a list of features of CAD/CAM that are of greatest interest to architecture (Chaszar, 2006):

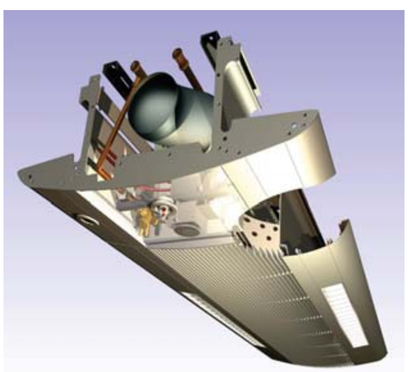


Figure 2.2.1.1 - Mechanical engineering in 3D

Visualization:

- the ability to present information realistically, or otherwise attractively or instructively, to produce physical models aiding comprehension of 3D forms and to animate 4D sequences;
Computation:
- the ability to perform numerical or even program operations at high speed and with great accuracy, whether for specific solutions or a range of scenarios;
Geometric Manipulation:
- the ability to deal with forms of great complexity or relative simplicity, arranging, generating, measuring, modifying and realizing them with improved speed and precision;
Standardization:
- the ability to faithfully communicate data from one instance to the next, allowing repetition of a particular design solution in recurring design situations;
Rationalization:
- the ability to make explicit the decisions leading to particular design solutions, similar to standardization but actually admitting of great variability.

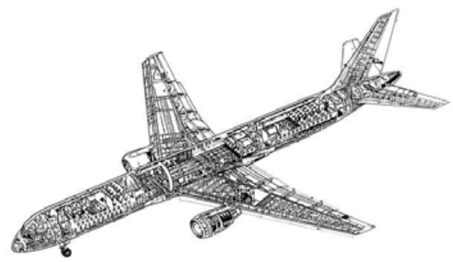


Figure 2.2.1.2 - Boeing 777

One of the most used examples of digital techniques is the Boeing 777, which was the first commercially produced airliner to be designed and documented entirely by digital processes. The vast quantities of data, numbers of participants in widespread geographic locations, and variety of methods and skills make it an enormous and profound undertaking. The requirements for the successful implementation of such a project demanded new forms of data management, rapid visualization and control of complex graphical files, and the ability for all parties involved to concurrently design and receive updates and changes. As a design case though, its relevance for architecture is tenuous. Where the contradictions of structure and skin are resolved too smoothly they lose architectural potential (Resier & Umemoto, 2006). In other words, aircraft design is too focused on optimizing for pure, structural economy that it

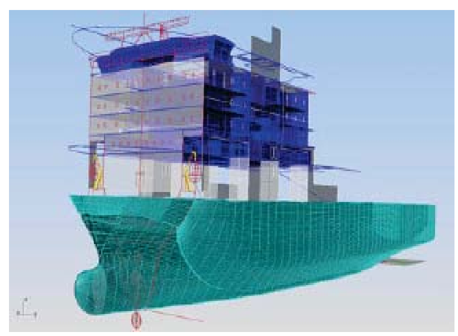


Figure 2.2.1.3 - Ship building industry


Figure 2.2.1.4 - Automotive industry

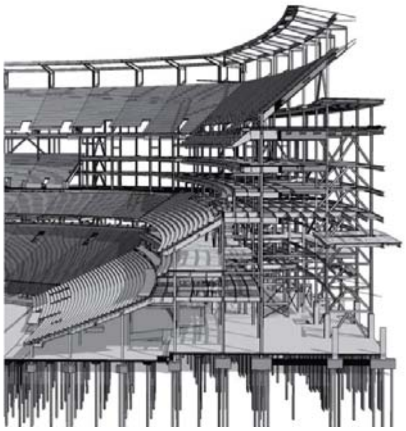


Figure 2.2.1.5 - 3D digital visualization

becomes a limiting factor for architecture.

The automotive and industrial design industries are also worth considering as sources for ideas to implement into the design and construction of buildings. In contrast to boats and airplanes, they are less restricted in terms of performance characteristics necessitated by air and water. The production techniques employed by these industries allow them to re-tool rapidly for different types of production and they manage to attain exceptional economy despite their high degree of complexity. Yet the link to architecture is quite weak because of numerous major differences; small scale, their use and lifecycle, and their overall systems of procurement. Techniques that we can learn from include 3D modeling methods, rapid prototyping of parts and assemblies, and certain manufacturing techniques.

The shipbuilding industry is perhaps the most relevant example to architecture due to its similarities in scale, complexity, one-off production runs, and systems of procurement. The strategies adopted to build ships in shipyards can certainly be applicable to the construction of buildings. The specific layouts and programmatic requirements, power generation, utilities and HVAC systems, safety and egress, along with structural forming techniques of complex, curved shapes are indeed relevant. Modern shipbuilding is highly advanced and takes advantage of available CAD/CAM techniques. It incorporates embedded assembly information and parametric modeling which allows for prefabrication and rapid customization.

2.2.2 . Technology Transfer to Architecture

If we are to transfer knowledge from other industries the question becomes one of relevance. We realize that architecture and the construction industry is far less advanced than other industries. How can examples from other industries be leveraged to benefit architecture? Certainly many of the digital design tools are applicable–the 3D modeling of forms, checking and visualizing how these forms come together, and the fabrication of individual components and assemblies. Yet much more relevant for us to learn from are the lessons of digital infrastructure-project administration, procurement, documentation, collaboration and communication, file transfer, detail resolution, and information exchange protocols. How do they deal with intellectual property, ownership, and legislation? Although the construction of the built landscape poses much greater challenges, both physical and immaterial, than perhaps all of these industries, we can still import many valuable lessons and techniques. Of particular interest are ideas for new ways to construct and tools for understanding and generating form. Designers can develop new vocabularies of making not only for the final product but also for models and documentation. The variety of new tools at our disposal can complement and extend the familiar traditional drawing and model making practices.

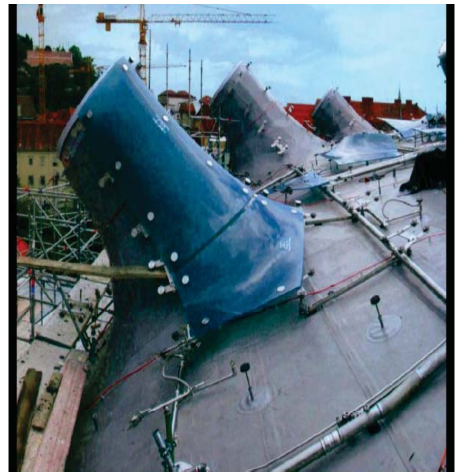


Figure 2.2.2.1 - Kunsthaus outer skin

Many architectural practices have begun to implement fabrication and assembly techniques from other industries. Smooth, doubly curved forms inspired by automotive and aircraft design, semi-monocoque rib-and-skin structural systems, the use of lightweight and super-strong materials are a few examples that have inspired designers. Advances in parametric modeling and building information modeling (BIM) software such as CATIA and Revit are being used to embed large amounts of detailed information into “smart geometry” that can be input into a digital fabrication process similar to those seen today in the aerospace industry. Building Information Modeling allows for architects to not only develop precise digital models of their buildings, but to embed construction data into the geometry. In parametric design, a building or component assembly is broken down into a varying number of parameters with relationships to help determine fluctuations and effects of changes within a given design. The use of digital fabrication equipment is closely linked to these new types of design software that are derived from the automobile, shipbuilding and aerospace industries. While these software technologies provide significant advantages in the precise development of designs, questions arise as to their relevance in the majority of conventional building projects. For example, would a project composed of mass produced and standardized parts and constructed through conventional means have need for the development of time consuming digital models with high levels of detail?

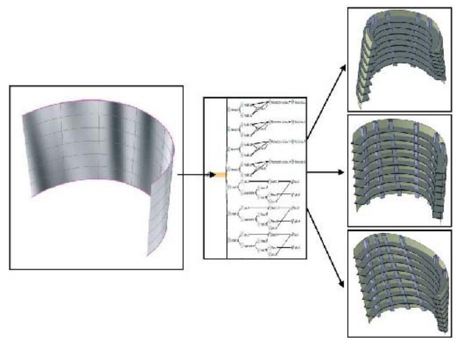


Figure 2.2.2.2 - Parametric modeling

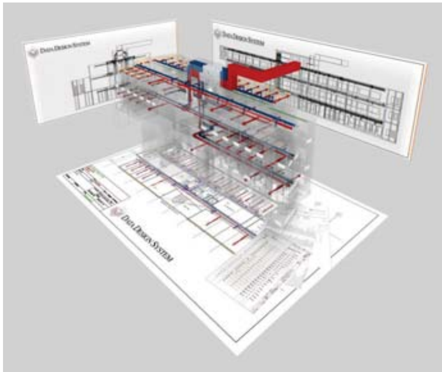


Figure 2.2.2.3 - Building Information Modeling

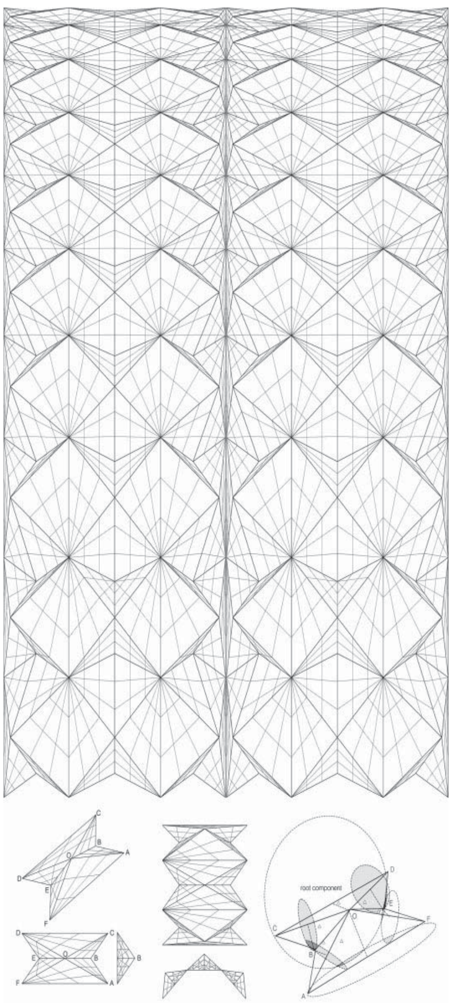


Figure 2.2.3.1 - Proliferation of a generative component

There are many barriers to the successful implementation of transfer technologies. Most designers and architects are not familiar with the specific details of these processes and the nature and scale of construction causes difficult interfaces between the new and conventional systems. The building industry is so entrenched in familiar regulations, budgets, schedules, and skill-segregated workforce. These technologies also require much greater collaboration with other disciplines than architects are accustomed to. This adoption of digital practices begins to "blur the lines of authorship" (Chaszar, 2006). Certainly it may give architects greater control over the overall form and design of details but the questions of authorship and responsibility in this type of scenario remain largely unanswered.

2.2.3 . Current CAD/CAM in Architecture

Most architectural practices use CAD for nothing more than simple drafting, rendering, and electronic file storage and transfer. Technology has been adopted to replicate existing methods and make them more efficient, yet for most designers and architects it ends there. The more ambitious practices have begun to use CAD/CAM for not only the description of building forms, but also for analysis and simulation. Building forms of great complexity, some of which are next to impossible to describe by traditional means, can be described and built accurately utilizing the capabilities of new software. A whole new language of form has arisen, far beyond the possibilities of traditional drawing methods. Most of these new tools also have the capacity to generate form. The mathematics of curves and waves, functions and algorithms are available to any designer who wishes to apply them to form finding investigations. Parametric and associative geometry allow a designer to describe the rules of transformation and regulate the relationships between the elements that comprise the digital model. Of far greater importance is the ability to analyze the structures and models that are created. Analytical tools can take us far beyond visual evaluation typical of traditional plans, sections, and elevations. Designers now may have rapid access to geometric properties of their models such as surface area, enclosed volume, the degree of curvature of non-planar surfaces and the unfolded shapes of faceted surfaces. The analysis of geometric properties allows us to determine constructability issues, which are used to evaluate appropriate material selection and fabrication processes. Many CAD platforms are beginning to merge with engineering software that can perform structural, HVAC, acoustical and lighting assessments. Construction logistics are also being modeled to realistically evaluate delivery schedules and simulate erection procedures.

2.2.4 . Future Opportunities. Tools and Uses

As tools, CAD/CAM technologies offer us many new possibilities and opportunities. They also raise a lot of new questions as they become ubiquitous in the design profession. What makes them so powerful is the ability to communicate and rapidly share ideas and information. Collaboration potential has been greatly enhanced by attention to file format compatibility, yet this still remains as an area of further development. Currently, many CAD platforms work in isolation and have no connection with CAM software. The greater the compatibility between architects, engineers, and contractors, the more advanced the process of design will be. The overall quality of design can increase substantially through the sophistication, refinement, and feedback that these tools offer. For example, performance criteria and their effects on structure, form, and cost through different design decisions can be easily generated and discussed in real-time with architects and engineers. Currently, software platforms could be enriched by tools that can help understand feasibility early in the design phases, especially when dealing with complex forms and fabrication procedures.

As we think of the potentials of these technologies, we must also take a step back and discuss potential limitations. Software platforms always have their own deficiencies. Architects rarely have any control over the logic behind their interfaces. Historically, tools used by designers have always had effects on the outcome of the architecture. When we select a design platform we must feel our way through its strengths and weaknesses and be open to selecting different tools for different tasks. As in the case of traditional tools, we will never find one tool that does it all. With these issues in mind and the fact that architects have a stake in how these technologies perform, would it not make sense for designers to take a more progressive approach with respect to the underlying programming? Does this current relationship between programmer and non-programmer inhibit progress? Many other significant questions for the future of digital practice arise: Will complex forms on a building scale always be fabricated by a combination of small 3D components, and 2D elements assembled into 3D aggregates? Or will CAM eventually be able to handle much larger 3D forms? Should architects be programmers? Which operations of design process should be computerized and which should not? How do we deal with digital contracts, transactions, and networks? How will we operate these new forms of practice in such an entrenched system of regulations and legislation? How do we get compensated for all of our research, knowledge, and study?

Figure 2.2.4.1 - Serpentine Gallery

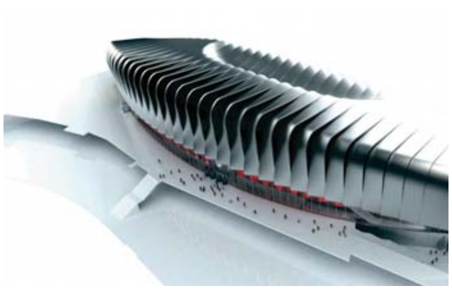


Figure 2.2.4.2 - Milan Exhibition Centre

2.3 . Case Studies of Digital Practice

The following sections examine four architectural practices that, because of emerging technology, are operating in ways that are not traditional. These practices have embedded fabrication research as a part of their process and are forging new ways of working. The goal is to portray the types of directions that these new opportunities have fostered.

2.3.1 . Designtoproduction

Designtoproduction is a multidisciplinary practice formed by Fabian Scheurer who is a computer scientist, and his two partners, architects Christoph Schindler and Arnold Walz. Their experience combines parametric design and process engineering-the primary focus being digital manufacturing. Their business model is based on expertise in the materialization of complex forms, which has uniquely located their practice in an area that simply did not exist a decade ago, working between architects, engineers and fabricators.

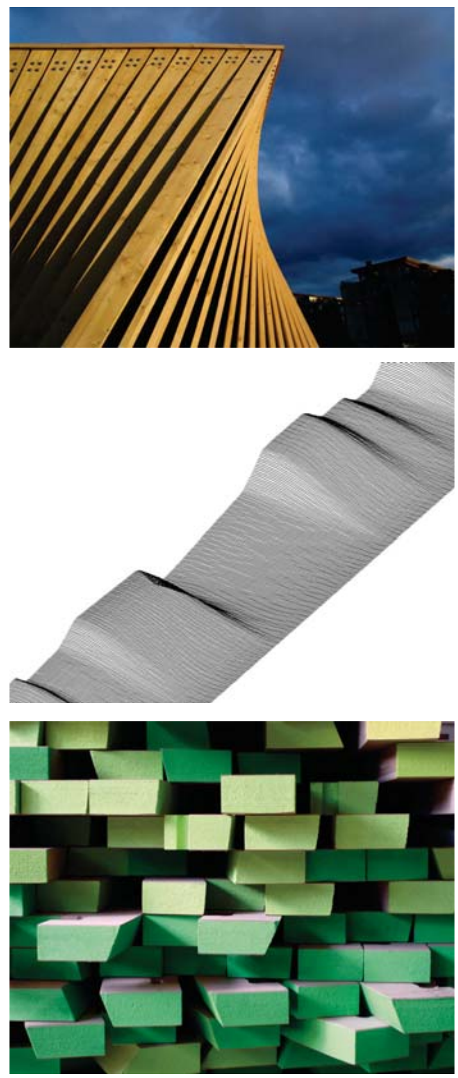


Figure Group 2.3.1.1 - Inventioneering Architecture by Designtoproduction

In just two years of practice, they have designed the production logic for Zaha Hadid's Nordpark Cable Railway Stations (Innsbruck, Austria, 2006), Renzo Piano's Zentrum Paul Klee (Berne, Switzerland, 2005), Daniel Libeskind's Futuropolis wooden structure (St Gallen, Switzerland, 2005), UNStudio's Mercedes Benz Museum (Stuttgart, Germany, 2006) and the EPFL Learning Centre now being built in Lausanne, Switzerland, by SANAA.

It is a significant point that all of their work is based on using standard materials to achieve complex forms. Flat sheets and straight beams from mass production processes are the starting point for all of their production logic. Fabian Scheurer explains that designtoproduction's use of the word 'complexity' does not so much refer to the complications of the geometry, but is used in the context of information theory to describe the amount of information that is embedded in a system and its components. Michael Weinstock uses the example of the construction of a brick wall to explain this:

> "We realize that there is no complexity in the bricks themselves, rather it is how they are arranged and assembled on site. The information that resides in the brick is the material property and dimension, and the information that the mason adds to the system is the order, position and orientation in space. Altering the order and pattern of assembly away from standard bond patterns adds complexity. And if more complicated building blocks are fabricated, some of the complexity is shifted from the assembly to the component and time on site is saved (Weinstock, 2008).

Adding information to the components themselves by altering their shape is highlighted in much of Designtoproduction's work.

Figure Group 2.3.1.1 - Designtoproduction

Hungerburg Funicular Stations

Innsbruck, 2007

Design: Zaha Hadid Architects

Engineering: Bollinger + Grohmann

Digital Production Logic: designtoproduction

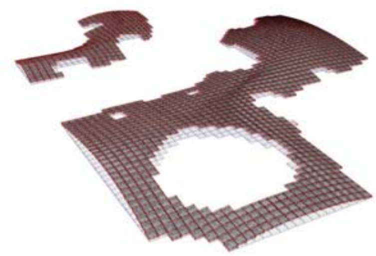
Description:

The four new stations designed by Zaha Hadid for the Hungerburg Funicular contain over 2,500 unique custom-cut polyethylene (PE) profiles, which connect the glass cladding of the roof to the steel ribs of the supporting structure.

Process:

A manufacturing method was established for the glass panels, each uniquely shaped, along with the construction method for the load-bearing steel structure. The joint between the glass and structure became a critical concern. The typical method would be to design and make metal adjustable joints, a cost-prohibitive process that would also require every single joint to be adjusted prior to mounting the panels resulting in extensive measuring and tweaking during assembly. The solution used an inexpensive material, which was simple to manufacture, and required no on-site adjustment. Individual profiles, each cut from polyethylene boards to its own specific angle, sit on the steel support ribs, and metal strips are glued to the glass panels and fixed to the profiles with simple screws. The geometry of the profiles was defined as spline-curves in a CAD model, and scripts were written to automate the production of the profiles, the placement of drill holes, the nesting of the profiles for the most economical use of the material in cutting, and the generation of the machine code for the five-axis CNC router. A unique identification code was also automatically generated for each component. More than 2,500 individually shaped parts were prefabricated, each fitting at the correct angle without further adjustments.

EPFL Learning Center
Lausanne, 2008
Design: SANAA
Engineering: Bollinger + Grohmann
Digital Production Logic: designtoproduction
General Contractor: Losinger SA



Description:
The large, doubly curved concrete slab of SANAA's EPFL Learning Center in Lausanne required a specific formwork solution. A smoothly curved surface was constructed in combination with standard scaffolding components, using nearly 1,500 individual wooden boxes.

Figure Group 2.3.1.2 - Designtoproduction

Process:
The new EPFL Learning Centre was constructed using an enormous concrete slab of 20,000 square meters that smoothly undulates up and down, with a height variation of more than 6.5 meters. Concrete can be cast into almost any shape, but standard formwork systems alone cannot produce doubly curved surfaces. The solution was to combine standard system with custom extensions. Scaffolding was

erected to a height just below the intended concrete surface and the remaining space was filled by a digitally fabricated wooden layer; a unique wooden box for every grid cell. The box is covered with a sheet of plywood, forced to the exact curvature by screwing it to vertical cleats, each individually cut from plywood. The doubly curved portion of the slab has an area of 7,500 square meters. This area was divided into 1,458 tables, making a total of 9,744 cleats, each of which is uniquely shaped and has to be designed and fabricated individually. Controlling the logistics is critical to ensure that each component is situated correctly, and the flow of information has to be designed carefully. In a project of this scale every extra minute is crucial because it can amount to an extra man month of work since it is being repeated thousands of times over.

2.3.2 . SHoP Architects

SHoP is an architectural practice operating out of Manhattan, New York. The practice was founded by five partners Christopher Sharples, Coren Sharples, Willliam Sharples, Kimberly Holden, and Gregg Pasquarelli in 1996 and has grown to an office of eighty members. The educational and professional experience of the firm includes architecture, fine arts, structural engineering, finance, and business management. The practice was founded on the notion that "intelligent, exciting, and evocative architecture can be made in the real world, with real world constraints." This belief has taken them far beyond the discussion and design of buildings. Each project is considered in its entirety: site, cultural and economic conditions, client physical needs and budget constraints, construction techniques, branding, marketing, and post occupancy issues.

SHoP utilizes computer-aided design technologies not only to produce innovative architectural forms but also to streamline the design and construction process and introduce new efficiencies and cost savings. Their design work as they describe it, demands that design, finance, and technology work together based on the argument that combining these forces in innovative ways will create a new model for the profession. The firm argues that conventional construction and fabrication techniques with their Cartesian structures and envelopes will remain dominant because of their simple logic and the nature of construction materials. If complex formal solutions can be realized in cost effective ways with obvious benefits, then they will slowly make inroads into mainstream construction. For this reason, SHoP places much effort into research of customized parts, manipulation of standardized parts, and the arrangement of standardized parts in non-standard configurations.

Figure Group 2.3.2.1 - SHoP architects

Working with complex geometries requires numerous strategies. CNC fabrication plays a crucial role along with methods of assembly. An effective organizational structure requires that those who will build a project (general contractor) must be able to manage the flow of information. Until a 3D model can be the sole construction document, traditional drawings will remain to communicate the necessary information. In an attempt to achieve smooth communication, SHoP has founded its own construction company called SHoP Construction. The primary goal is to utilize emerging technologies to provide sustainable construction management. SHoP has fully embraced Building Information Modeling (BIM) to produce its architectural projects and combines it with a Virtual Design & Construction (VDC) process, which allows project coordination to begin earlier than a traditional linear approach to project delivery. Project schedule (4D) and cost (5D) information is embedded into the virtual realm to enable more effective project management throughout this process. SHoP Construction also integrates 'green' project criteria directly into the process to assist owners in attaining LEED compliance and certification. When the project is complete, SHoP Construction delivers Facilities Management (FM) models to reflect the as-built conditions and serve clients well into the future.

Another strategy employed by SHoP deals with the cost and availability of skilled labor. The cost of materials and skilled labor often have significant influence on the selected design strategy, SHoP argues that this further reinforces the trend towards CAM since components can be manufactured and assembled simultaneously, off-site, rather than consecutively, on-site, and skill-intensive tasks can be automated or outsourced to lower cost labor markets (Sharples, 2006). This does increase the accountability of the architect since elements are not built to fit on site, requiring a high level of precision in the architect's design documentation.

These strategies reveal an interest in utilizing digital tools and fabrication far beyond solely formal applications. The goal seems to be more about the validation of CAD and CAM through an interest in rational processes and the generation of applicable value traits versus formal ones.

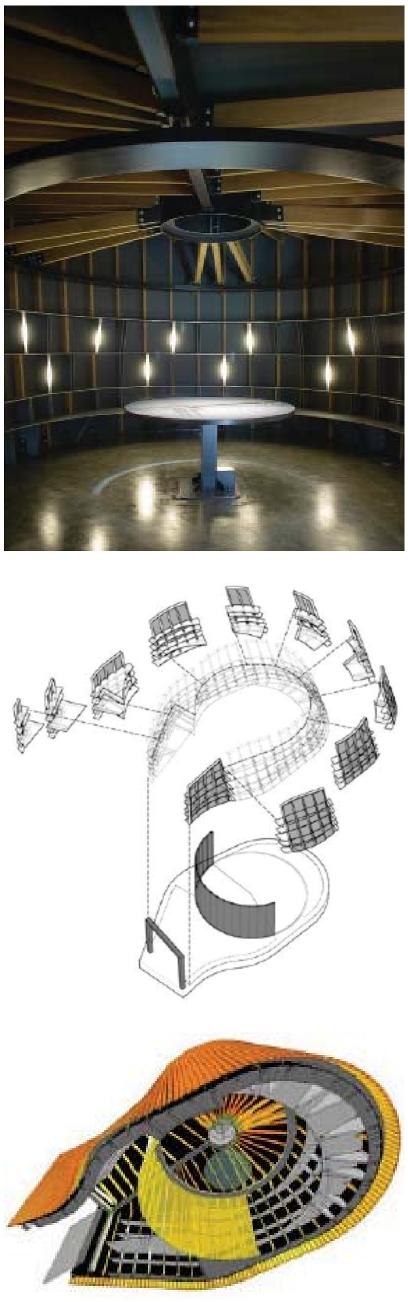


Figure Group 2.3.2.2 - SHoP architects

Camera Obscura

Mitchell Park, Greenport, NY, 2005

Design: SHoP Architects PC

Client: Village of Greenport

Area: 350 sf

Description:

The Camera Obscura is one of four buildings designed for Mitchell Park, a waterfront park for the Village of Greenport on Long Island, New York. Through an optical lens and a mirror, a live image of the Camera's surroundings is projected down onto a flat, circular table that is raised or lowered to adjust focal depth. The Camera Obscura was conceived as a research and development project that is small in size but not in scope. The goal was to construct a building entirely from digitally fabricated components. In the past, SHoP had utilized digital fabrication for individual trades, such as laser-cut metal panels or CNC millwork. For the first time, SHoP brought multiple processes together to test tolerance and coordination issues. Designed entirely as a 3D computer model, the construction of the Camera was communicated as a kit of custom parts accompanied by a set of instructions for assembling the components. Primary aluminum and steel components were laser-cut using digital files directly extracted from the computer model. Full-scale templates were provided for wall and roof sheathing.

The project is also a test case of working with CAD/CAM processes within a strict public bidding process. The selection of bids is based on the lowest bidder; bids that are determined by the values of traditional labor and off-the-shelf products. SHoP used this project to display the ability to maintain great control and flexibility while working within these confines. Custom components were specified by the architect, bid out to numerous fabricators, and then sold to the general contractor as if they were parts from a catalogue. In this respect, the project is a profound case for CAD/CAM applications as a cost-effective alternative.

2.3.3 . Kieran Timberlake Associates

Kieran Timberlake Associates is an architectural practice founded in 1984 in Philadelphia by Stephen Kieran and James Timberlake. The firm is currently comprised of fifty-four professionals working within a mandate that includes education and research to complement their growing body of built works. With common interests in building technology, Kieran and Timberlake joined forces to tackle a primary goal; to change the way that buildings are made. This ambitious vision is being explored by expanding the architect's role beyond mere 'design' to become 21st-century 'master builders'– through the development of new materials and new ways to save energy, and introducing methods of collaboration and fabrication drawn from the automobile, airplane and shipbuilding industries. All of their work places emphasis on materials and the construction process, subjects often neglected in North American architectural education.

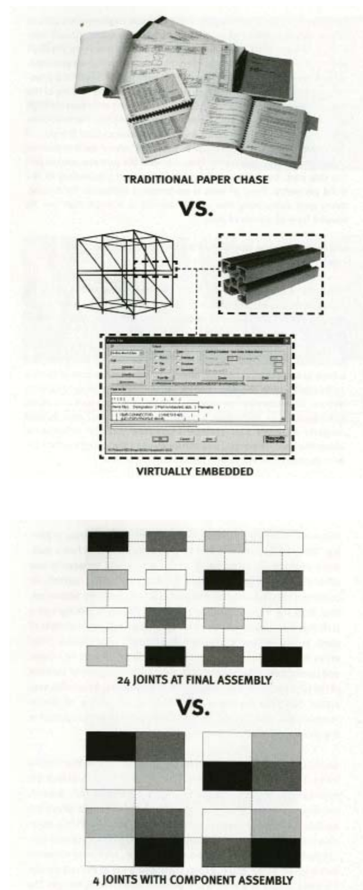


Figure Group 2.3.3.1 - Kieran Timberlake Associates

The research into materials, processes, and fabrication are the core source for the development and implementation of new ideas. Kieran and Timberlake believe that the failure to look at process instead of image has led entire generations of architects to overlook transfer technologies and transfer processes. "The new architecture will not be about style, but rather about substance — about the very methods and processes that underlie making" (Kieran,Timberlake). For this reason, their practice has extensive in-house manufacturing capacities, both manual and digital. The firm's research on the fabrication processes being used in the transportation industries has convinced them that architects need to give up the typical top-down approach to ‘design’ because it usually limits their involvement, separates them from the building process, and causes ignorance of advances in construction technology. Kieran and Timberlake are pushing for a collaborative process that involves architects, contractors, materials scientists and product engineers, working together with digital communication to streamline the process from project conception to finished product.

Materials science is an essential part of the firm’s process based on the belief that using the wide range of new materials available can allow for significant gains in efficiency and precision, save energy, cost less, last longer and can be easily adapted to prefabrication processes. Their “nuts-and-bolts” approach to architecture along with their emphasis on ideas of mass customization are being realized in many different forms. An emphasis on building technology is also helping them achieve higher levels of environmental sustainability than most practices because they have the knowledge and resources required for implementation.

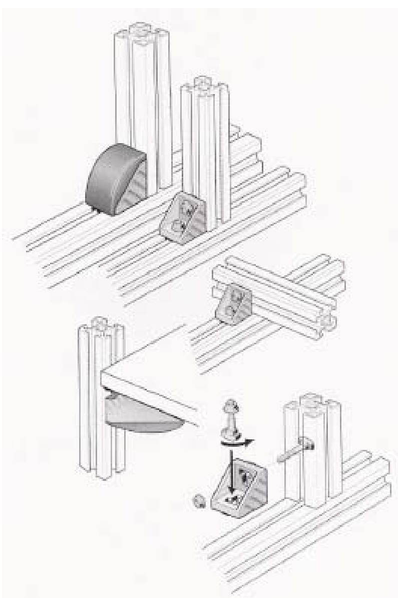


Figure Group 2.3.3.2 - Kieran Timberlake Associates

Loblolly House
Taylor’s Island, Maryland, 2006
Design: Kieran Timberlake Associates
Project Manager: Arena Program Management
General Contractor and Fabricator: Bensonwood Homes

The Loblolly House is a holiday home that Kieran built for his family in 2006, which demonstrates the possibilities of prefabrication. The house is made entirely with factory-made parts and is a reflection of their visions-the benefits of off-site fabrication, a re-organization of the construction paradigm, and the levels of quality and efficiency all made possible through the use of digital technologies. The Loblolly House is named for the loblolly pine forest in which it sits, on the shores of Chesapeake Bay. Accordion-like glass walls and retractable translucent airplane-hangar doors open the house to its surroundings. Only a few trees were cleared from the sensitive site for construction and timber piles raise the retreat high into the air to protect it from flooding. In only six weeks, the house's prefabricated parts were hoisted on to a platform and set into a scaffold when they arrived from the factory. Entire rooms with ceilings, walls, windows, plumbing, electrical connections and lighting were set within 300mm deep horizontal sandwich panels made of plywood and cement board filled with ductwork. The horizontal panels contain the insulation, vapor barrier and sheathing. The 204 square meter structure was designed for disassembly and most of its parts are recyclable. The architects are currently working with a developer on a mass-producible version.

2.3.4 . Gramazio and Kohler

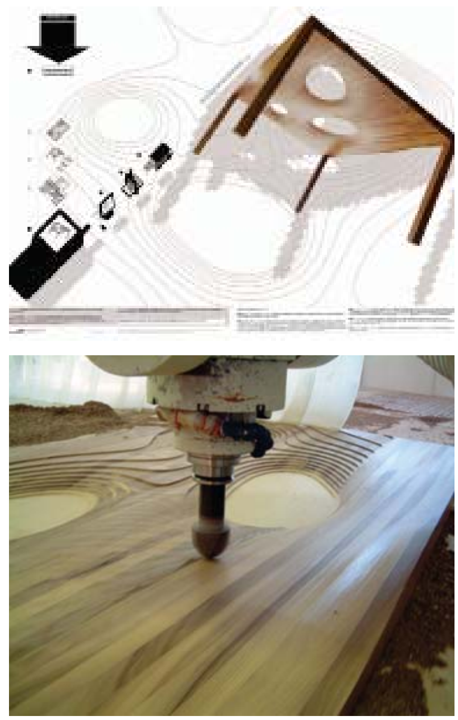


Figure Group 2.3.4.1 - Gramazio and Kohler

Gramazio and Kohler is an architectural practice based in Zurich, Switzerland. The primary approach of this practice is to combine "the physis of built architecture with digital logics" (Gramzio, Kohler, 2008). The architects describe their work as a design culture that uses the potentials of both the computer and digital fabrication in concert with traditional design, construction, and building methods. This philosophy has been applied extensively in both built works and research. The process manifests itself in a transformation in the expression of architecture, which they describe as a novel "digital materiality." The term "digital materiality" is used to describe the enrichment of materiality with digital characteristics. The material and digital worlds are typically distinct from one another, yet this practice is synthesizing the two together by weaving data, material, programming, and construction. The techniques of digital fabrication allow for this to happen. The architect takes control of the manufacturing process through design data and as a result the material is enriched by information-material becomes "informed." This points to a future where the ideas of architects will permeate the entire fabrication process, giving rise to new possibilities for the practice and design of architecture.

The concept of digital materiality leads to new forms of expression. The architects describe it as “a new sensuality in architecture” (Gramzio, Kohler). Precision, quantity, detail, and scales of formation primarily characterize this sensuality. The precision is a result of the processing power of digital logics, while machinery accurately translates digital information into the material world. The quantity refers to the ability to precisely arrange and order any given number of elements with a specific address in space. Machinery and robots instead of the human hand also perform this arranging. The sophistication of detailing is also attributed to this process of digital to material translation of information. The degree of sophistication can reach levels that are unthinkable for conventional modes of construction (remarkable exceptions do exist). Digital materiality also understands materials beyond surfaces or textures. Age-old materials like brick or wood, which have familiar formations, appear in new and innovative ways.

Figure Group 2.3.4.2 - Gramazio and Kohler

The firm achieves digital materiality by integrating construction and programming within the design process. They compare a computer program with the fabrication of a building component. A computer program processes data in a series of sequential steps. Similarly, a physical building component is also fabricated in individual steps. This sequence of steps has an order where each step is critical for successive steps and the steps build off of each other. The individual components have their own “program” but are also part of a much larger program that can create an assembly or a building. This type of mapping of construction into a programmed process allows for an intimate level of control over digital fabrication. It is not only the overall form that is designed, but also the production process itself. If one operates in this manner it means that a design will incorporate its idea and production process from its inception.

Gramazio and Kohler have incorporated the use of industrial robots in much of their research and have also extended the traditional prefabrication process by developing a mobile robot that can be shipped to the jobsite. The motivation for this is based on the insight that architecture is generally constructed through the addition of parts and assemblies. Bringing a robot to a construction site allows for these additive principles to be realized on a much larger scale. The architectural robot can directly link the “digital reality of the computer with the material reality of built architecture.” The industrial robot is like a personal computer, which is suitable for a wide variety of applications instead of a specific purpose. A robot can be taught “manual” skills to directly link digital information to material construction.

Figure Group 2.3.4.3 - Gramazio and Kohler

Digital tools allow for variation to emerge because they facilitate the design of large numbers of elements in different ways. The potential of digital design and production processes rests on this ability to combine large quantities of parts, which extends human capabilities. Traditionally, architects have used grids and repetition to manually organize and create variation, maintaining control and constructability. Digital tools allow for this negotiation between system and variation to be re-evaluated. Industrialization’s premise is based upon serial repetition. A new language of diversity founded upon the design of processes versus form is emerging allowing for different elements to combine adaptively into a coherent, harmonious whole (Gramzio, Kohler).

Often the expressions of such digital materiality remind us of biological systems but digital systems do not rise out of biological conditions. Digital systems are a cultural construction that is a result of a historical human fascination and engagement with logic. Humans have always tried to extend their capacity and continually create new relationships with their environment in inorganic ways.

The work of Gramazio and Kohler is recognizable as the design of material processes instead of static forms. This format of design gives up the traditional notion of geometry as the primary basis for design decisions. Instead, the process has more to do with the definitions of relationships and intentions that become the guiding rules for design. Instead of being faced with static plans, a programming approach offers a dynamic set of rules; the design of a behavior. The architect who designs processes and behavior strengthens his or her role as a true author of the work.

3 Fabrication Experiments

3.1 . Introduction

The architectural design process has historically been a process of representation and fabrication. The use of the human hand to manipulate material to create objects and the development of tools to extend this ability has been a continual process throughout the history of human civilization. Initially, these tools were primitive- perhaps the hammer and chisel were first followed by much more complicated tools like the saw that could cut and the drill that could bore holes. All of these developments led to a much wider range of possibilities as to what could be constructed. Tools have long since become mechanized and the current product market is flooded with power tools that offer a wide variety of sizes and operations. Up until now such tools have been sufficient for the realization of design needs of buildings that are an outgrowth of the industrial revolution (Kashyap, 2004). Bill Mitchell observes that the hand-tool relationship is similar to the computer-mind relationship (Mitchell, 2004). The computer as a tool, he argues, can be thought of as an extension of the mind. It is hard to imagine our work environments without computers and they now proliferate every aspect of our lives. Their power as tools lies in their ability to handle vast quantities of data and their ability to calculate functions and formulas. This allows designers to increasingly derive more and more complex systems and geometries adding new languages of shapes, curved topologies, splines, and surfaces to their digital repertoire of techniques. These tools, however, still have limitations and constraints. Typically, a designer using a software platform is limited to those operations, which the software developer has set up in the user interface. This creates a situation, which usually has the end-user working in a series of static relationships between points, lines, curves, and surfaces. This research also wishes to explore the inner workings of computing so that the designer can invent his or her own tools to solve a specific problem. The potential of building new tools can allow us to create much more than digital explorations into new forms, shapes, and geometries. It is these tools that may allow for the possibilities of digital technologies to transition into actual fabrication.

3.1.1 . Digital Modeling

My explorations combined digital modeling and manual assembly. Some of the experiments were done completely with fabrication equipment, while others were a combination of the two. The primary goal of the study was to translate digital models into material objects. The focus was on process and architectural production. A number of modeling platforms were used and some in conjunction. They included AutoCAD Architecture 2009, Rhinoceros V4, Solid Edge V 20, Bentley Generative Components, and 3D Studio Max 2009.

3.1.2 . Fabrication Methods

The explorations used computer controlled fabrication machinery to build physical representations of the digital models. This machinery is comprised of two broad groups: CAD/CAM fabrication machines (CNC machines) and Rapid Prototyping machines. (RP or 3D printer) The fabrication equipment used in this thesis included a five-axis milling machine, a laser cutter, and a 3D printer.

3.1.3 . Generative Methods

One goal of these experiments is to explore end-user programming so that the user participates in the software development process. In other words, the user becomes the software developer and begins to design his or her own tools to perform specific tasks. The experiments performed in this manner will use Rhino Script, which is based on Visual Basic Programming language. Scripting languages allow a user to create new functions within existing software platforms by accessing their underlying structure. The basic structures of programming language that include variables, loops, arrays, conditions, and functions are often intimidating for those who are not accustomed to this environment of rational logic. How difficult is it to operate in this manner? What potential benefits arise from this manner of expressive control and procedural process? The results of these experiments will discuss the issues that arise.

3.1.4 . Parametric Design

Parametric modeling, also called associative geometry, refers to the construction of models in systematic ways, where the geometrical components are associated in sets of relationships that are subject to parameterization. This means that the components have a specific behavior based on the values of the parameters. This kind of thinking is particularly useful if one is creating a hybrid model that can respond to different input. It allows the model to remain dynamic so that it can respond to multiple iterative cycles of analysis and evaluation.

3.1.5 . The Intent

In general, this work explores technique. It will also discuss the benefits and limitations of digital tools and fabrication methods as it relates to the design process. The experience, views and ideas generated should add to an understanding of how forms, once conceived, can be controlled and realized.

3.2 . Sectioning

3.2.1 . Sectioning A

An image of a NURBS surface created in Rhino. Two NURBS curves are lofted and the software generates a control lattice of iso-parametric contours. Developing an understanding of surface properties, underlying algorithms and mathematics of surfaces, and a knowledge of how the software actually creates the surfaces becomes an inspiration for the creation of new design evaluation tools.

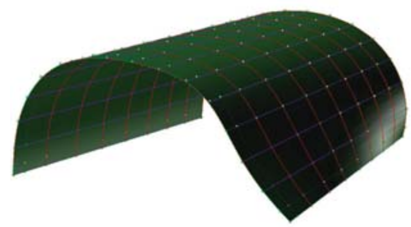


Figure 3.2.1.1 - NURBS Surface

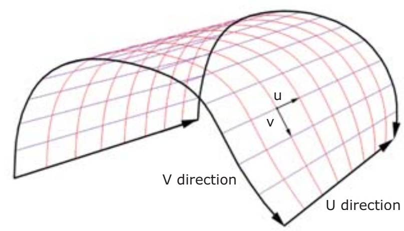


Figure 3.2.1.2 - How the software approximates a NURBS Surface

The acronym NURBS is an abbreviation of non-uniform rational B-spline. NURBS curves are defined using a small number of control points connected to a control polygon. From the control points, a geometric algorithm derives a smooth curve automatically. Each control point has an associated weight that determines the extent of influence on the curve. As the name indicates, the control polygon is used to control the shape of the curve. Modifications to the control polygon will change the connected curve. The term spline originates from a tool that shipbuilders used to draw smooth curves by hand. A thin flexible wood or metal rod was bent to accommodate different shapes of freeform curves as needed by the designer. This is a nice example of how simple tools can be used to inform new systems of representation and making. The simple bending of a rod based on its materiality is the inspiration for an entire geometric design language and the mathematical definition of a family of complex curves. In terms of geometric modeling, a spline

Figure 3.2.1.3 - Shipbuilder's spline tool: An example of how simple tools can inform complex systems and languages

curve consists of several continuous curve segments. The Romanian mathematician Isaac Schoenberg coined the term B-spline. The B stands for “basis” but essentially indicates that the curve actually consists of several Bezier curve segments. (Pottman et al., 2007) Control points, degree, and knot vector define a B-spline curve. These can be easily and interactively manipulated offering an infinite range of mathematical surface and form possibilities. The advantage of NURBS surfaces is that they offer the possibility to be easily read and fabricated by digital fabrication machinery based on their inherent definition logic.

Goal:

To quickly fabricate physical models of NURBS surfaces using digital modeling, generative logic, and 2D fabrication machines.

Methodology:

The physical representation of NURBS surfaces in this experiment is based on an understanding of how the software creates these surfaces. The idea is to use the iso-parametric definition of the surface as the basis for a system of structural members to be developed. Since this definition is inherently parametric and can infinitely be adjusted, a user can easily manipulate the structural system by adjusting the spacing and quantity of members in both U and V directions. The U and V definition of iso-paramteric curves is simply a device of the software to make these parameters unique from the general X, Y, and Z Cartesian coordinates of three dimensional space. Developing a structure based on these U and V isocurves means that we have to extract them from the surface. If we are to develop a system to build these structures we also have to develop a joint where these lines intersect. Rhino scripting was used to extract the curves and their intersection points. The user offers a surface to be analyzed and inputs the number of curves in both U and V directions. The user also inputs the depth of the members and the script simply extrudes the curves to this depth. The script develops a joint by taking a proportion of the depth and ensuring that the interlocking members meet flush to each other. Since the joint is parametrically defined, a level of tolerance can be added depending on the complexity of the surface and the material being used.

The result of this procedure creates a system of interlocking members that can be quickly assembled to represent the desired surface. If the surface is not regular and is defined by complex curvature, this will be evident in the individual rib components. Since each isocurve is extracted individually each one becomes unique.

Once this tool has been initiated, it has the ability to perform these operations on any NURBS surface and can be re-run on any one surface as many times as needed to adjust the physical structure to a desired level. The manufacturing and assembly of these parts requires them to be extracted from the program into a language that the laser cutter can read. It is also desirable to have a system that can label each part and aid the construction of these assemblies. Based on the scale of each construction, calculations for material quantities, weight, and visual tools

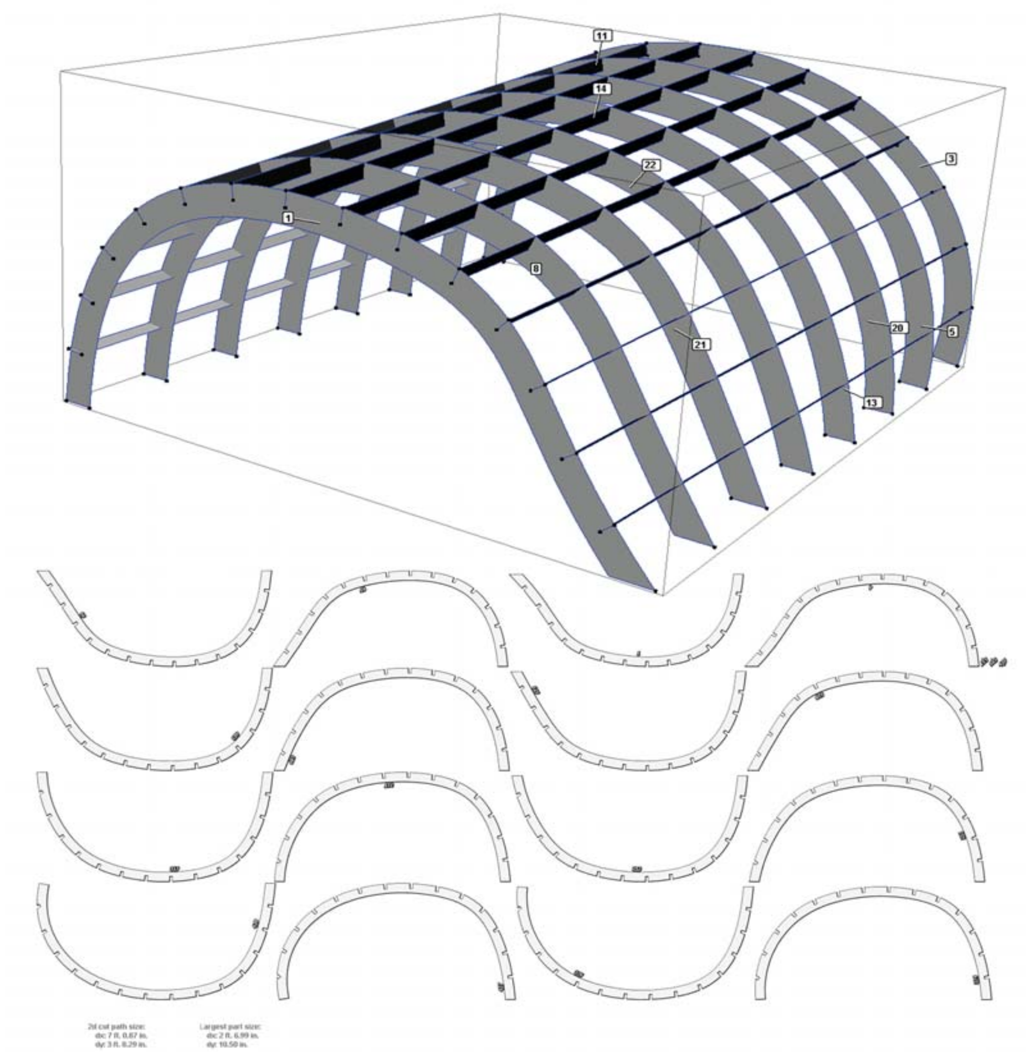


Figure 3.2.1.4 - System for assembly
A visual representation of the assembly is supplemented with labels that match the labels attached to the individual parts. A project description gives a readout of all the project information which is used for quantity take-offs of material, weight, scale, units, and costing.

would be a significant benefit to assist in dealing with the complexity of assembly.

3.2.2 . Sectioning B

This experiment is an iteration of the simple NURBS surface described in the previous exercise. It uses the same logic for a much more complex surface to further show the application of this generative programming and its variability.

Figure 3.2.2.1 - Nurbs Surface 2

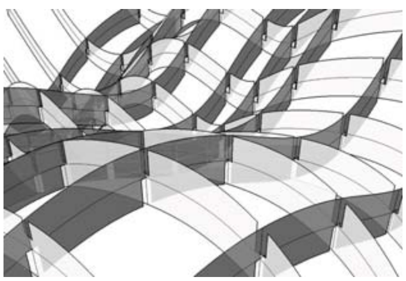


Figure 3.2.2.2 - View of interlocking joints

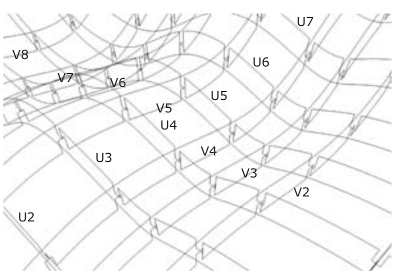


Figure 3.2.2.3 Rhino definition of joints and members

Results:

The experiments provide a means of achieving an accurate approximation of a digitally created NURBS surface that could be used to evaluate formal ideas early in the design process. The physical assembly of these small-scale artifacts provides insight into the issues of assembly, scale, and tolerance. In these situations, the material is forgiving and can be flexed to fit together, which could never happen at a larger scale. Scale becomes a much broader issue especially when thinking of building structural components at their true scale. In these instances we are limited only by the size of the bed of the laser cutter, but in reality the fabrication of large-scale doubly curved members and their actual locations within a construction sequence pose extremely difficult implications. The system also begins to break down when dealing with very complex topologies and extreme curvature.

A key result in this process understands the value of tackling a problem with generative logic and parametric definitions. If one was to try to achieve iterations of a similar nature manually, it would be extremely time consuming since every iteration would have to be rebuilt and would remain static. The automation of such laborious tasks drastically increases efficiency, control, and displaces human error. The value of prolific iterations could help achieve better overall results in a similar time frame.

Once we have created a new tool whose idea originates from a specific application, we realize that the tool can perform a much wider range of applications than originally intended. Figure

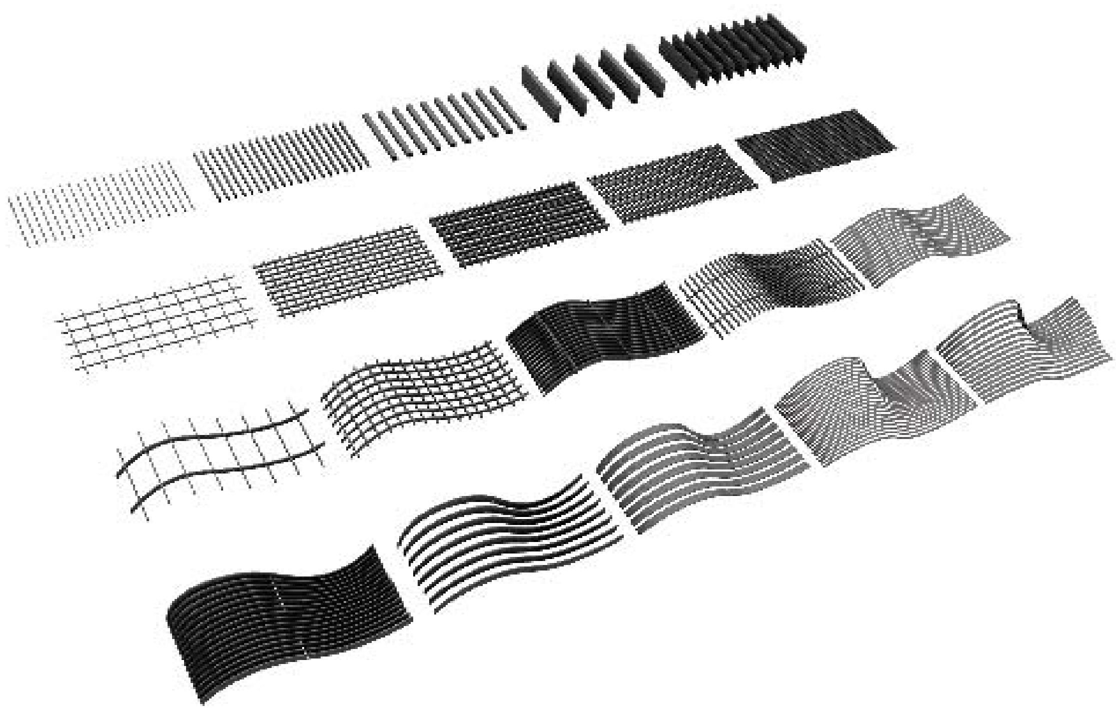


Figure 3.2.2.4 - Further studies
showing use of new tool for a variety of potential applications

3.2.2.4 shows explorations using the same tool to generate new possibilities. These possibilities can be rapidly produced and fabricated into physical objects.

3.2.3 . Sectioning C

Task:

A different approach was taken to try representing the previous NURBS surface. Instead of creating a structural system to represent the surface, which does result in a significant operation and requires the use of a laser cutter, this experiment looks simply at materiality and the surface itself.

Methodology:

If a material has enough flexibility it can be cut so that the curved edges, when joined, can force the material into a desired surface. This poses an interesting notion of applying material sensibility and understanding of the physical properties. This type of knowledge is usually not mutually inclusive in digital modeling and the question of materiality is typically applied after a digital investigation is complete or well underway.

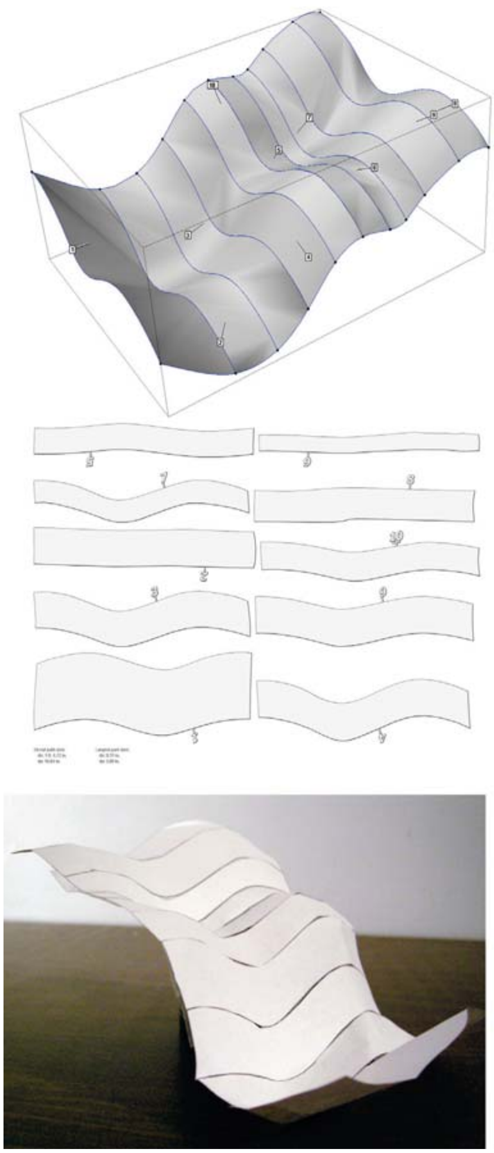


Figure 3.2.3.1 - Paper model of NURBS surface 2

In this example paper is used as the material of choice. Paper is very flexible and easy to work with, yet simply bending it or folding it cannot achieve such a surface or form. It is the edge profile that is required to develop the surface.

Results:

The results of such a simple test are actually quite interesting. At first it seemed doubtful that the desired form could be achieved in such a seemingly primitive operation, yet as layer by layer was taped together the form naturally appeared. Some of the edges with more extreme curvature really begin to test the flexibility of the paper but it is this type of exploration of materials and their limits that helps develop extremely important knowledge in terms of material selection and characteristics.

The results of this experiment show how the approximation of a surface can be done very simply and reasonably accurately. One hour of cutting paper and taping it produced the desired surface and all that was required was paper, tape, and scissors. The nature of the assembly process draws attention to the material properties especially when one is using their hands to join edges together and observing the results. Further experiments could be undertaken to explore the weaving of flexible materials. For example, it would be interesting to attempt to weave thin plywood into a sculptural formwork. The nature of the weave at the edge condition could be performed digitally so that the joint is automated with appropriate perforations by cutting technology. One could then assemble the formwork by simply weaving the edge condition to flex the plywood into the desired topology.

3.3 . Ribs and Panels

Task:

This experiment attempts to fabricate a complex space and surface with two dimensional operations. The initial experiment considered approximation of surface only through straight members. What if the structural members had to be curved in order to accurately construct a desired complex structure or space while yet maintaining manufacturability? What strategies might allow for this to happen? Are they in any way reasonable or realistic? What issues might arise?

Figure 3.3.1 - User input NURBS curves

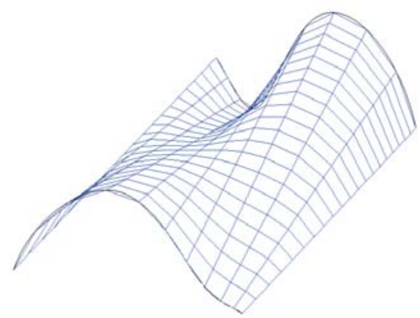


Figure 3.3.2 - User input degree of segmentation in both U an V directions

Goal:

To approximate a complex structure clad with panels.

Methodology:

This experiment is performed with Rhino scripting. The approach is to loft NURBS curves and simplify them into segmented members that approximate the original curve. This segmentation makes it possible to understand the structure in terms of planar elements. The accuracy of this approximation depends on user input-an increase in segments directly results in an increase in accuracy, but only by significantly increasing the level of complexity. The reverse is also true, and the level of approximation is decided by the end-user. Once the user has defined the degree of segmentation, the script approximates the curves with line segments that become the basis for all other operations. These line segments are extruded vertically with

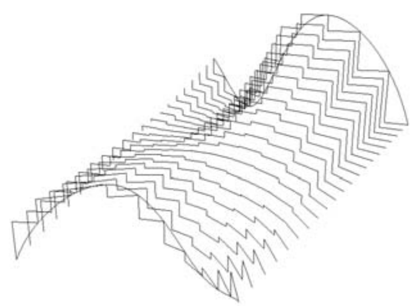


Figure 3.3.3 - Segmentation strategy of surface structure

a parametric operation to define the structural components, which can be resized by re-running the script and changing the inputted values. In this situation this operation was repeated with an offset to create a truss-like structural member. The vertical lines used to generate the truss, by definition, have points both at the base and top of the structural members and are located at every intersection. A search algorithm returns these endpoint values and adds surface planes, which correspond precisely to the structure. Since these lines begin at the bottom of the structural members, an option of creating planes on the underside of the structure also exists.

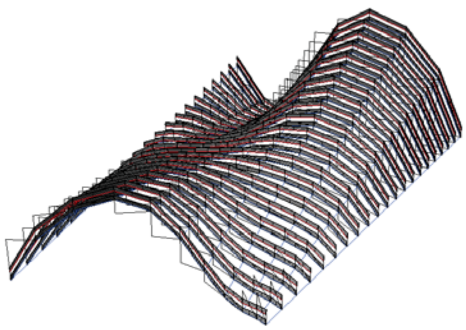


Figure 3.3.4 - Generating structure by extruding and offsetting line segments

Figure 3.3.5 - View of segmented structural truss system

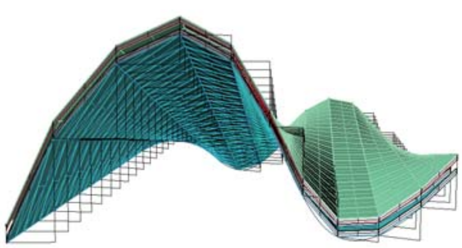


Figure 3.3.6 - Panelization of both top and underside of structure using endpoints of vertical offsets of original line segments

The script can be modified and re-run to achieve as many iterations as desired. In order to change to the overall structure and form, one has to simply adjust the original curves and the script will respond accordingly. It is interesting to note that if one were to make the curves planar, than every structural member will also be planar giving a similar result as the first experiment.

Results:

There are currently numerous problems with this experiment at this point in time. Further development of this tool could make it much more realistic but the level of scripting is quite advanced and difficult. Many of the same issues arise as in experiment 1. The scale is difficult to apply to real scale building components and the strategy of planar elements and panelization should be reworked. First of all, mimicking curved members through segments for the entire structure could be changed to re-sectioning the surface into straight sections and minimizing the curve approximation to the boundary conditions. This will drastically improve manufacturability. Secondly, it is now clear that the search algorithm that creates the panel sections simply does what it is asked and creates the planes whether they are planar or not.

There are three solutions for this. The most obvious is to simply triangulate these planes but that results in an enormous increase in complexity-double the panels and joints. The second solution is to force the generated planes into a planar condition, but they will peel away from the structure. The final solution is to ensure that the geometry offers a surface that is developable. Such a script could be of great use to handle multi-layered constructions in a realistic way.

Another problem that arises is that since the vertical offset is not normal to the geometry it creates a condition of awkward chamfered joints. The script returns planes but if these planes have a depth to them, the edge conditions must be dealt with almost on an individual basis or a high degree of tolerance must be built into the system.

This experiment is beneficial to discussing the manufacturability of design propositions. It makes very clear the need to incorporate proper geometric principles within any design process if we are interested in applying the work in a real-world design context.

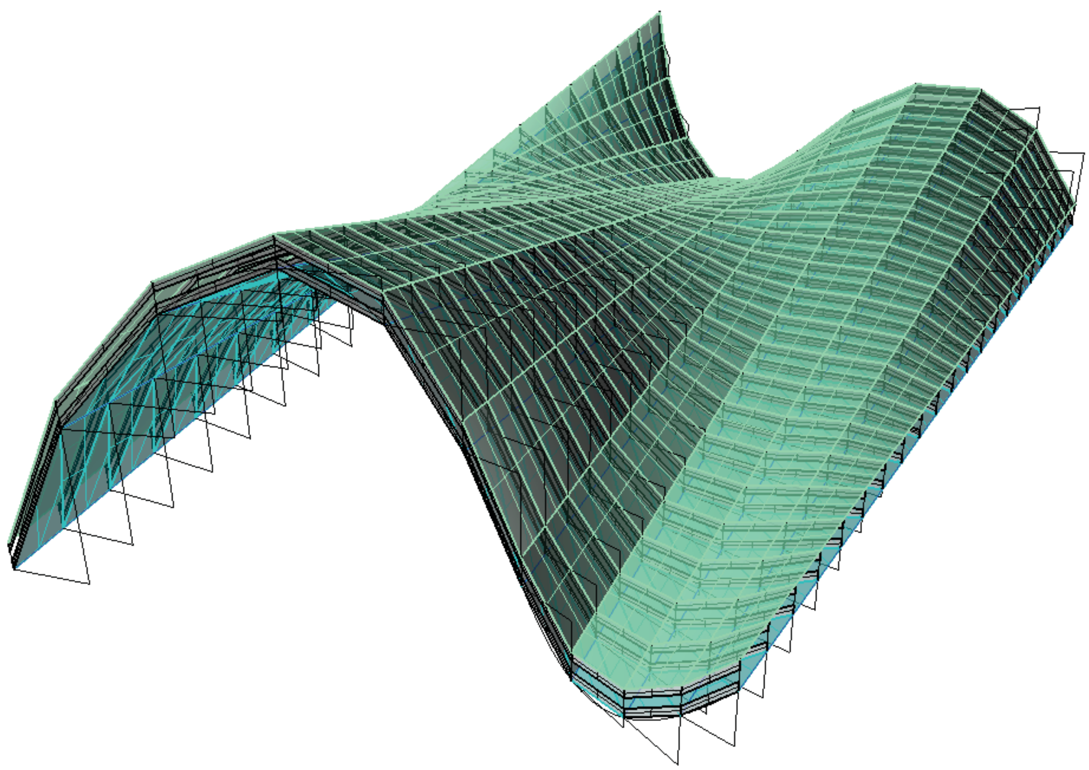


Figure 3.3.7 - Complete rib and panel structure

3.4 . Components

3.4.1 . Component A

Task:

This experiment creates a component system to help evaluate exploratory structures early in the design process.

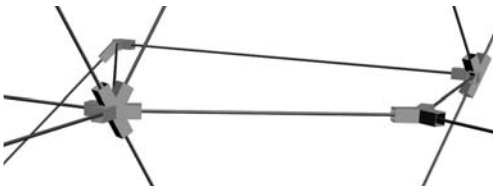


Figure 3.4.1.1 - Components generated at nodes

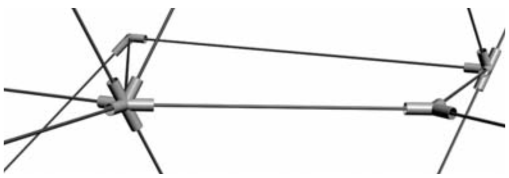


Figure 3.4.1.2 - Components can change size and profile to receive variable types of model building material

Goal:

The goal is to develop a parametric component that can be adjusted to receive typical model building materials such as wood dowels or square stock to allow the rapid assembly of variable and complex structures.

Methodology:

The user inputs the geometry to be built and the nodes of intersection are extracted from the structure. A component is developed at each each node by extrusion of a profile. The profile can be adjusted and sized according to the material to be used for the members. Once the components have been extruded it is up to the user to observe whether the extrusions are

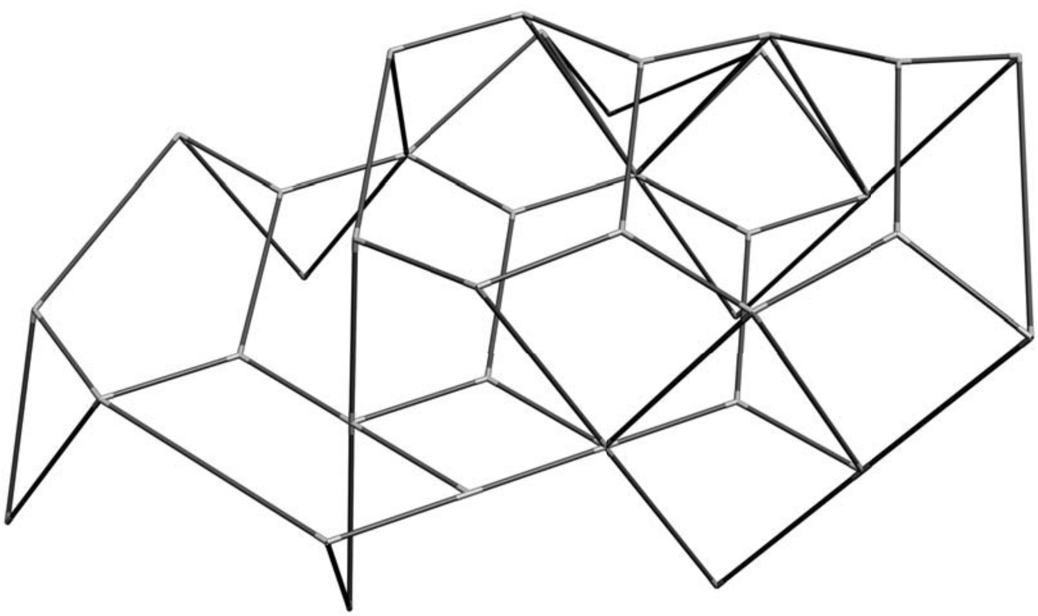


Figure 3.4.1.3 - Complete structure based on 6mm wood dowels

satisfactory and do in fact clear each other. These components can then simply be printed with the 3D printer. A cut-sheet for the lengths of the stock material to be used and a visual aid of the assembly makes for a quick and precise translation of the digital model.

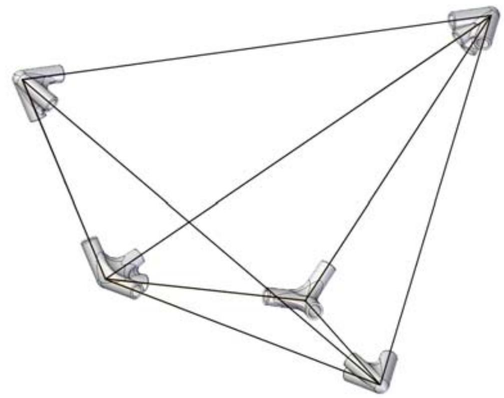


Figure 3.4.1.4 - Visual aid to orient parts in space

Results:

The combination of regular model building materials and the digital fabrication of complex components to join them is a cost and time effective process. Due to cost, the printing of small components with a 3D printer is appropriate, and could not have been done more effectively with any other fabrication technology.


Figure 3.4.1.5 - Component structural refinement to increase integrity prior to print

The generated components were further refined after their initial definition. This was done to increase their structural integrity by adding webbing between them prior to the printing process. This process of optimization cannot effectively be handled through automation, especially when the digital model geometry has to be perfect in order for the software to accept it. Optimization is a significant issue to be considered when trying to perform automated processes and is a much broader manufacturing issue in general.

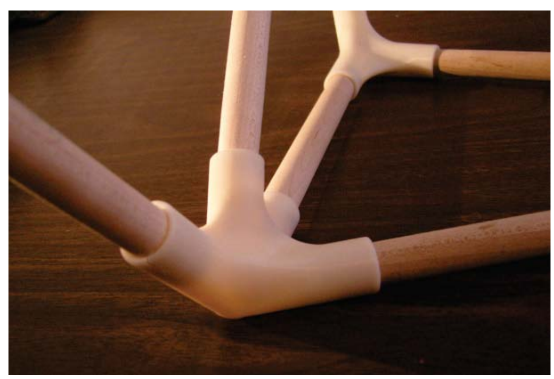


Figure 3.4.1.6 - 3D printed joints

Assembling the structure by hand raises some important observations. Without a visual aid it is very difficult to assemble, especially in this case where the tubular geometry of the joints allows them to rotate slightly. Dealing with the actual physical object and being able to physically rearrange the components and assembly in real time is of intrinsic value for further development of ideas. Seeing an object or assembly digitally, and then experiencing it as a tactile object are two completely different experiences. The physical evaluation in this case was much more valuable than the digital.

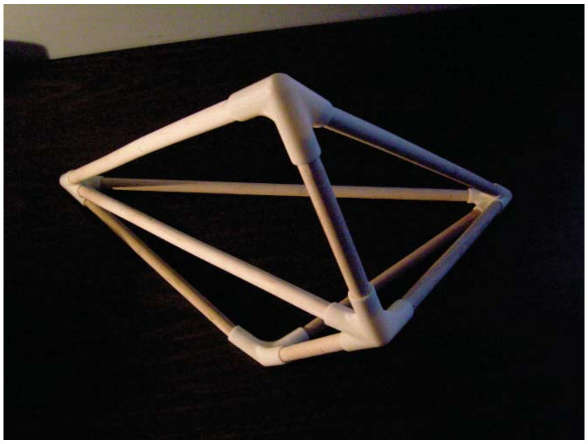


Figure 3.4.1.7 - Test Assembly

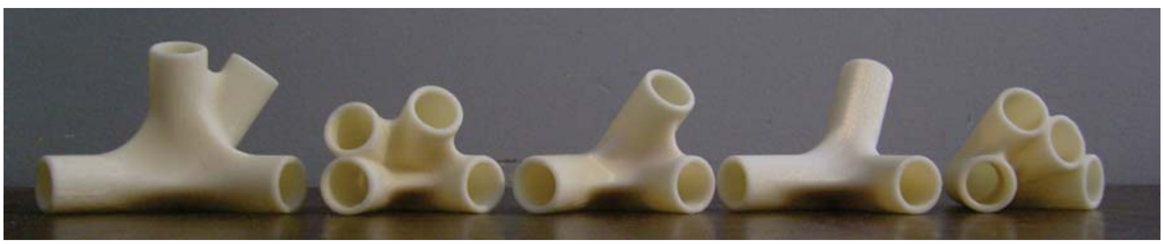


Figure 3.4.1.8 - 3D printed components

3.4.2 . Component B

Task:

To design a relatively complex joint and experience the rigors of having it manufactured. The designed component will be test-run as if it were going to enter production.

Methodology:

The schematic design shows the development of an idea of simplicity and orientation followed by surface sculpting. The result is an object where three surfaces create four joints and every surface is identical-the plan of the object is the same as its elevation. Initially, the idea began with three axis within a circle evenly spaced at 120 degrees each. Then it was decided to include the vertical orientation as well and the horizontal object was morphed with an identical object in the vertical orientation. The edges were then sculpted to create a seamless object. Once the sculptural component was complete, further exploration into possibilities of its application began. Joining and re-combining the seemingly limited components creates a

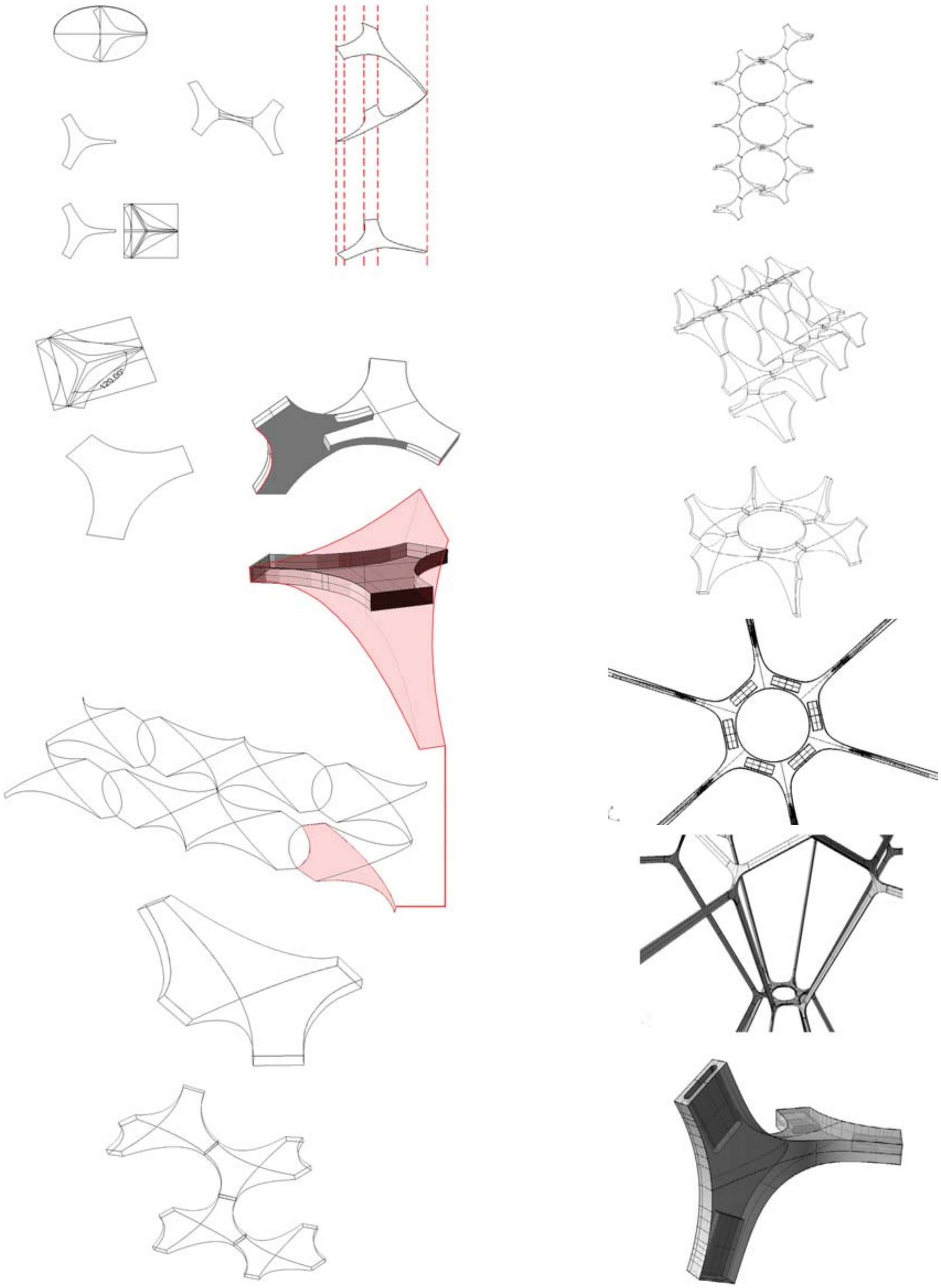


Figure 3.4.2.1 - Schematic design

whole new language of systems and assemblies and provides inspiration for a variety of different applications and possibilities for further investigation. The nature of the object also creates a discussion of the joint. The design of various joint elements becomes a separate design proposition altogether. Currently a single connector joins two components together, but various joint typologies can begin to link structural members and allow them to connect to the components.

The design was then taken to Palcam Technologies located in Newmarket, Ontario for manufacturing. Palcam manufactures dies, molds, and prototypes for a diverse clientele including automotive, aerospace, military, and a variety of associated industries. The shop is primarily set up with arrays of 5 axis CNC milling machines that can handle blocks that weigh thousands of kilograms. The milling machines have different setup orientations to optimize production runs. There are also a number of three-axis machines of varying sizes and typical industrial equipment such as band saws and chop saws. A manual finishing station takes care of any final finishing that the machines cannot do and laser digitizers are used to check accuracy of prototypes and reverse engineer parts into production. The machinery is accessed by an overhead crane system and powerful magnets are used to move parts and change manufacturing jigs. Each milling station has powerful computers to handle the digital processing of information to the machinery, which have their own processing power. The entire production of the component took approximately seven hours. First the digital file was translated into Hyper CAM and scaled to fit within a block of solid aluminum

Figure 3.4.3.2 - Palcam Technologies facility

Figure 3.4.3.3 - Manufacturing process

stock. The operator designs how the machinery can be utilized most effectively. The part must be secured at all times during the process of milling which requires knowledge of the machine's operating limitations and also knowledge of the specific material properties. To have a part break during an operation can be disastrous not only for the cutting tool but also the machine itself.

In this case, the part was machined in two separate orientations. The first operation is to hold the block in a vise and mill whatever is possible for the machine. Prior to this, part of the block is modeled to fit a jig that can hold it once it has been flipped over. This requires complete understanding of the machine's limitations. Simulations are run and become critical to ensuring that the milling machine spindle and cutting tools do not collide with the jigs and rotating table. Each orientation has twelve separate operations meaning that the component is milled in 24 steps using 4 different cutter heads. The machine automatically changes the cutter heads based on the operation designed by the programmer.

Simulations of cutting operations are critical to the process. Animations are used to check for clearances between cutter head, machine spindle, and the jig holding the part. The jigs are controlled by hydraulic pressure-by adding or subtracting fluid from the bed of the machine that holds the jig.

The final operation is manual. The remaining parts are cut off and the surface is polished. This exercise makes it clear that it is very easy to underestimate the amount of embodied knowledge that is required to create such a component. It is remarkable to experience how intensive the process really is. It requires a high level of skill, experience, and mastery over the production machinery. And even at the end of the process we still don't know if this would be the best way to make such a part.

Figure 3.4.3.4 - Completed component

4 Part 1 Critical Review:

Part 1 of the research work thus far provides us with a pretty thorough picture of the current mainstream paradigm. We began with the effects of the digital revolution and the advancements of the architectural profession as a result. We discussed the new capabilities available and how this has resulted in the increased diversity of the built environment. We covered new areas of research and the changing of roles within the profession. We also looked at where the inspiration for much of these technologies has come from and further interdisciplinary possibilities. After this overview, we examined four architectural practices that are considered by the author to be operating at the forefront of contemporary practice. We then dove into a series of experiments that reflect current digital fabrication techniques; sectioning, tessellating, scripting, and examples of additive and subtractive fabrication.

Although, fundamentally and personally, the research concerning the impact of advanced technology on architectural design, practice and fabrication is extremely interesting and valuable, it has become obvious through reflection and discussion that the current paradigm is one that tends to be bound up in the techniques of its own construction. The author himself, throughout the course of this research, has experienced this consuming dogma with unease. A rampant fascination to embrace technology in all of its forms seems to have led the discipline into losing itself within self-referential exercises that are meaningless outside of the profession. A good portion of the works studied by the author over the last number of years (certainly not all), reiterate this rampant fascination that has resulted in a limitless number of gratuitous projects that do not seem to claim any one motivating principle beyond technique for the sake of technique; form for the sake of form. Certainly technique is a part of the cultural situation, but we cannot forget about the more important underlying issues. Architecture is primarily a socio-cultural production, and not technological determinism.

Instead, architecture should generate behaviours in its built fabric rather than simply pursue form. It should act environmentally, structurally, programmatically, economically, contextually, or in any other multiplicity that has purpose and cultural relevance. The case studies of the selected practices were chosen for the very reason that they display this type of multivalent approach that is meaningful. If we are able to develop some narrative of use, then at the very least it can provide a necessary guiding principle to our endeavors. But beyond today's exceptional practices, what is the new paradigm? What can architecture do for technology instead of the other way around?

The chosen answer is to study *matter*. Matter has the potential indeed, as Kwinter has spoken of, to become the ‘new space’. Matter will not necessarily offer forms, but more importantly, processes to think about form; recipes that mix material and environment. From these mixtures and relationships, form will emerge. Architecture , in conjunction with computer-based design and analysis tools, has the means to adopt a much more serious incorporation of matter into our work. The physics of our universe, the studies of force, substance and mass are examples of possible architectural mixtures for technology to follow.

We have seen how the mainstream design paradigm typically works: 2D or 3D forms are generated and then sent to engineers for analysis and optimization. A study of matter should allow us to turn this design paradigm on its head; we start from the analysis and material properties, and begin to allow these to generate form. This inversion should develop ideas that will help invent new technologies and contexts for a particular purpose, instead of exploring existing technologies and seeing what we can do with them.

The following sections lay the foundation for such a scenario.

5 Part 2: Developing a Critical Agenda

5.1 . Introduction

The growing awareness of ecology and sustainability, global warming, rising fuel prices and renewable resource depletion are major concerns in our resource driven economy. As a result, the negotiation of performance criteria, engineering, and fabrication with design has been a central topic for contemporary architectural discourse. The emerging tools of the digital workspace have re-established energy driven form finding in architectural design through a range of analytic tools that can encode real world physics. This ability to simulate reality makes possible “form generation models that recognize the laws of physics and are able to create ‘minimum’ surfaces for compression, bending, and tension” (Cook, 2004). For example, common finite element analysis uses algorithms to imitate the physical quantities of force and material properties. This allows us to use actual quantities of the physical world as design drivers. This approach to energy, where we organize matter into optimal configurations and the consumption of matter and energy are minimized through intensive research on form (Antonio Gaudi, Buckminster Fuller, Frei Otto) is certainly familiar to us.

Not so familiar is the approach to energy proposed by Cristina Diaz Moreno and Efren Garcia Grinda. Their suggestion is to instead seek systems in which the formal and material characteristics are driven by thermodynamic exchanges:

> “The goal is a dynamic vision, with systems regulated by processes of energy exchange, with exteriors that dissipate, consume and capture energy: in short, complex organizations defined to manage energy through their formal characteristics, technical devices and material definition, all of which evolve over time. A building is no longer just the material form adopted by a particular and singular energy configuration, but a complex thermodynamic system that works through cold or heat, with or without order, with differences or homogeneity, and also evolves over time” (Moreno, Grinda, 2009).

Essentially, they wish to replace both our technical culture and visual predominance with a climatic approach. Instead of being “fixated on what we typically have-geometric composition, constructability, structural thinking, surface design, parametric blankets or the proliferation of identical but different components, our aim is to define meteorological fields and landscapes at small scale” (Moreno, Grinda). Their approach also criticizes the typical response of form, which usually accounts for a singular energy configuration. Philippe Rahm, in a similar frame of mind, asks:

> “Might not climate be a new architectural language, a language for architecture rethought with meteorology in mind? Might it be possible to imagine climatic phenomena such as convection, conduction or evaporation for example as new tools for architectural composition? Could vapor, heat or light become the new bricks of contemporary construction?” (Rahm, 2008)

It is the negotiation between these very different approaches to energy where this thesis develops a methodology and establishes a definition for an ‘energanic’ architecture. The term energanic, coined by the author, reflects this negotiation of energetic thinking; the coupling of real world physics with the imaginative possibilities of natural phenomena and energy exchange methodologies.

5.2 . Matter, Structure, and Form

5.2.1 . Defining Matter

Although the general definition of matter is ‘anything that has mass and occupies volume’, there is no single accepted meaning of matter, as different fields of science use the term in different ways. The search for a definition that explains the fundamental building blocks that make up the physical world around us is one that has been contemplated throughout the history of natural science. And yet, “it is normally stated that radical transformations of matter are those that bring about drastic and authentic revolutions in our discipline”(Moreno and Grinda, 2009). Without the time to explore the numerous theories, the thesis borrows an understanding of matter described by Henri Bergson in 1896:

> “Matter is a cohesively operating network of discrete energy states, synthesized by modifications, perturbations, changes of tension or energy and nothing else” (Bergson, 1896).

This is simply understood as matter being defined and determined by energy. Matter’s infinite numbers of permutations are all “aggregates of the same fundamental building block differing only in levels of organization and order” (Frumar, 2008). This thesis is not suggesting pursuing a transformation of matter per se, but rather the way we view matter. If we could develop an idea of what these (energy) transformations might be or how they could be modified, it could lead to ideas of future materials, systems, and contexts that are not based on the revelation of new techniques but instead on the ideas themselves. In doing so, we would be giving emerging technologies a badly needed *raison d'être*.

5.2.2 . Force, Action, and Form

When we turn to the actual material world instead of the abstract nature of matter in general, the discussion becomes one of force, action, and form. There are numerous analytic tools available that allow for a clear and accurate mapping of forces within materials. What is more interesting and less discussed is the relationship between force and form, where form results from this direct interaction between a material and force or through the imposition of exogenous forces. The meaning of form has always been and always will be a central topic for architecture. Certainly Louis Sullivan's famous phrase from 1896 where "form follows function" is better known than Ann Lee's description, where "every force evolves a form" (Davenport, 1981). Deleuze, using Nietzsche's philosophies on form, describes every object as "an apparition of a force" (Deleuze, 1983). In the 1740's, French mathematician Pierre-Louis Maupertius developed the principle of least action, which demonstrated that in all natural phenomena, a quantity called

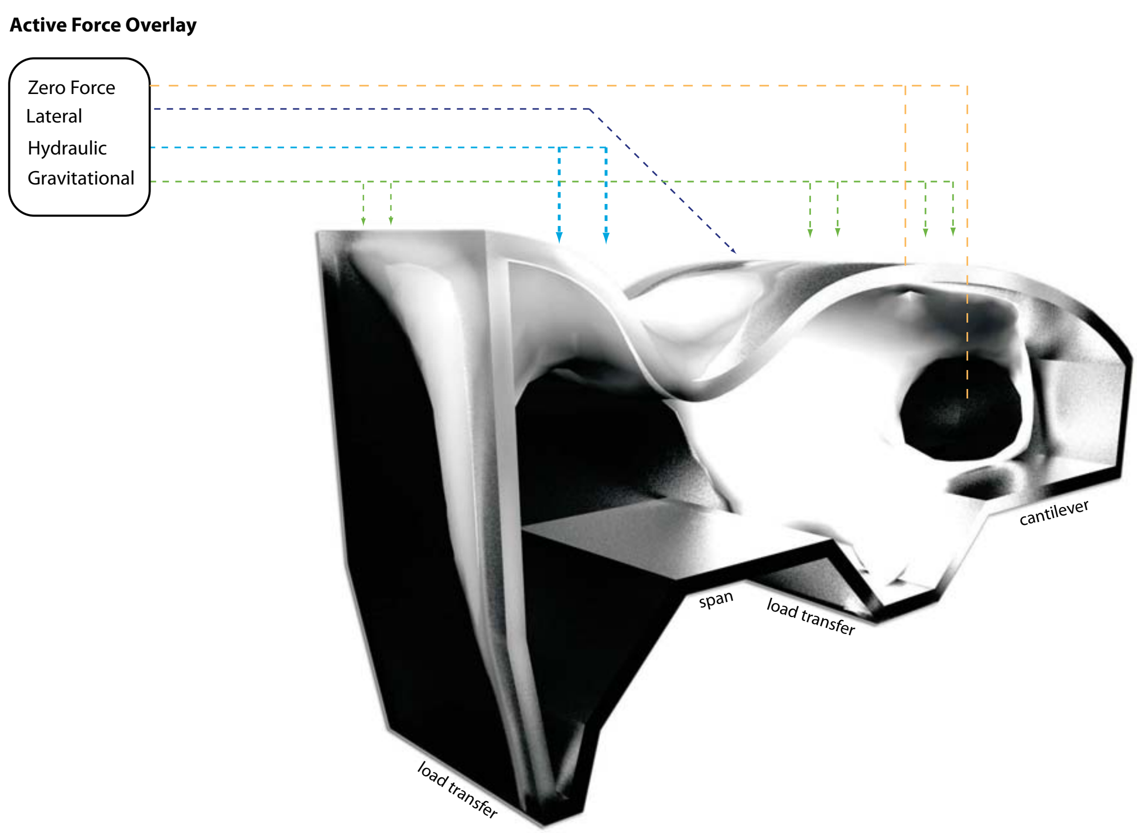


Figure 5.2.2.1 - Abstract digital geometry vs. Energetic digital geometry
This figure, prepared by the author, shows an active force overlay that represents the morphogenesis of form according to loading conditions described. It visually depicts where the structure is required to be thick and where it can be thin, in striking contrast to an abstract digital form.

action will always be minimized. In other words, an object, when subjected to forces, will follow the path of least work. D'Arcy Thompson, in his book *On Growth and Form*, states that "the form of any particle of matter, whether it be living or dead, and the changes in form which are apparent in its movement and its growth, may in all cases be described as due to the action of force" (Thompson, 1917). Thus, the elegance and efficiency we observe in natural structures are consistent with these characteristics, and lead to the belief that force and action regulate the ordering of matter, and consequently, form and structure. Jerome Frumar succinctly sums it up: "force and action are vital features of the energetic continuum that shapes our universe" (Frumar).

5.3 . Energy Driven Form

5.3.1 . Local Change, Global Consequence

We have established the notion that matter is ordered by energy. The principle of least action also implies that matter has the ability to self-organize. Both organic and inorganic materials respond to external forces in such a manner, restructuring to channel forces evenly and efficiently. This phenomenon can be adopted as a design methodology for architecture; where we utilize digital processes to emulate the real-world morphogenesis of form.

In his essay *Landscapes of Change*, Sanford Kwinter discusses the morphological ordering of matter by energetic forces and provides metaphors for systems and processes that designers can engage with. Kwinter highlights Waddington's diagram of an epigenetic landscape as a visual representation of such a design process. The diagram represents a flexible landscape of dynamic equilibrium in which a local change is "relayed throughout the system…to affect,

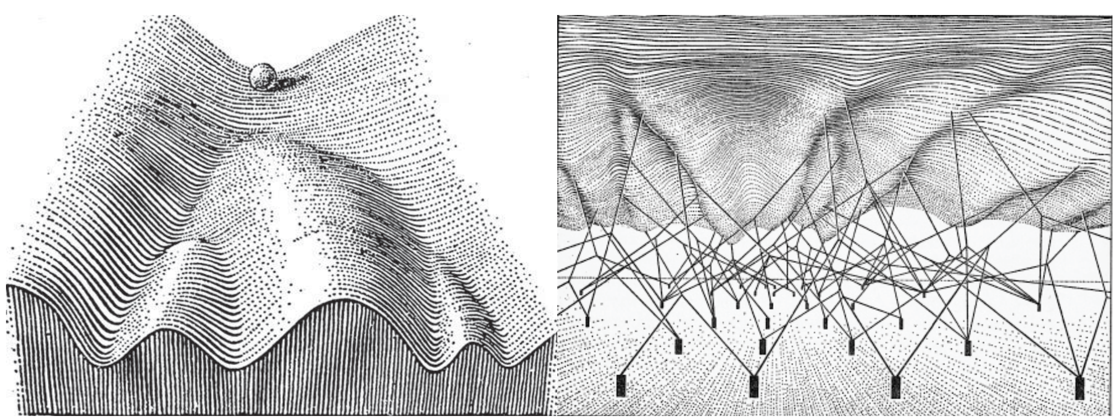


Figure 5.3.1.1 - Conrad Waddington, Epigenetic Landscape

in turn, conditions all across the event surface" and where "global behaviour is an emergent property unpredicted by local rules" (Frazer, 1995). Kwinter then challenges designers to explore this type of realm, where "forms exist only in evolution or equilibrium, that is, as event-generated diagrams" (Kwinter, 1992). His challenge, to utilize the principles of self-organization, evolution, and equilibrium as design processes, is one that suggests the deployment of generative digital processes. How difficult of a challenge or tall of an order is it? He is asking for a dynamic design process that is somehow infused with the sensitivity of life itself.

5.3.2 . Frazer's Evolutionary Architecture

In 1995, John Frazer responded to the metaphors and challenges posed by Kwinter through his book *An Evolutionary Architecture*. He proposed a strategy that uses computing to model physical, material, and environmental characteristics in a simulated process of self-organization and evolution. He wished to pursue an architecture that would express the "equilibrium between the endogenous development of the architectural concept and the exogenous influences exerted by its environment" (Frazer, 1995). Evolutionary architecture is defined by a set of designer rules, a genetic code that responds to external forces by self-organizing into optimum minimal form (Frumar). The architect defines a generative system that can produce infinite variations from which to choose from, and thus, changes form making into form finding. In order for 'evolution' to occur, the critical step is how to abstract physical, environmental, and material characteristics into a digital language that can be translated into architectural design. The distinction of form *finding* versus form *making*, is of utmost importance, because it explicitly moves energy and force to the foreground of the design process.

5.3.3 . Wiscombe's Vascular Systems of Energy

The problem with typical engineering, argues Tom Wiscombe, is that it still falls under the Otto-esque mantra of 'optimization', which has developed "a mental block for the profession at large because it assumes a single optimum condition rather than a multi-optimal ecology" (Wiscombe, 2009). Wiscombe gives us an example of how a 'multi-optimal ecology' could work, using a typical beam condition one might find in any given structure:

> "If a beam becomes a luminous pleat that can also move air, it may not result in the most efficient beam or duct or lighting system, but it will do work, and more importantly, it has the potential to produce nuanced jungle-style architectural effects. This is, to be clear, not an issue of engineering, but rather of design" (Wiscombe, 2009).

The example provides an interesting parallel with biological species where mutations, possible advantages or inefficiencies, and functions are not necessarily legible or obvious because of

Figure 5.3.3.1 - EMERGENT, Lizard Panel Facade, 2009
A facade prototype combining a greywater capture system with an algae photobioreactor system in a way that produce sstructural as well as ornamental effects

the nature of a 'multi-optimal' approach. It is this type of give-and-take attitude, where overlaps of form and function allow multiple types of work and energy configurations to occur, which is needed to liberate us from our tendency to operate on the singular configuration. In such a spirit of compromise, one optimal configuration may be superseded by another, or perhaps neither even approaches peak optimization when viewed individually, yet it makes sense when viewed together.

The beam example also expresses a different type of prefabrication than we are accustomed to. It is a composite assembly that is integrated as a three-dimensional 'chunk' versus the typical industrial prefabrication of the postwar era that assumes the individual and separate layering of structure, skin, fluid and airflow devices, and lighting. Wiscombe's beam presents a powerful example of what an energetic prefabrication system could be, one where the design of elements appear to be more like vascular systems. His work is also unique in that it engages with prototypes of parts or 'chunks' without necessarily concentrating on any whole at all. This, he describes, is intentional:

“Importantly, they are not cells or agents that aggregate into scripted swarms, nor are they processed though a parametric gradient routine or ‘blendshaped’ into a visual whole. They are not parts to be repeated or varied in an array-a characteristic of false emergence; rather, they are fragments of a whole that does not yet exist and cannot be predicted” (Wiscombe).

5.3.4 . AMID (cero9)’s Thermodynamics

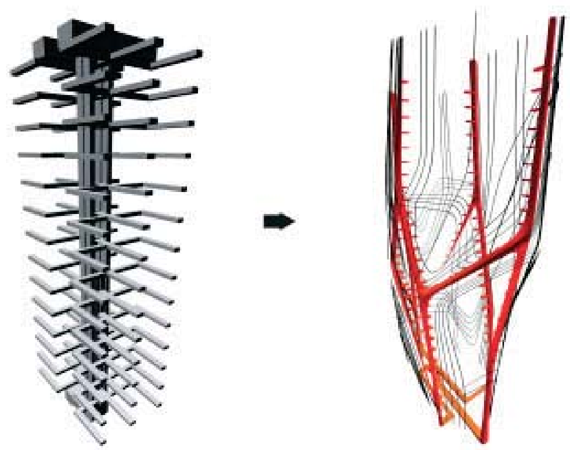


Figure 5.3.3.3 - EMERGENT, Guiyang Office Tower, China, 2008
The aim of this project, based on hybridising structural, mechanical and lighting systems, was to avoid expressing the literal image of technology in favour of ambient atmospheric effects. Supercolumns become hybrid ducts, while a pattern of micro-pleats runs along surfaces, housing a heat-exchange system for cooling. At night, the beam ducts glow from behind the glass skin, creating elegant colour effects and gauzy silhouettes.

The approach to energy driven form explored by AMID (cero9) is also one that seeks a plurality of techniques operating at various scales. AMID (cero9) suggests that instead of working with energy to organize matter into an optimal (minimum) condition, we should be engaging energy with respect to thermodynamics. In other words, we should focus on systems of energy

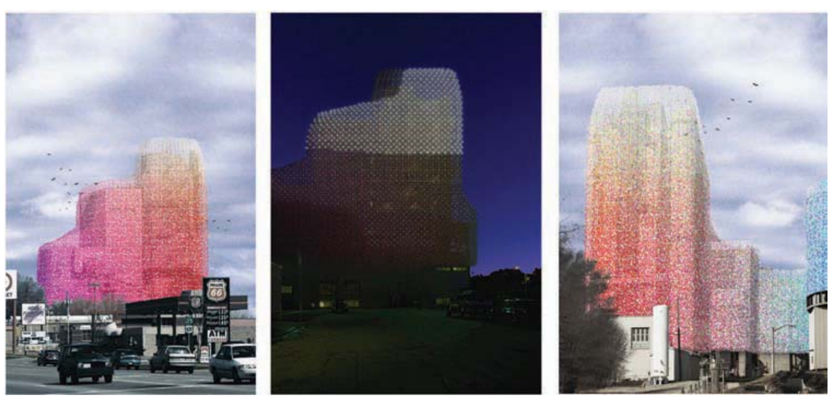


Figure 5.4.3.1 - Ames Powerplant
Converting the latent heat of a powerplant into a natural, artificial monument

conversion. By doing so, the formal and material characteristics will be driven by these energy conversion systems. In this scenario, the formal characteristics, technical devices, and materials will all be defined by their ability to manage energy; a complex thermodynamic system that generates its own action and form. Much of their work produces architecture that is like a 'machine', one that not only makes its own environments but also produces ideas about nature and possible future environments.

A good example of their method is reflected in their international competition entry that proposed the transformation of an enormous thermal power station in the city of Ames, Iowa, into a 'magic mountain' (2002). The architects proposed transforming the power station into a new, artificial landscape within the city. This was achieved by challenging the established methods and concepts of gardening, species breeding, and 'natural' ecology. The power plant was to be entirely covered with a membrane of roses, honeysuckle and lights that would unify the volumes of the existing power station with a single common material. Using the latent heat of the power station, the membrane would transform it into a vertical garden of living walls. The vegetation of this shroud was based on the genetic material developed by a local citizen, Griffith Buck, who grew many species of roses that were adapted to the harsh local climate. It was to be planted in a grid of recycled polypropylene pallets that were mechanically attached to the reinforced-concrete walls of the station, while a structural box girder at the base would contain the necessary soil for the plants to grow. A perimeter pathway between the shell and the walls was

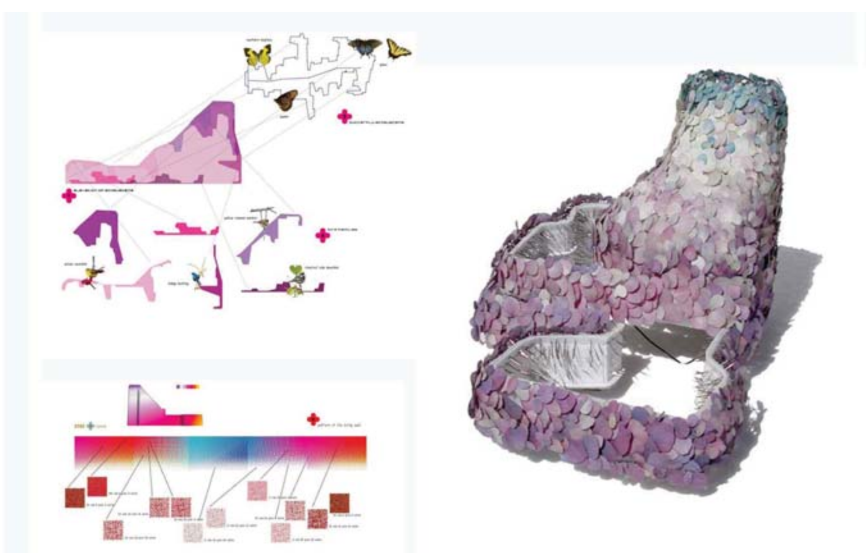


Figure 5.4.3.2 - Ames Powerplant
Energy infrastructure, heat transfer, bio-enginnering, and human interaction reconsiders nature in the city

incorporated to allow for maintenance, pruning and upkeep of the plantings. The city of Ames is located on an important North American migratory route and the membrane would attract the most important butterfly species in the northern US, at the same time transforming the power station into a bird sanctuary that would find attraction for the water tanks and insect populations in the vertical rose garden. The power station thus provides a resting place for migrating birds –an artificial alternative to the forests and wetlands that in recent years have disappeared from this area, and an ecosystem that is dependent on human interaction.

Here, architecture and energy infrastructure create a compelling story. A decrepit monstrosity, typical of North American cities, is converted into a living system using bioengineering techniques to create a 'natural' monument that is generated artificially.

5.3.5 . Rahm's Invisible Architecture

The work of Philippe Rahm has been initiated by a reaction to the mobilization of the building industry to tackle global warming. The building industry has attempted to lower CO2 emissions with measures such as improving insulation standards, using renewable resources, calculating the life cycle costs of materials, focusing on compact building design, and so on. Although these social and ecologic objectives are commendable, the work of Philippe Rahm implicitly provokes us to think that perhaps these responses to our global problems are too simplistic or reductive. Instead of dallying with end-of-pipe type solutions as we typically do, Rahm challenges us to expand our horizons by suggesting that climate itself could become an architectural language:

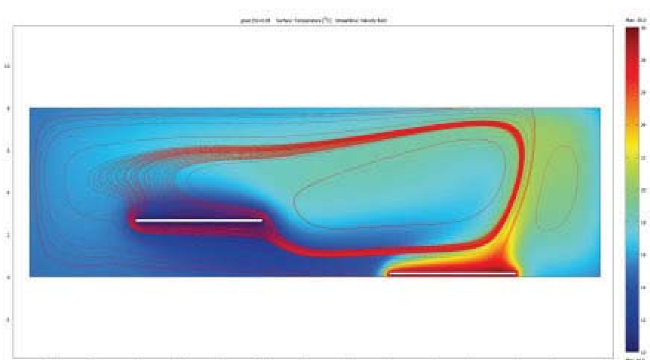


Figure 5.3.5.1 - Philippe Rahm's "landscape of heat"

> "It is no longer a case of building images and functions, but of opening climates and interpretations; working on space, on the air and its movements, on the phenomena of

conduction, perspiration, convection as transitory, fluctuating meteorological conditions that become the new paradigms of contemporary architecture; moving from metric composition to thermal composition, from structural thinking to climatic thinking, from narrative thinking to meteorological thinking" (Rahm, 2009).

In his work, by using climate as a driver, the interactions of energy and space begin to reassemble the structure of social and cultural life. For example, in his Archimedes House (2005), Rahm investigates how the simple rising of hot air could transform the spatial organization of a single-family house into a more energy efficient object. If heat rises, which rooms would we want to be the warmest and most humid and which the most dry and cool? By inverting the traditional home, the three-story house becomes larger as it rises and harnesses

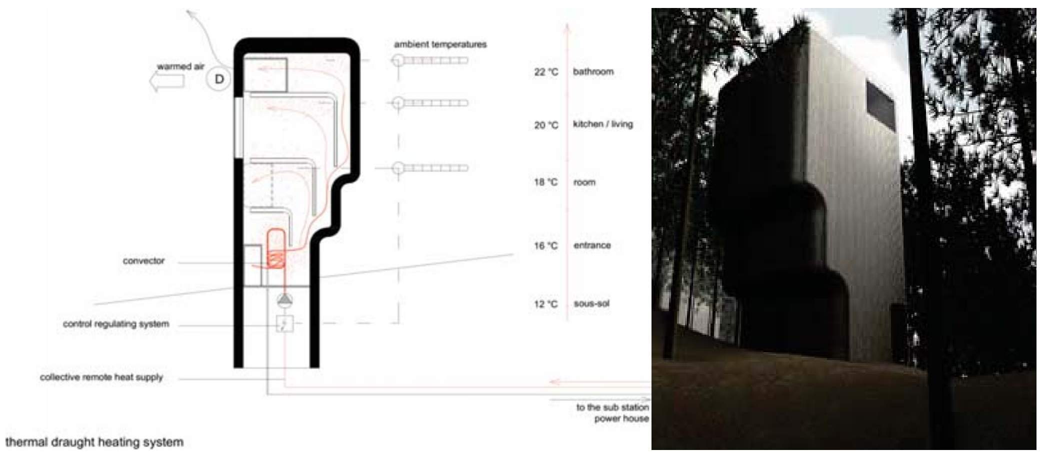


Figure 5.3.5.2 - Philippe Rahm's Archimedes House

heat, with bathrooms on the top floor and living spaces on the bottom. The home is 'driven' by a heat exchanger in the basement that links the levels together (Gissen, 2009).

Rahm's architecture is based on the invisible properties and phenomena of different forms of energy. By encoding his work with the climate-related aspects of space-radiation, pressure, convection, evaporation, conduction, and digestion, new concepts, sensualities and forms of architectural composition arise that are much more than simply a critique of existing strategies; they are a new philosophy and manifestation of energy driven architecture that has the ability to invert and agitate social conceptions.

5.3.6 . R&Sie

The technologic experiments and operations of R&Sie are provocative engagements with building, context, and human relations. A common theme linking their varied projects is the search for any means possible that architecture can perform ecologically useful functions. Their architectural structures are shaped by organic, robotic, and climatic processes, all of which help to create territorial changes, parasitic relationships, and vegetal and biological dynamics.

In many circumstances, R&Sie capitalize on the most unpleasant aspects of a location, whether it is pollution, mosquitoes, or any other disturbing agents. Yet behind the organic and biologic projection of their work, there is a critical view of current modes of 'sustainability' and a quiet reliance on innovative energy transactions and devices. For example, in 2002 the firm developed a proposal (In Dusty Relief), for a new art gallery, that considers the role of the "white cube" gallery in the context of Bangkok, Thailand. This is a city known for its high degree of

Figure 5.3.6.1 - R&Sie: In Dusty Relief
Electromagnetic dust collector; white box galleries 'clad' in pollution

environmental control and 'sustainable' ideals, yet the dust and particulate matter is so heavy that it even has the capacity to modify the climate. The gallery is organized into several box-like volumes that are designed as contemporary display areas that aggregate into a multi-level stack of spaces. Surrounding these volumes, the architects wrapped an electrostatic skin that attracts the dust and pollution from the surrounding air, filters the air, and maintains appropriate qualities for the space within the skin. The juxtaposition of the white cube, aseptic and globalized gallery experience of art and culture, wrapped in pollution and relying on that same pollution, is a brilliant provocation.

In Hybrid Muscle (2003), R&Sie displays the breadth of their imagination. Who would have thought to use a buffalo as an “engine” to generate power for an exhibition space? The animal was used to lift a two-tonne steel counterweight and the mechanical energy stored through the lifting of the weight was transformed into enough electrical energy to power ten light bulbs, a laptop, and cell phones.

Figure 5.3.6.2 - R&Sie: Hybrid Muscle

In Unplug (2001), R&Sie was commissioned by the French Public Electricity Company to develop an office building. Their proposal was a building ‘unplugged’ from the energy network that would gain all of its energy from the sun through a reactive façade; a façade covered in hair-like thermal sensors and a swollen skin of photoelectric cells. It is a great example of a fusion between a profound understanding of biology and the abilities of computer technologies and manufacturing capabilities. The building is equipped with photovoltaic surfaces and solar collector tubes that provide the building with heat and hot water. The skin is very flexible and acts like “an absorbent flesh” primarily for the purpose of reorienting the photovoltaic cells throughout the different seasons of the year. This project is commendable because it does not take natural processes literally but instead attempts to interpret them according to known technology.

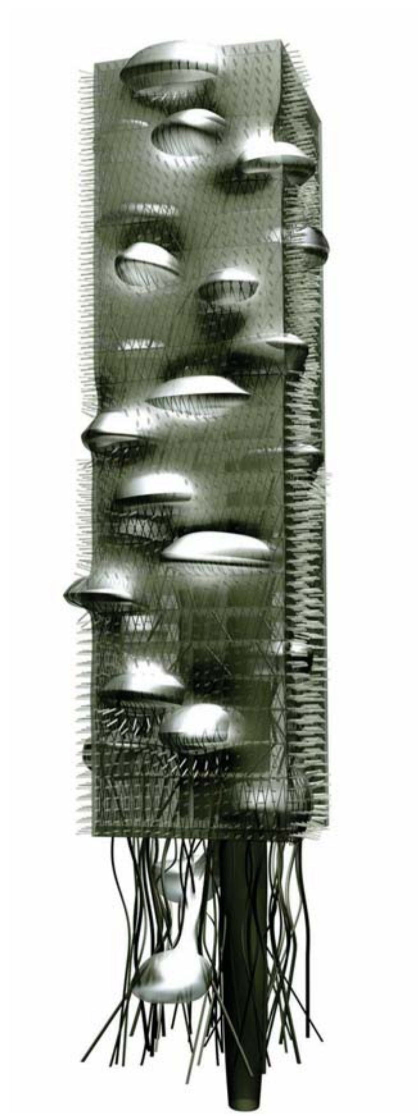


Figure 5.3.6.3 - R&Sie: Unplug

5.3.7 . Lally’s Energy Fields and Boundary Conditions

The work of Sean Lally, similar to AMID (cero9), Rahm, and R&Sie, seeks to build new environments, climates, and contexts that explore new types of social interactions, activities, and spatial organizations. Lally describes his work:

> "These should be investigations into the creation of contexts and sites previously unseen and tested, presupposed to be either out of our range of implementation or simply discounted as being unable to absorb the responsibilities associated with architecture" (Lally, 2010).

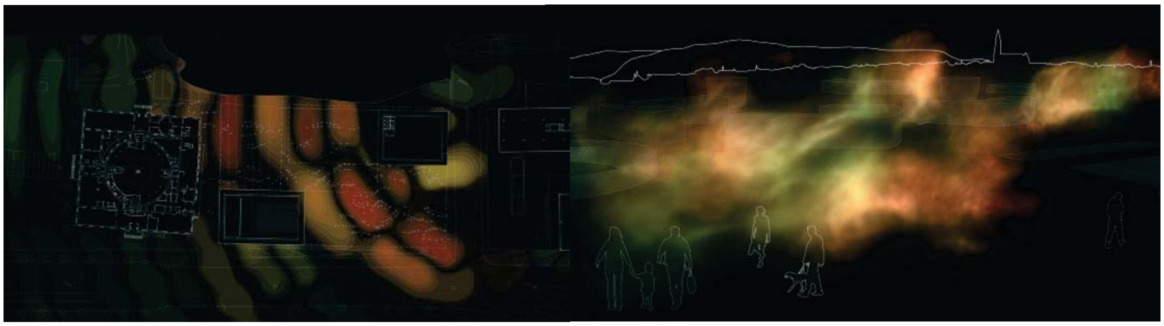


Figure 5.3.7.1 - Vatnsmyri Planning Competition, Reykjavik, Iceland, 2007
An urban plan defined by gradient thresholds. Originating from the existing geothermal resources, the air, sculpted earth mounds and vegetative soil are warmed, creating variable microclimates for recreational activities, circulation and site organisation.

What is unique about Lally's approach is a very specific attack on what it is that constitutes a physical boundary in architecture, and ultimately, where the responsibility of an architect begins or ends in relation to such a boundary condition. If we examine the scientific definition of a boundary, physicists define a boundary not as a tangible thing, but rather as an action, seeing the environment as an energy field where boundaries are transitional states of that field (Addington, Schodek, 2004). Boundaries, therefore, are understood as a behavior rather than a physical object. This also means that they remain variable and exist only when energy is transitioning from one state to another. Meteorologists, climatologists, and engineers utilize a variety of techniques for visualizing gradient conditions such as atmospheric pressure, thermal boundary, and air velocity.

If we think of our cities and buildings and the amount of heat, light, pollution, and other forms of energy they expel, we realize that they create aggregates of all sorts of microclimates that are completely unintended or not thought of because of their association to the exterior climate. We know that these material energies are clearly no longer outside of human action. An extreme example of such action is China's modification of weather patterns using artillery (2008 Beijing Olympics). Beijing officials had set up several banks of rocket launchers outside the city that could blast threatening clouds with silver iodide and cause them to release their rain before it would reach the capital. This in effect, dramatically increased the boundary of the city, from a boundary on the ground to one now thousands of meters in the sky (Wade, 2008). Lally's work, although not nearly as extreme, makes a case for imagining ways to harness energy fields and explore their spatial and social implications.

Figure 5.3.7.2 - WEATHERS, Wanderings, 2009
Microclimatic zones are created with the aggregation of independent components that serve to manipulate specific aspects of the climatic variables in their vicinity and introduce opportunities for augmented natures and environmental contexts.

5.4 . Summary

Climate change, environmental degradation, and resource depletion are central topics for current architectural discourse. They have become the focus of competitions, educational curriculums, and research practices. Thus, the development of an energetic agenda is very relevant to the global concerns of our time.

An important distinction of this agenda is the shift from geometry as an abstract regulator of the materials of construction to an idea where matter and materials are involved and evident in the geometry itself. We defined matter as something that is determined and defined by energy. This in turn led us into a discussion of force and form; where form became the evolution of force. We then criticized that the modernist engineering tendency to optimize for efficiency is too one dimensional of an approach for energetic thinking, that it precludes other possibilities of organization, program, and effects. The goal is to proliferate all potential opportunities inherent in the matter-force relationship.

Through a number of practitioners, we were able to see examples of variations in energetic thinking and the kinds of results that have arisen out of the process. AMID (cero9) presented a powerful case of energy driven form that generated a new form-an artificial ecosystem that is dependent on human interaction. Tom Wiscombe described how a multiple-ecology could work through the often, illegible overlaps of form and function. Phillipe Rahm made the suggestion that climate itself should become an architectural language and backed it up in a process that resulted in the reorganization of social space. Behind the organic and biologic nature of the work of R&Sie, we discovered a critical view of 'sustainability' made evident through provocative and innovative energy transactions and devices. The work of Sean Lally raised the important notion of boundary and examined the social and spatial implications of energy fields typically not explored.

As a collective, the work of these practitioners makes a very strong case for an energy-centric approach to architecture. The mixing of imaginative possibilities, energy driven form, the harnessing of natural phenomena, the development of energy exchange methodologies, all lead to a definition of an *energanic* architecture.

6 Design Prototypes Produced

6.1 . Fibrous Muscle

This prototype represents the beginnings of a proposed fabrication system of energy driven form. A volume of enclosed space that meets the set program requirements has undergone testing for potential solar gain and aerodynamics. This is achieved by setting up a parametric

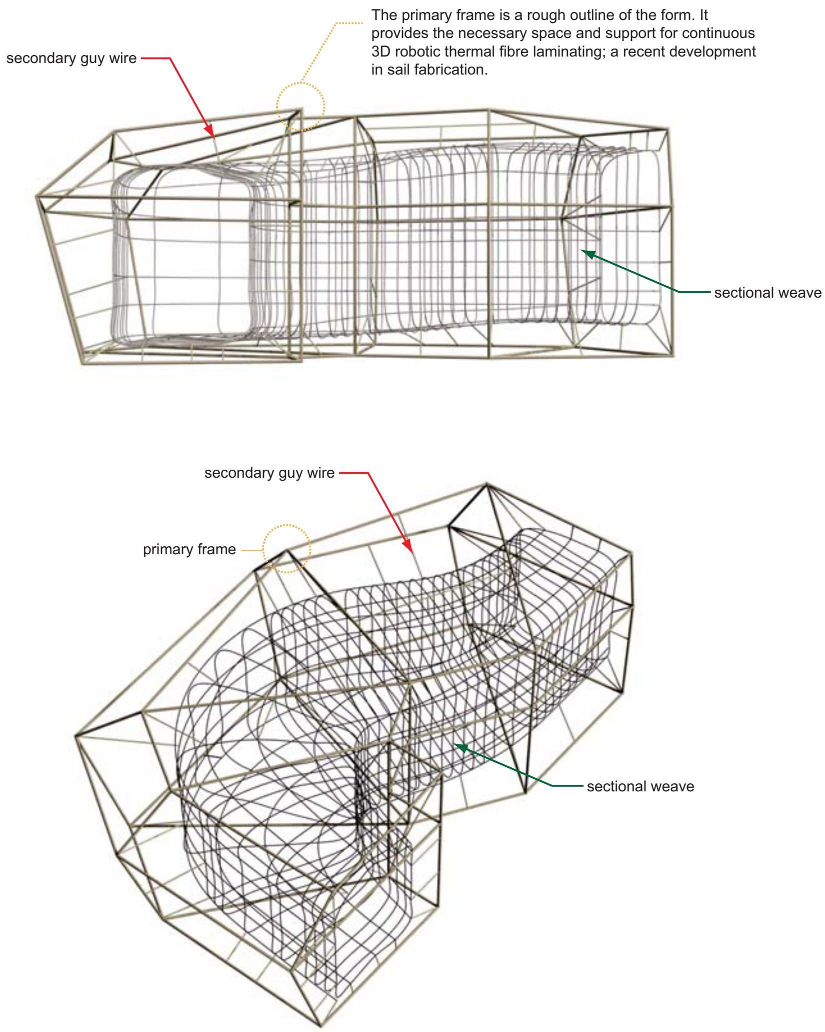


Figure 6.1.1 - Weaving a homogeneous form

model that delivers forms to be evaluated by analysis software in a scenario of form finding versus form making. The model delivers energy forms that meet specific site requirements such as obstacles, possible support locations, views and access.

Often, the results of such procedures return complex forms. Typically we would then break down and rationalize these forms into an element-based system of fabrication, since that is what we are accustomed to. The idea of this prototype is to begin thinking of a new universal construction method that instead, builds large homogeneous pieces. Such a method will allow us to embed energanic thinking into the process, instead of always resorting to what is accepted or currently possible.

By adopting continuous weaving, winding, and thermal laminating, we can introduce adjustable energy gradients that proliferate the relationship between matter, force, program, and effect. The inspiration for the method comes from the manufacture of ship sails, which are woven into a continuous material by robotic weavers. A framework is required to support the computer-guided weavers, which have the ability to rapidly weave in multiple directions and in varying thicknesses.

Although currently not used as a known construction method, the idea of being able to produce large, homogeneous pieces whose material can be adjusted for density and strength has great potential in theory for design and construction.

In this example, a framework that roughly approximates the form has been set up. From it, the form is strung using a wire framing method that ties back to the framework. Fiber can then be spun around this wireframe to create the first solid layer of material. The first layer provides the substrate for stiffening members and all the necessary services and systems. They are compressed and bonded to the substrate by the third layer, effectively creating a rigid, integrated, and homogeneous structure.

This potential ability to create integrated multiplicity–form, structure, function, and ecology is representative of an energanic approach. Instead of simply introducing a static form to any given context, we can now introduce an energanic object; an idea that promotes continual activity and environmental calibration.

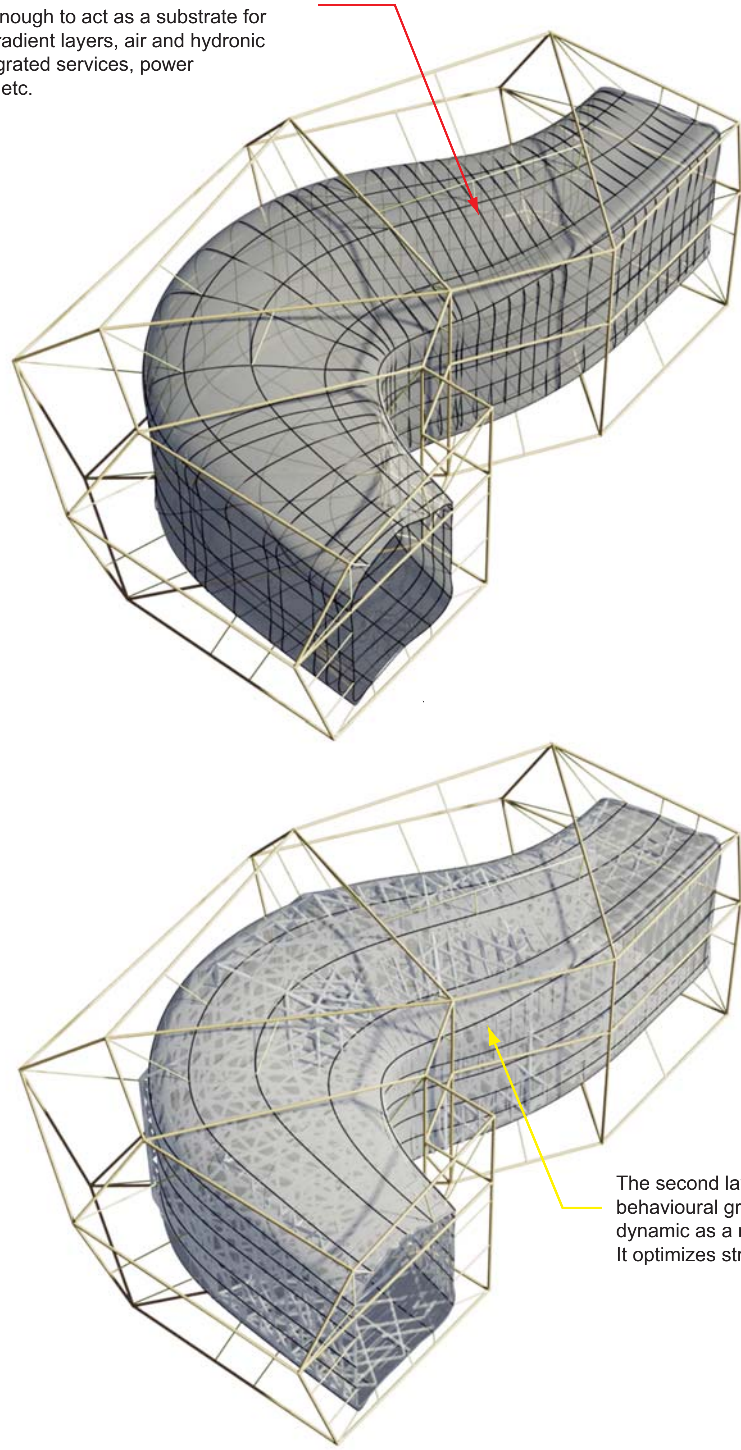


Figure 6.1.2 - Integration layer

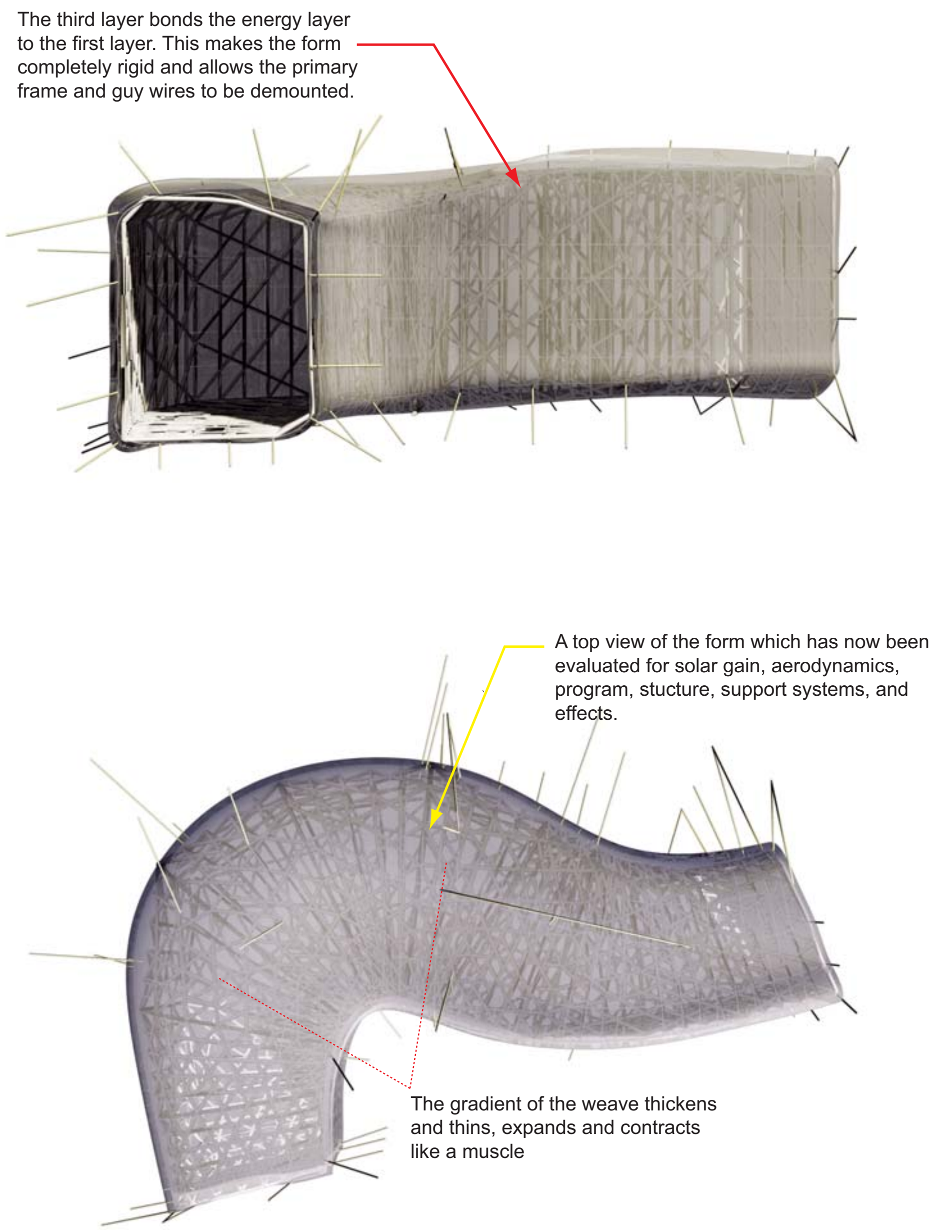


Figure 6.1.3 - Form stiffening

Taking it to the next level, this type of robotic and energetic prefabrication has the ability to imbed, within itself, the logic of organic and climatic processes.

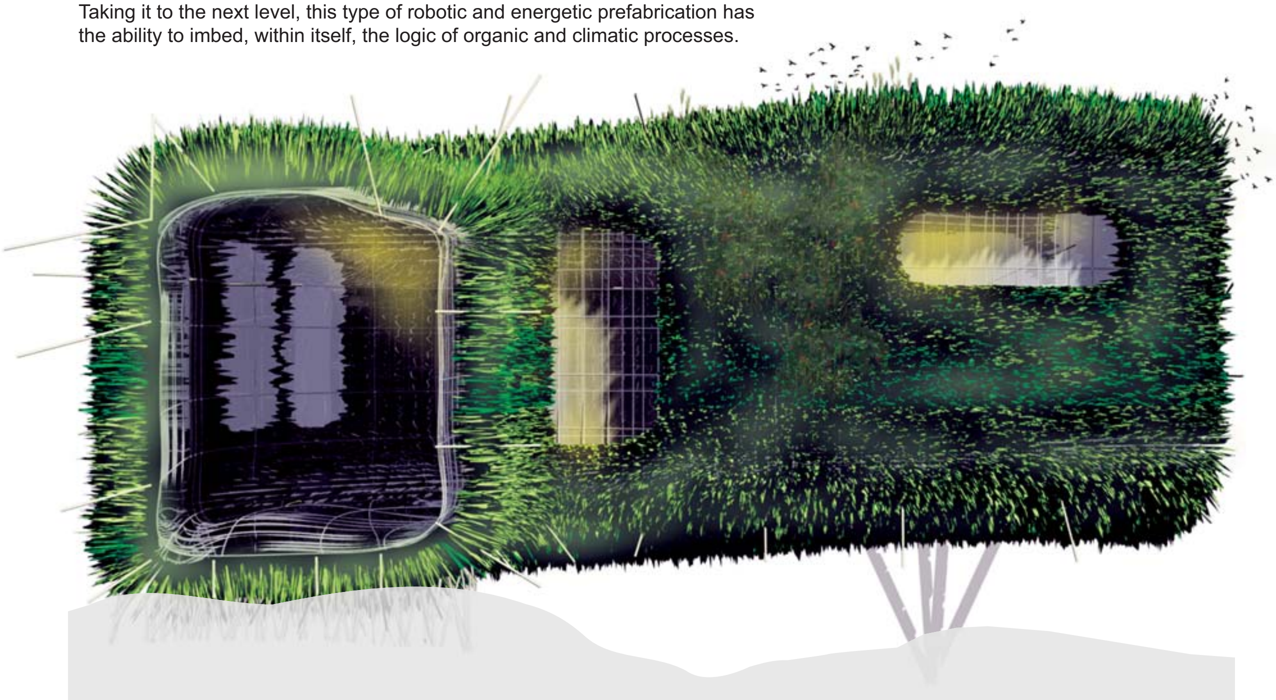


Figure 6.2.4 - The next level of thinking

6.2 . Caustic Collector

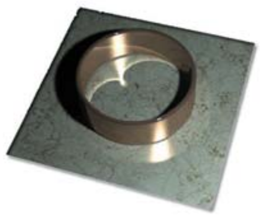


Figure 6.2.1 - Everyday phenomena of light

A caustic surface is often called a “burning curve” in geometric optics because of its intensity and concentration of light. It is a boundary condition that separates accessible and inaccessible regions for incoming light rays. The light rays ‘pile up’ against the boundary but they can never cross it. The boundary, therefore, describes an envelope with respect to the invisible phenomena of light.

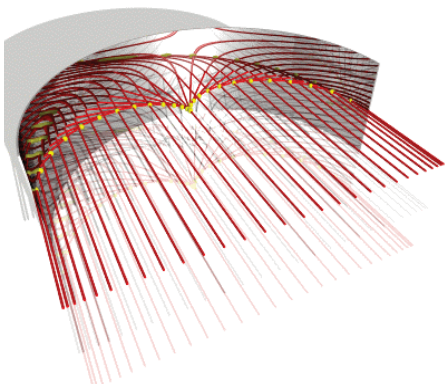


Figure 6.2.2 - Transposing caustic curves into 3D surfaces

Caustics are very common in everyday life. For example, we can see the double crescent-shaped cusp of reflected light in the bottom of a coffee cup or inside a wedding band. Yet, the energetic possibilities of such phenomena often escape us because they are operating at either a microscopic or invisible scale.

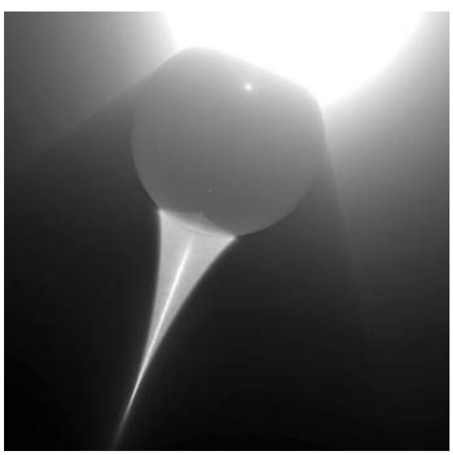


Figure 6.2.3 - 3D Max test render of caustic collector

On any given day, the sun radiates approximately 1000 watts of electricity per meter squared of earth. This magnitude of energy should easily provide more power and heat than we require. We just need to imagine new systems and scenarios that explore the harnessing of this power above and beyond our current methods.
In this prototype, caustic geometry is used to artificially amplify the relationship of energy to surface area. The method consists of capturing caustic surfaces through circle-packing and hemispheric geometry. Light can be reflected through hemispheres and focused into powerful beams of light and heat.

The prototype wishes to bring these invisible properties of light to bear in the public sphere. It envisions that these properties can be contained and made visible through a combination of lenses, nanomaterials, color filters, and fiber optics. Light is captured and focused into transparent caustic columns. The 'invisible' light travels through a colored filter to make it visible, even in broad daylight. The columns can contain the heat generated to create ambient heat sources in exterior climates and the light can also be driven into spaces that do not have solar access.

This energanic concept wishes to give form to energy that is invisible. Typically solar energy is captured by photovoltaic devices or thermal collectors and is spirited away as an unseen element. Instead, this energy prototype wishes to visibly engage and affect social and spatial realms.

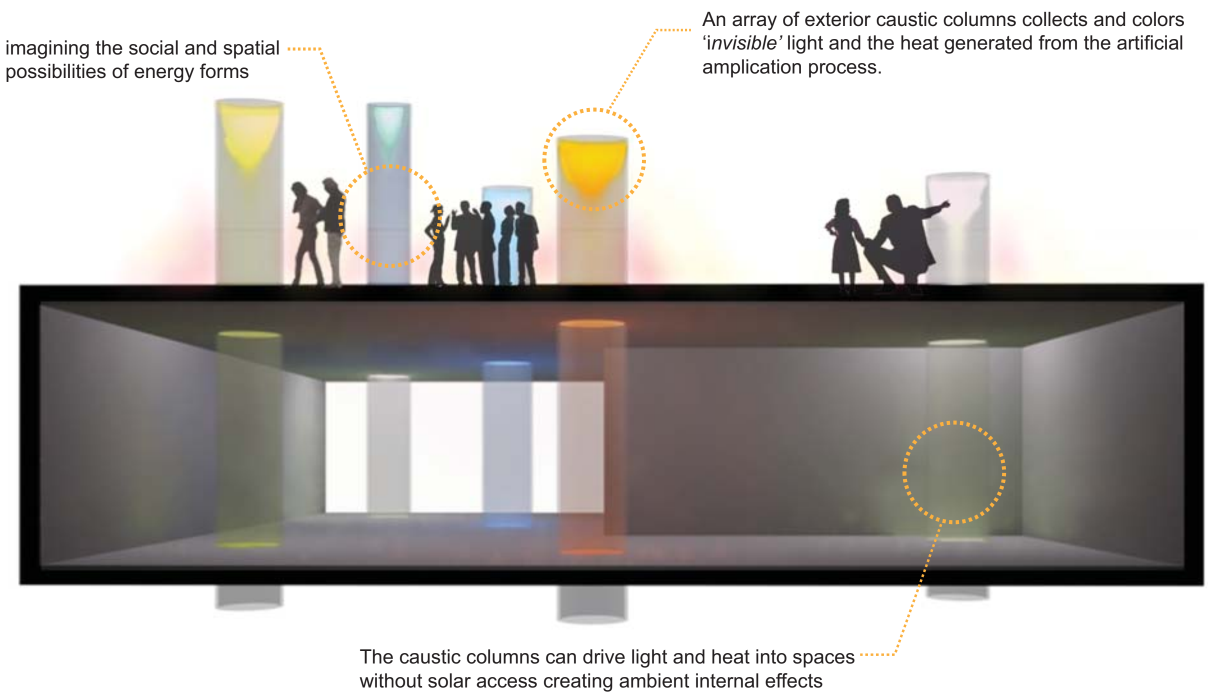


Figure 6.2.4 - An array of caustic columns

6.3 . Liquid Force

Liquid force represents a prototype that begins with a simple idea of water collection. Water is an undervalued and underutilized resource. In our temperate climate it is consistent and plentiful. It can also be destructive to the integrity of systems and buildings and as a result is typically directed away as fast as possible.

This prototype explores water as a potential material energy. Instead of only shedding water, it both collects and sheds it for very specific reasons. The prototype wishes to take advantage of water's incredible mass, its phase change properties, and its thermal regulation potential.
The structure is designed as an extremely delicate, lightweight and tenuous assembly that relies on the force exerted by the collected liquid. As the liquid collection increases the structure's wings open and maximize its collection ability–not only water, but also electricity from photovoltaic cells integrated into the wing surfaces. This corresponds to the season. The open position presents the correct angle for maximum electricity gains from the spring and summer sun.

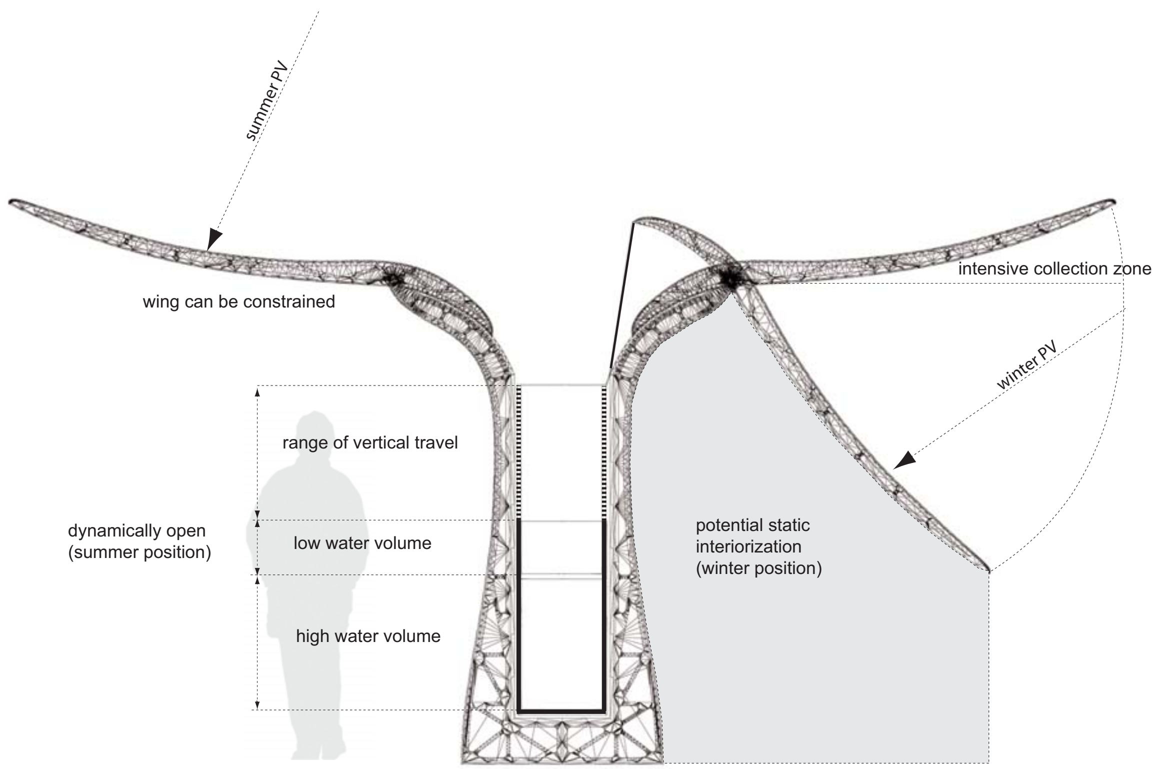


Figure 6.3.1 - Liquid force module

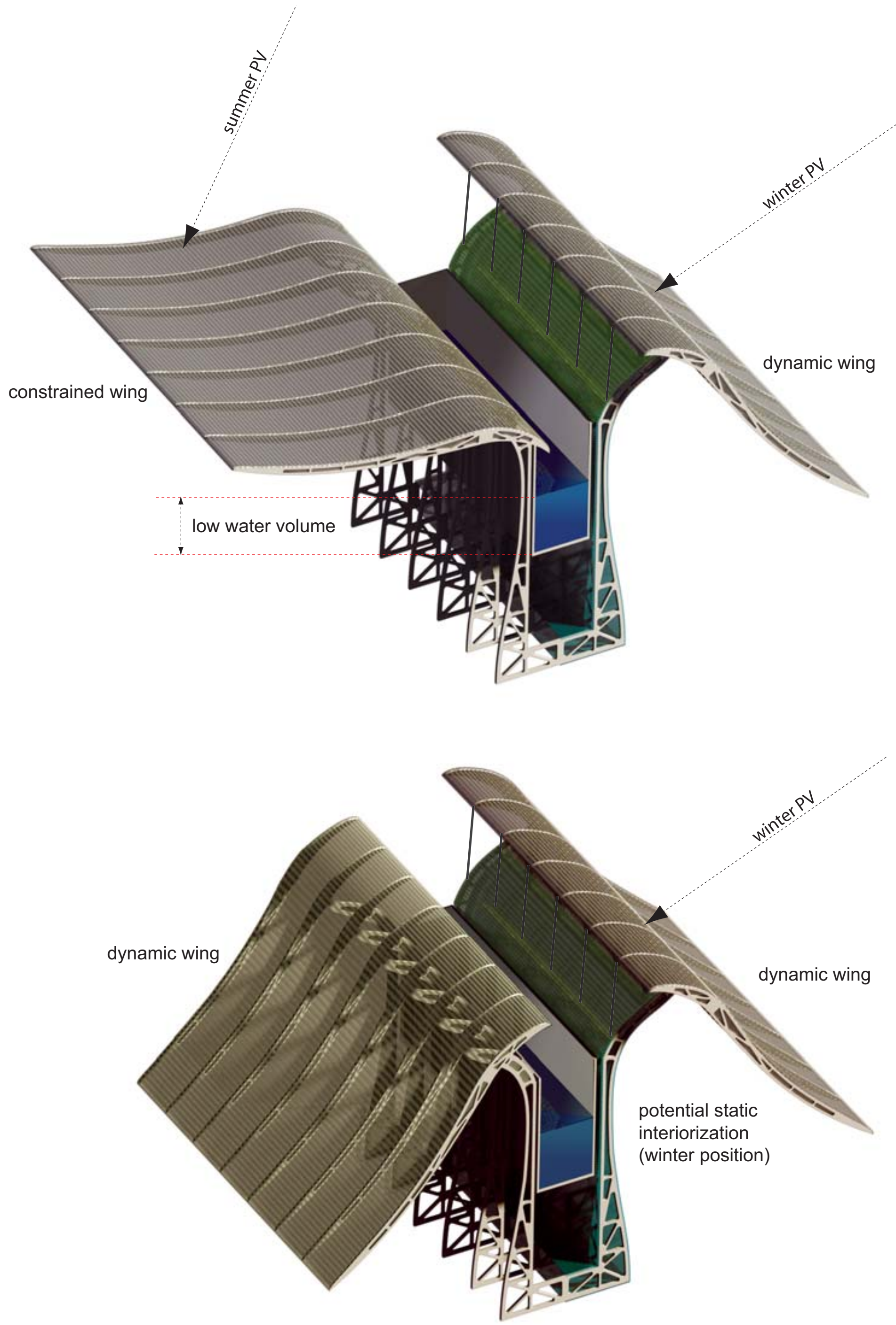


Figure 6.3.2 - Liquid force module principles

The demands for water are much higher in our peak precipitation months and so the structure collects as much water as it can. Humans, who are now interacting directly with the device, use

Figure 6.3.3 - Joining modules

the water for numerous applications–toilets, plants, washing, etc. As the water is consumed, the structure begins to droop, visually expressing to its users their consumption habits. This of course, should not happen in peak season because the device will collect and store precipitation both day and night, directing excess water to holding tanks.

Figure 6.3.4 - Seasonal contraction

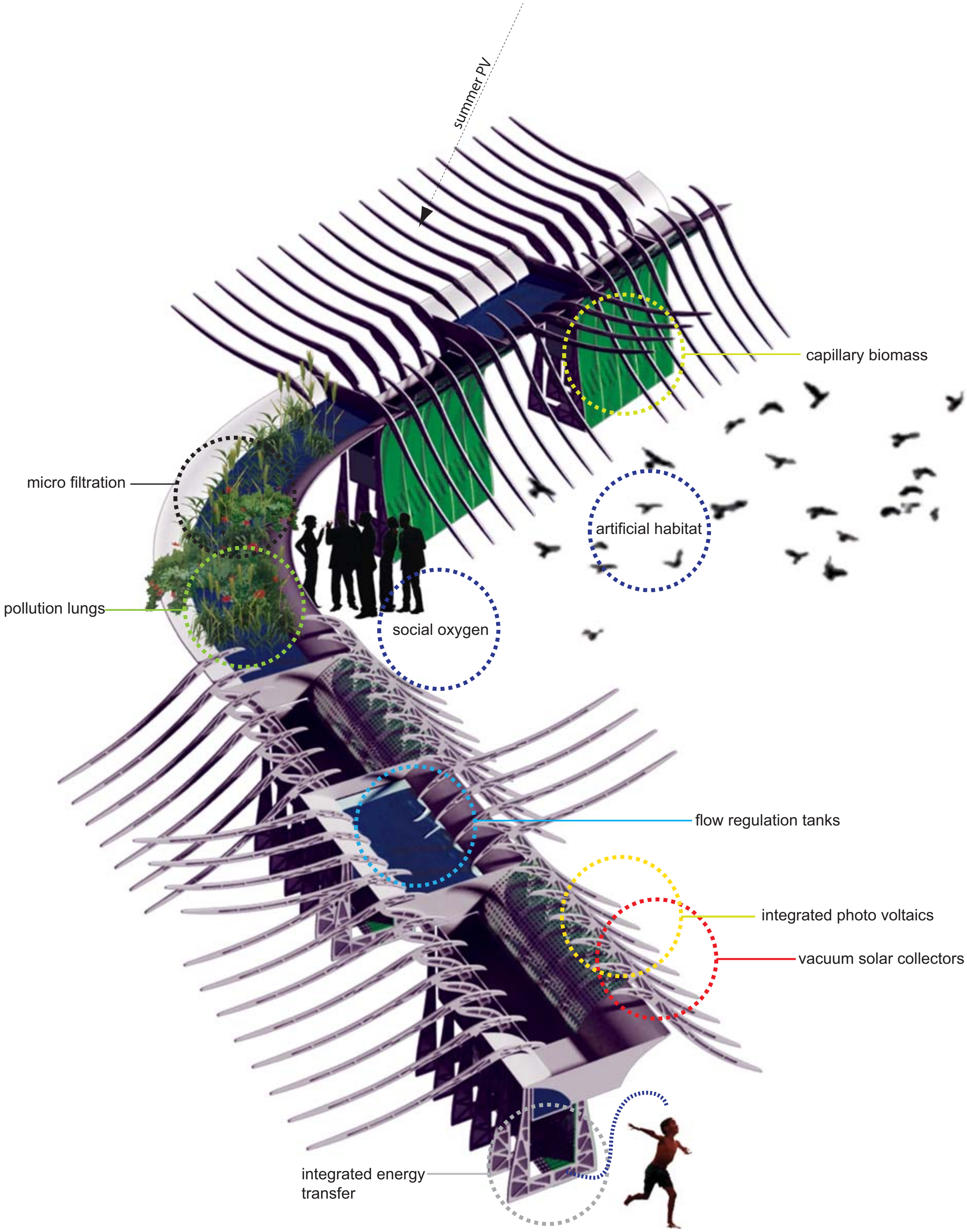


Figure 6.3.5 - A new energy infrastructure; a new aqua-cology

In the winter, the device can contract to create enclosure. A panel system seals the open ends and since the structure's cladding is based on fiberglass elements, the space becomes a translucent/transparent sunroom. In its most deflated position, a quantity of liquid remains in the system that is effectively heated by integrated vacuum solar collectors that are incorporated into the wings. The space now becomes a covered walkway, an area to grow plants, edible biomass, or a temporary space for relief accommodation from the elements. The angle of the wings now corresponds to the low altitude of the winter sun, once again increasing the electrical energy potential. Thus the structure moves from a dynamic, open and shade-providing canopy, to a closed, compact shelter.

When the module is propagated, it begins to create its own energy infrastructure that is much more diverse. It develops new contexts and ecologies. It gains strength in numbers and as a result is less prone to abnormal fluctuations in climate.

Our cities are full of small shelters. Small canopies and pavilions providing shelter, dot our parks and streetscape. Potentially, this propagation could be combined with transit and park infrastructure since they are interconnected. We will then create a new, elevated artificial aqua-cology that collects and cleans water, generates power, provides new ecologies and habitat, and cleans the air we breathe. These natural ecologic operations, which used to be a part of the landscape, have been decimated by development and continue to disappear. We can create new, artificial wetlands and landscapes in even our most polluted environments–and the heart of the city.

Liquid Force is the beginning of such action. Its dynamic instability is a celebrated feature that interacts with its surroundings. It is a genesis device that mediates between matter, events, and society.

6.4 . Radiant Hydronic House

The *Radiant Hydronic House* is a prototype for domestic space that represents a series of overlapping systems that feed into one another in order to produce various gradients of behavior–structural, mechanical, circulatory and programmatic. The house appears as a series of large oversize radiators that self-stabilize due to their fluid mass and link to each other to create a coherent and active system.

The radiator assemblies themselves would not be able to stand up alone, but by leaning into each other they gain stability. Once they are full of collected liquid, they become ultra stable. Thus, these devices are much more than simply radiators–they organize behavior and generate activity and flow. Besides acting as heat exchangers used to transfer thermal energy for the purpose of heating and cooling, they also promote convective air flow and the recycling of waste water and the growth of edible biomass through filtration and percolation. Their large volume allows them to operate freely on gravity and pressure.

The radiators and roof connect the various infrastructures into a hybrid monocoque structure. Together they appear as a monolithic and fluid object that senses its natural environment and inflects its surfaces to take advantage of various forms of energy capture. The top surface of the roof is a combination of solar electrical and thermal collection and evaporative cooling. Water percolates slowly from pool to pool as to maintain a consistent thermal thickness, while not being allowed to stagnate. For heat, the radiators transport liquids from the solar pools, some designated solely for heating, down to a radiant floor plenum inside the house. This hydronic system also works in reverse. The self-ventilating form of the structure can draw cool air though the subfloor plenum to chill the thermal mass of the house as needed. This in conjunction with rooftop evaporative cooling is effective.

The exterior surfaces can also be activated for biomass growth and fluid filtration. Grey water is directed to trickle through vertical biologic matter and can be fed back into the system.

In such a variable landscape of heating and cooling, individual comfort levels and activity along with specific living requirements determine the spatial organization. Thus the system's interaction with its environment resonates with its interior activity.

The prototype is an interface of multiple effects combined with thermodynamic exchanges. Its energanic approach suggests positive possibilities for a new way of conceiving domestic space.

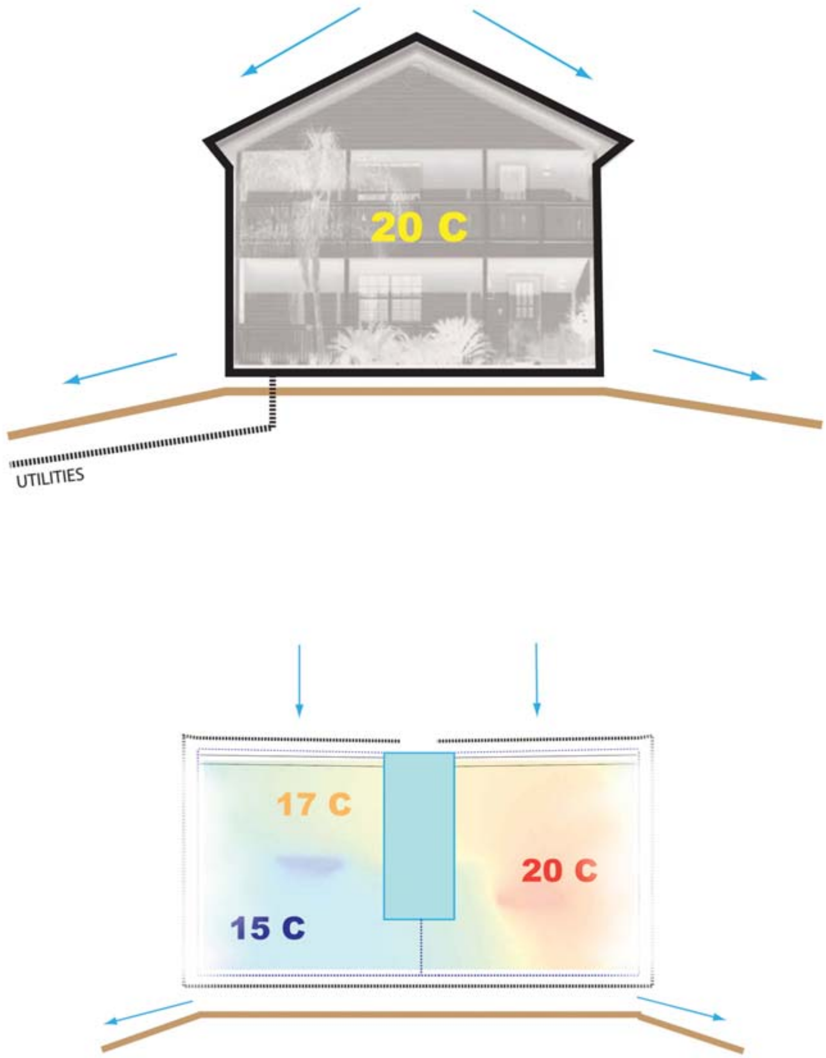


Figure 6.4.1 - Traditional versus energanic

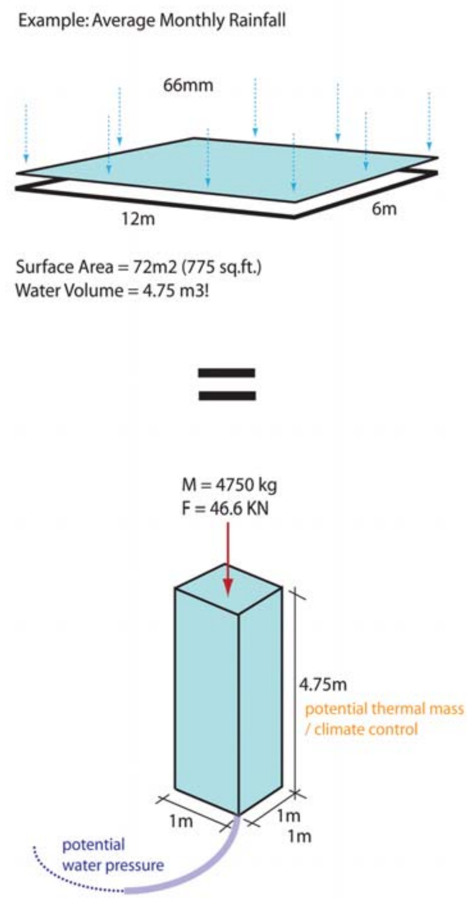


Figure 6.4.2 - Fluid collection possibilities

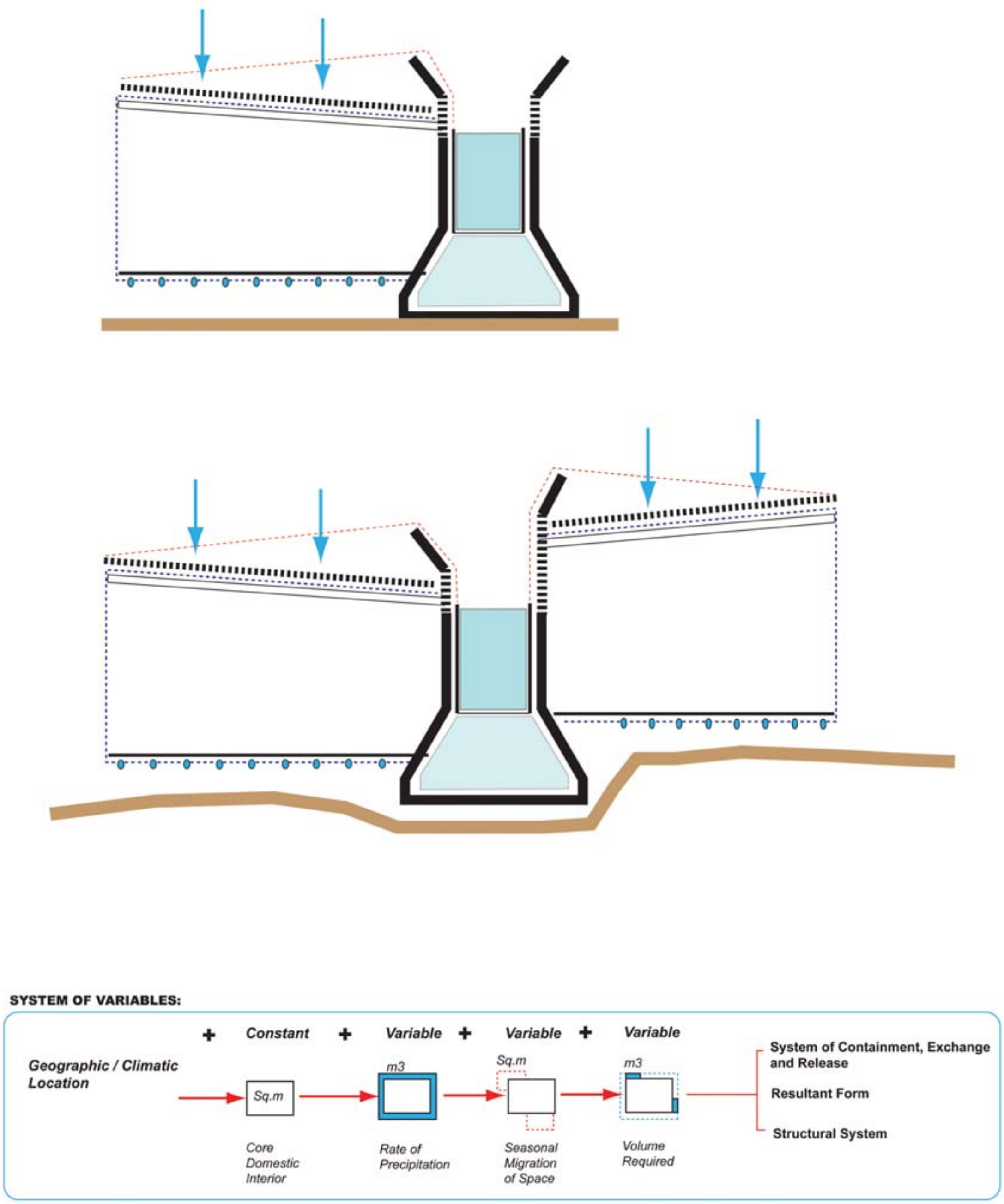


Figure 6.4.3 - Dynamic system principles

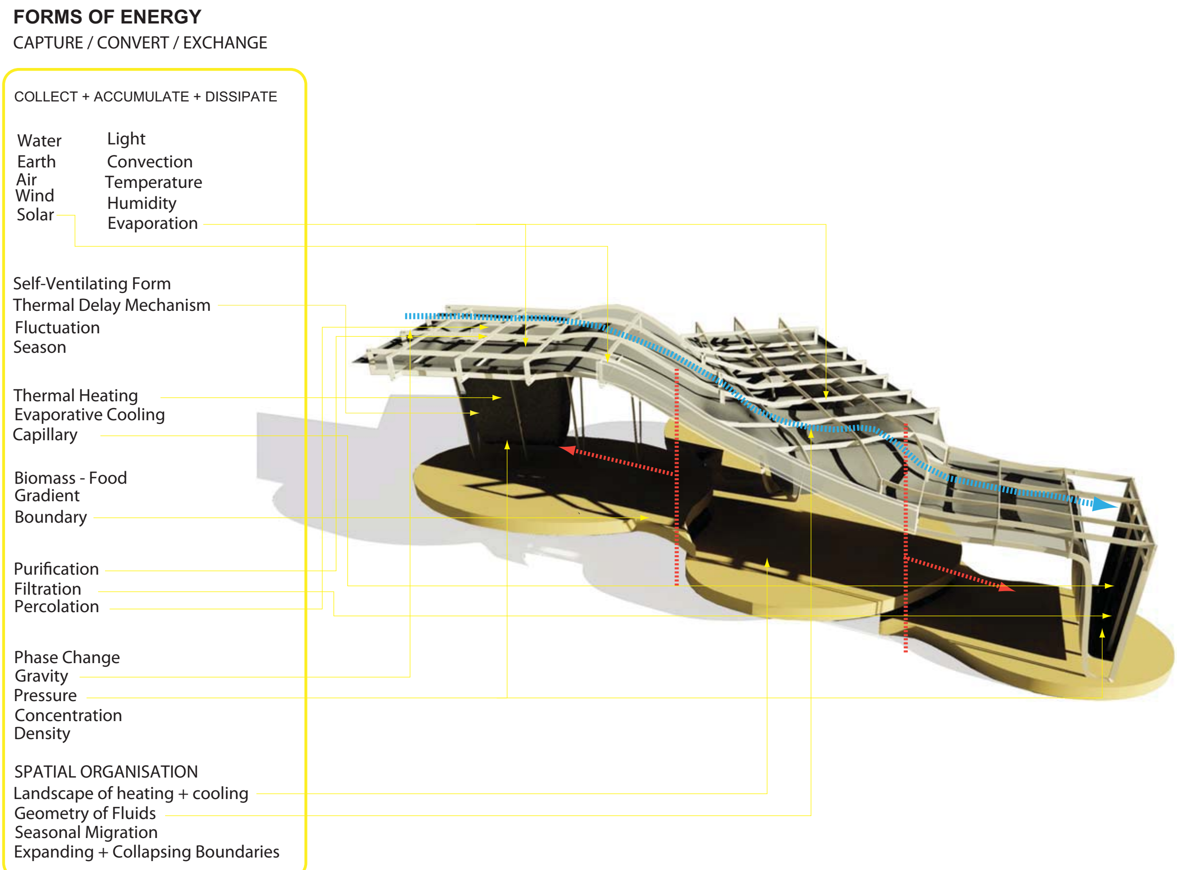


Figure 6.4.4 - Prototype schematic 1

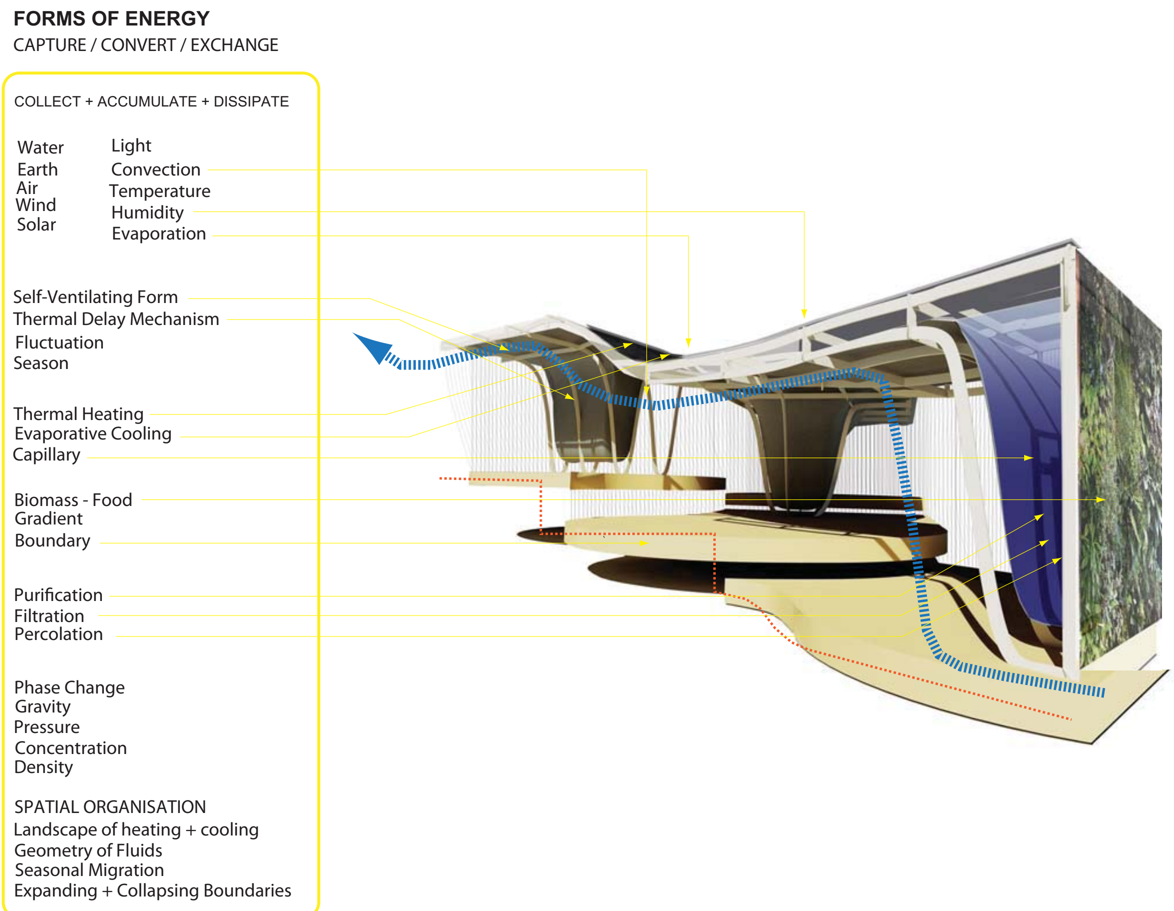


Figure 6.4.5 - Prototype schematic 2

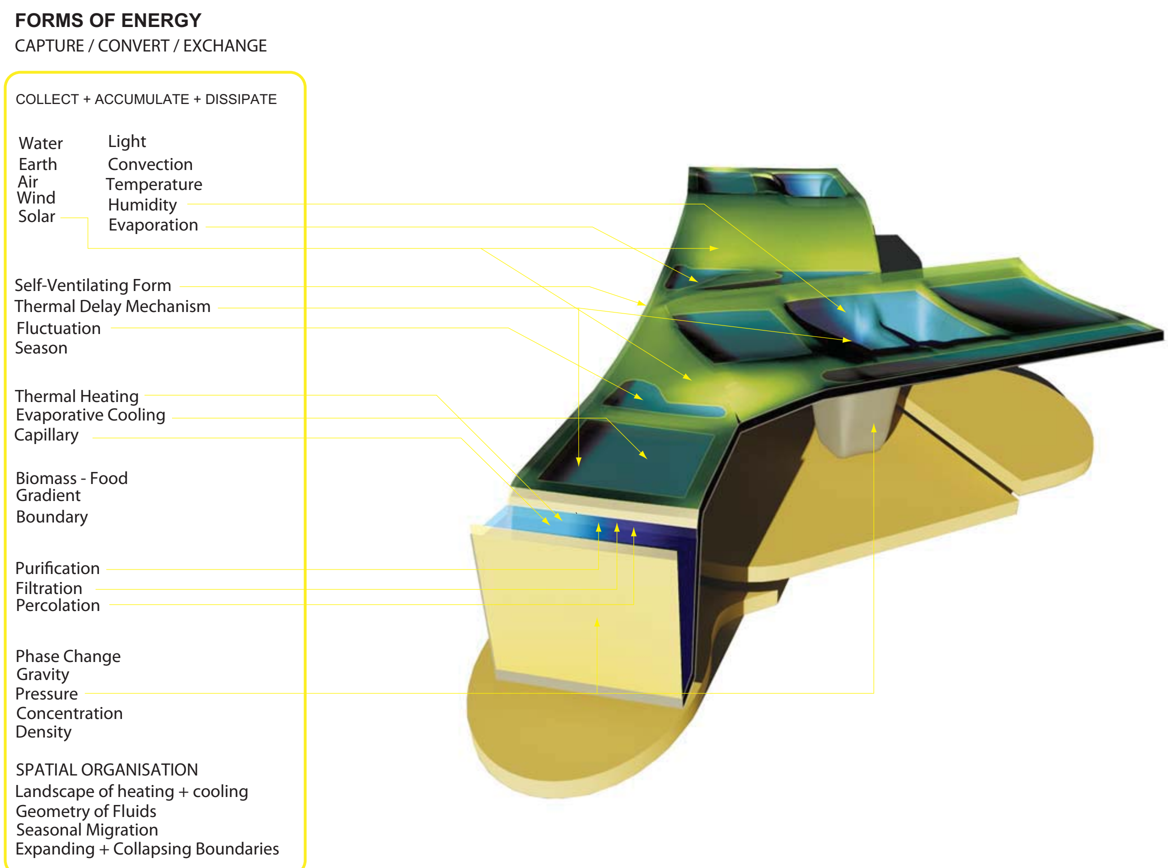


Figure 6.4.6 - Prototype schematic 3

7 Conclusion: Ending at the Beginning

When we explore the concept of energy as a model for design, most would quickly assume that it would be categorized as energy-efficient architecture or one that aligns itself with the current modes of sustainability. These mainstream trends, although based on valuable objectives, are for the most part, guilty of a weak imagination. In contrast, this thesis project has given energy the role of an *agent provocateur*, a role that incites ideas of new formal languages and spatial understanding. This, as we have seen evidence of in the preceding pages, requires a very different way of thinking and challenges established preconceptions of what architecture could be.

The author describes the work as the beginnings of a *post-digital* inquiry, an inquiry that synthesizes dense mixtures of reality and the virtual, the artificial and the biological, and the visible and invisible agents of change. Moving from a generation of *digital* architectural work bound up in the techniques of its own construction, we seek an arena where ideas will once again trump technique, where our imaginations are free to lead, and where technology, rightfully, will follow. The study of energy, in its many forms and associations, facilitates an architecture that becomes a genesis device- one that generates activity, form, environments, and ideas about their future. This is ***Energanic Architecture***.

Energanic is a term never used before in architecture. It combines ‘energy’ with ‘organic’-not to be confused with the “organic” theories of modernity, but instead represents a negotiation between the physical realities of matter and the imaginative potential of natural processes and natural phenomena. Thus, *energanic* not only finds itself between matter and events, but it also brings new pluralities of possibilities into existence. Energanic Architecture, the culmination of ideas presented in this thesis, may well be a convincing series of first steps towards a theory of the post digital in architecture:

Energanic is matter, which is defined and determined by energy.
Energanic is a balance between material geometry and force.
Energanic replaces static materiality with the dynamics of thermodynamic exchange.
Energanic is a new materiality, therefore a new expressionism.
Energanic is multiplicity: multi-form, multi- structure, multi-function, multi-ecology.

Energanic is action. It is often understood more as a behavior rather than a physical object. It remains variable and is seen to exist when energy is transitioning from one state to another.

Energanic celebrates the artificial. It understands that our world is completely artificial and that developing ideas for new materials or environments is not only desirable, but necessary for progress.

Energanic understands that material energies (e.g. convection, conduction, radiation, pressure...) are clearly no longer outside of human action. They should be acted upon to agitate social and cultural preconceptions of space, nature, and order.

Energanic critiques existing strategies by assembling matter into new strategies.
Energanic is sometimes perverse, sometimes unconstitutional, and often unsettling.

And finally, our world cannot continue too much longer without *energanic* thinking. It is relevant and timely, but above all, it wishes to operate not in the receiving end of change but in *generating* change.

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figures

Figure 2.1.1 - The Digital Revolution. Image from Refabricating Architecture. Courtesy of Kieran Timberlake Associates.

Figure 2.1.2 - The evolution of tools. Image from Detailing Digital Fabrication by Travis James Wollet. Images found at http://etd.ohiolink.edu/send-pdf.cgi/WOLLET%20 TRAVIS%20J.pdf?ucin1148477360.

Figure 2.1.3 - The Digital Temple. Image from Parametric Design by Mark Andrew Cichy. Image found at http://uwspace.uwaterloo.ca/handle/10012/2866

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Figure 2.1.7 through 2.1.1.1. Images from Manufacturing Diversity. Courtesy of Architectural Design.

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Figure 2.1.5.1 - Medieval Master Builder. Image courtesy of Kieran Timberlake Associates.

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Figure 3.2.1.3 - Shipbuilder's spline tool. Image found at http://www.bowdoin.edu/bowdoinmagazine/archives/features/002157.shtml

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Figure 5.3.1.1 - Conrad Waddington, Epigenetic Landscape. Image found at http://integrationandincompletion.blogspot.com/2009/06/chapter-2-kipnis-kwinter-and-yoh.html.

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Figure 6.2.2 - Transposing caustic curves into 3D surfaces. Image found at http://www.math.harvard.edu/archive/21a_spring_06/exhibits/coffeecup/index.html.

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