# Dimension

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*Big shell formwork. EPFL learning center, Lausanne. Photo courtesy designtoproduction*

Cad Sakes warned, the methods by which corn is grown (energy is produced) and harvested (collected, stored, and consumed) outweighs the rate its production, cultivated area, and political incentives.

### Drawings

As Cad Sakes aged, his contempt for the bureaucrats who ignored or stole his experimental ideas grew stronger. Pete Sakes, on the other hand, may have been the first uneducated explorer of American agriculture to recognize the relationship between the earth and our synthetic crops in dynamic ecological terms. As a boy, Pete would climb the old Southern towers and draw for hours what he imagined to be the agrarian “ecology.” He began diagramming the relationships between crops, the earth, population, and the environment, and without knowing, he was describing the ecology of agrarian dependant civilizations, independent of any mainstream theories like those of Malthus or Godwin. Pete’s agrarian/ecological accounts would have redeemed his father’s radical ideas had the drawings been found prior to the collapse of the agrarian system during the 1930s. Pete hid the research and drawings in the earth below a Virginia tower before fleeing the south to fight for the North in the Civil War.

By tilling the historic furrows of the peasant and the politic one finds that the ecologies of agrarian energies, production, population dynamics, economics, and land use patterns yield a complex layering of systems in which dimension exists in literal drawings of theoretical and fictitious history, existing through sensation, not measurable definition. This ecological dimension absorbs and blends into the sponge-like social flow oscillating between policy, commodity, and energy. As expressions of the relationship between the real, the imagined, and the forgotten, history provides a strange, false non-fiction that is left as notational scars on the face of the earth through the ecological, economic, cultural, and social markings of production. Pete’s drawings of agrarian relationships have been mapped as field conditions inter-relating environment, crop components and adaptive mechanisms, population and flows of energy via a sensate circulatory system that is at once parametric while inherently dislocated. By using his categorical maps, which include environment, population, synthetic inputs, outputs, natural resources, and economics, a notational device expressing general ecologies between the elements is developed and used to create ‘historically’ dimensional drawings. These drawings plunge into the agricultural history/future of corn and tobacco—into the articulate yet atmospheric field of Pete Sakes’ ecological and inventive heritage. They do not function as solutions and they are not literal devices for evaluating our current or historic state of social/political/or economic condition, but rather the drawings offer unique non-spatial, non-territorial, yet qualitative landscapes of an invisible ecological world, synthesized by agrarian-to-urban policies, energies, production, and synthetic means of sustaining populations as imagined by Pete Sakes, an uneducated agrarian wanderer.

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**Clark Thenhaus** *started Endemic Architecture as independent research and drawings in 2006 while studying at the University of Pennsylvania. Currently his research focuses on agrarian ecologies and varying social, political, and cultural conditions that operate outside of normative urban systems on a rogue axis between production, technology, ecology, and population. His work has been exhibited widely in galleries and at special events, including at the Institute of Contemporary Art in Philadelphia. He currently works as a designer in Los Angeles.*

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**SCHEURER, Fabian**

# Size Matters: Digital Manufacturing in Architeture

More than a decade ago, I had the chance to visit a top-secret laboratory. After getting dog-tagged with an RFID visitor pass, being scanned by a metal detector, and crossing a single-person entry lock that automatically noted every body’s net weight on the chip he was wearing around his neck, I entered the halls where BMW builds prototypes of future driving machines. I do not remember if I managed to get a glimpse on the body of a then confidential SUV study, but I clearly recall one thing that impressed me greatly at the time: a big grey cabinet in one of the corners that was introduced to me as a stereo lithography printer. Brand new and mindbogglingly expensive, a window in the door allowed me to see a laser beam zig-zagging through a small basin filled with a clear fluid. To my amazement the liquid slowly materialized into the interestingly curved shape of, well, a washer fluid tank. I was stunned. I had expected that the miraculous high-tech apparatus would be used to create design models of streamlined car bodies. Instead, it produced 1:1 prototypes of engine parts in order to streamline the assembly process. BMW was trying to optimize the serviceability of its cars and to save mechanics from breaking their fingers when trying to repair the windscreen washer, by building full scale mock-ups of engine compartments in the early development phase—with top-of-the shelf rapid-prototyping technology.

### Trickling Down

Now, only a few years later, 3D printing technology has become so cheap that architecture schools around the world proudly present gypsum printers on their websites and students are fond of the curvy building models that they produce. Some of those may come pretty close to the form of a washer fluid tank but, of course, they have a completely different meaning and purpose. Architects have always worked on representations of buildings, be it plan drawings or scale models. Usually they are conscious about this and the fact that at the last stage of the design process the translation into full scale production becomes an issue. With the introduction of CAD software some feared that this consciousness would erode. The scalelessness of the computer models was one of the main reasons why my professors at architecture school were skeptical about the first clumsy CAD-drawings I presented to them. Some years later, when the CAD software had learned the mathematics of NURBS and Splines (developed in the car industry, by the way), I started to think that they were at least partly right. And now, since computer-aided manufacturing is becoming ubiquitous, the threat to scale-consciousness has reached the physical world—and I am starting to sound like my former teachers.

### Grinding Down

In 2005 designtoproduction were asked to help realize Instant Architect’s design for Inventioneering Architecture, a traveling exhibition of the four Swiss architecture schools. The doubly curved exhibition platform measures 40 by 3 meters with varying heights up to 1.5 meters, following a crosscut through an abstract Swiss topography. What we had was a 3D CAD-model and a 1:50 working model of the platform. What we were looking for was a manufacturing method for the full scale platform.

Manufacturing a landscape model from wood or rigid foam is a rather straightforward task if there is a digital model and a CNC router at hand. You just feed the model into a CAM system and adjust a few parameters depending on the tool and the material used. The CAM system generates tool paths, which a postprocessor then translates into the G-Code controlling the CNC router. Then you turn on the machine, and wait until the excess material has been removed layer by layer by the rotating milling bit. For the 1:50 model of the platform, this could take maybe an hour, depending on the material and tool used.

How long would the same machine have to run in order to produce the same structure on a 1:1 scale, fifty times larger? The answer is pure mathematics: The platform is 50 times longer, 50 times wider and 50 times higher than the model. Thus, the volume of the excess material would be 50×50×50 times the volume cut away in the model. If it is removed with the same accuracy and speed this would take 125,000 hours, which is just a bit more than 14 years and 3 months—leap years taken into account.

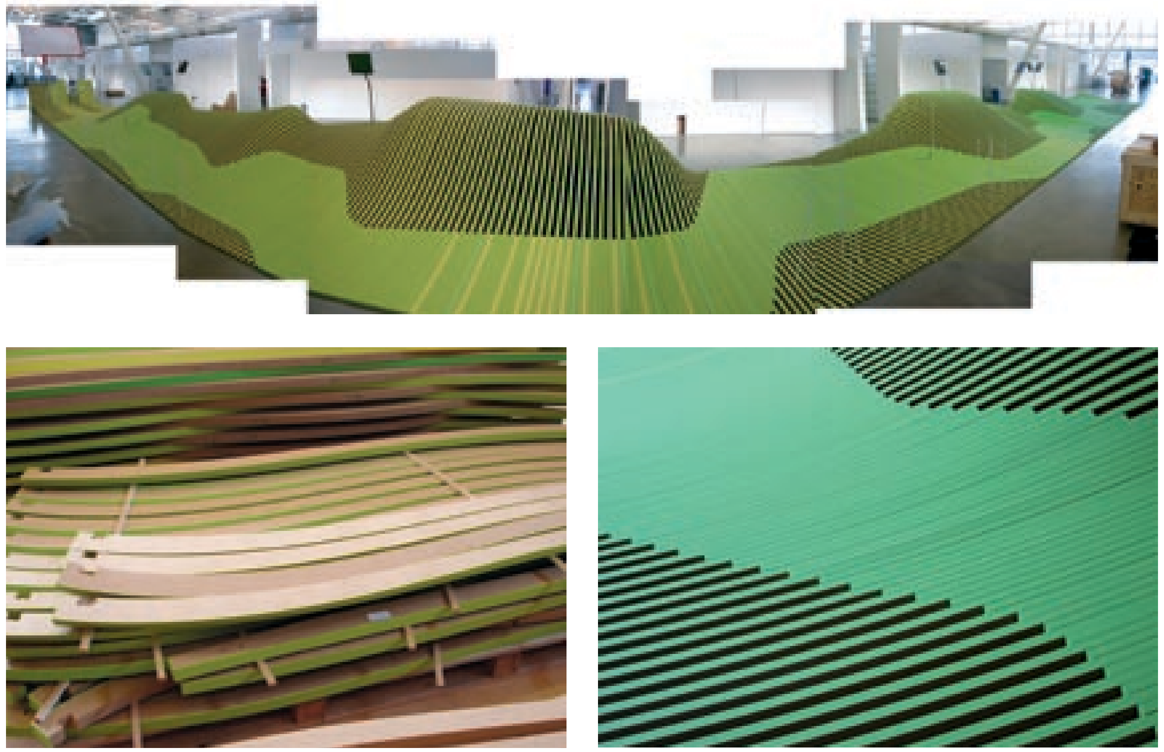
The same effect appears when using additive fabrication methods, such as 3D-printing. Material cost and manufacturing time do not grow in direct proportion to the scale of an object but to its volume, thus resulting in cubic growth. The only way to regain speed is to reduce resolution and precision by using larger tools (or larger building blocks) at higher speed. But even though larger machines are available up to a certain size, another problem is not yet solved. Weight is also proportional to volume, bringing the structural integrity into question.

In short, machines that create complex form from homogeneous materials are very convenient and simple to use at a model scale, but when naively applied at full architectural scale, they inevitably reach a point where they lead to both inefficient production processes and overly massive structures. Manufacturing methods are all but scalable.

### Chopping Up

Our solution to the Inventioneering Architecture project was to chop up the geometry into 1,000 sections, each of them 40 millimeters wide. They are cut out of flat MDF boards with a five-axis CNC router and then mounted side by side. So we ended up with 1,000 individually curved “rafters” supported by a vertical board at the backside. By rotating the cutting tool around its axis of movement, the upper side of each section becomes a ruled surface that follows the curvature of the platform along both directions. Interdigitating from both sides of the platform, the overlapping parts of the rafters indicate the closed surface of the visitor path, while the exhibition area is marked by gaps. Carefully placed dowel holes ensure the exact placement of adjacent components.

Key to the efficient production of 1,000 individual parts was the implementation of a continuously digital production chain from design through manufacturing. This was accomplished by a set of scripts—small programs—within a standard CAD-system. The first script imports the NURBS-surface defined by the designers, generates a cross-section every 40 millimeters, reads the coordinates for every rafter, and determines the angles of bank for the upper surface. A second script translates this information into the tool paths for cutting and the drilling-locations for the dowels. A third script finally arranges and optimizes the rafters on the MDF-boards (nesting) and generates the G-Code programs that control the movement of the five-axis CNC-router. Those machine codes are then passed on to the manufacturing experts who can directly run them on their equipment and produce the parts without further fabrication-planning.



*Inventioneering Architecture, Instant Architect, 2005. Above: Panoramic view of assembled platform, courtesy Instant Architect. Below: Some of the 1,000 rafter components after painting, and detail view of the path formed where the rafters integrate from both sides along platform, Photo courtesyof designtoproduction*

### Complexity

Designtoproduction is founded on the firm belief that architecture is built from components. You can either use very simple, similar building blocks like bricks and put a rather high effort into the assembly process on site. Or you put some effort into prefabricating more complex building blocks and save assembly time on site.

Complexity in this case does not necessarily mean curvy forms or the usage of rocket-science manufacturing methods. The term is used in the context of information theory and describes the amount of information that is embedded in a system and its components. From this point of view, a pile of bricks does not contain very much information. Apart from its material properties and dimension, which are all the same for a certain charge, the only variables left to the individual expression of a brick are its position and orientation in space. This is normally the information a mason adds to the system by arranging the bricks in an orthogonal pattern, which takes a certain effort of time and energy. One way of adding more information to this system is to alter the pattern based on more complex rules, as for example our Zurich colleagues Gramazio/Kohler do (www.gramaziokohler.com). They use an industrial robot to prefabricate walls with slightly varying brick orientations and achieve stunning graphical effects. Another way to add information is to gradually alter the shape of the single components, like in the Inventioneering Architecture project above. Note that here already a pile of components contains most of the information, since it is embedded in the individual shape of every single component. The effort to assemble the final structure is much lower, provided that the rafters are correctly numbered. The neighbors just snap into place.

In both cases the effort shifts from handling the material to handling the information. It may be easier for a machine to process large amounts of material, but it takes a certain time to program a brick laying robot or a script that generates G-codes for 1,000 individual rafters. The effort stays an effort, the complexity is not reduced.

### Adaptive Building Systems

According to the definition above, the problem with non-regular building shapes is that an enormous amount of information is needed to describe them. Since it is not possible to reduce the complexity, the ultimate goal is to transfer it down the production chain as smoothly as possible. Four free-form roofs with doubly curved glass skins shelter the new stations of the Hungerburg funicular in Innsbruck, Austria, designed by Zaha Hadid. After finding a manufacturing method for the individually

*Hungerburg Funicular, Innsbruk, Austria, Zaha Hadid, 2006. Alpenzoo Station during construction with most of the glass panels installed. Photo courtesyof designtoproduction*

*Hungerburg Funicular, Innsbruk, Austria, Zaha Hadid, 2006. Profiles mounted to the steel sections of Lowenhaus Station. Photo courtesy of designtoproduction*

*Hungerburg Funicular, Innsbruk, Austria, Zaha Hadid, 2006. Alpenzoo Station detail. Photo courtesy of designtoproduction*

*Hungerburg Funicular, Innsbruk, Austria, Zaha Hadid, 2006. Alpenzoo Station finished components stacked and ready for shipment. More than 2,500 individual such components were fabricated for the four Hungerburg stations. Photo courtesy of designtoproduction*

shaped glass panels and an appropriate construction method for the load bearing steel structure, the last challenge left was to connect the two. Together with the engineers at Bollinger+Grohmann the steel contractor Pagitz had developed a series of alternative, universal solutions, which would adapt to the varying angles between steel and glass. But moveable cast iron joints would be expensive to fabricate and they would have to be adjusted before the panels were mounted—resulting in laborious measuring and fine-tuning during the crucial assembly process.

The final solution was modeled closely after the Inventioneering Architecture rafters. It uses cheap material, it is easy to manufacture und it needs no adjustment at all: More than two kilometers of profiles are custom cut from polyethylene (PE) boards. They sit on the steel ribs of the support structure and gradually change their angle of bank according to the skin surface. Metal strips are glued to the glass panels and fixed to the profiles with simple screws.

The prefabrication here had to be integrated seamlessly into a large-scale architectural project. The geometry of the profiles was provided by the engineering partner in the form of spline-curves in a CAD-model. Designtoproduction automated the segmentation of the profiles, the placement of drillings, the nesting on boards, and the generation of G-Code for the 5-axis CNC-router fabricating the parts. The production documents were also automatically generated, including stickers with the unique part identification codes and information for subsequent production steps of every part. Production was executed just-in-time for every station, following the pace of the construction process and enabling last-minute changes to the geometry. More than 2,500 individually shaped parts were prefabricated and fit perfectly.

This is what we call an adaptive building system: a system of parametric components, which are multiplied over the shape of the structure and adapt to the local geometry. A closed digital production chain ensures that information travels from design to production and the system timely adapts to changes within certain boundaries. The geometrical information is completely embedded into the components so that they fit in only one place and there define the geometry for adjacent building parts, in this case the correct angle of the connection without further adjustments. The complexity of the non-regular shape is shifted almost completely from the material world to the informational side and only reappears at the end of the fabrication process—where a computer controlled tool does not care whether it is producing similar or individually shaped parts, as long as it gets valid input.

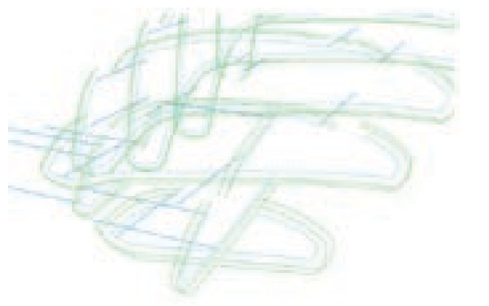
### Learning from Mass-Customization

The Hungerburg project also shows, that smart prefabrication highly depends on a thorough understanding of not only the fabrication but also the assembly process and the logistics. The total value of a solution is measured over its total lifespan—that is why car manufacturers even optimize service tasks during the development of a new engine—which brings us back to the introduction and to the last paragraph about scale effects.

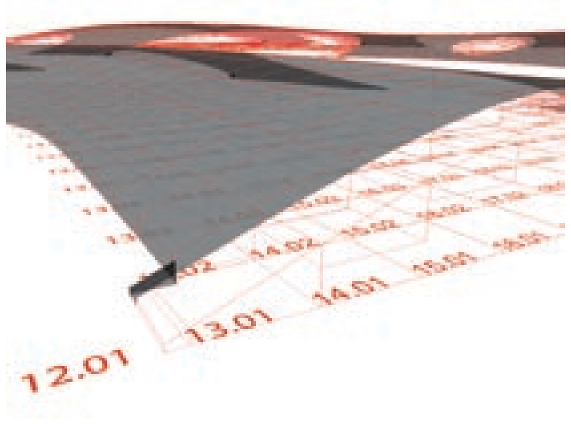
The efficiency of the automotive industry is still mainly based on rationalization and enormous production quantities. But since the times of Henry Ford things have changed considerably. You can order the same car model in other colors than black and the new Fiat 500 theoretically comes in more than 500,000 different configurations. Mass-production has turned into mass-customization. But of course, the customer still only can choose between predefined options. If she wants something completely different, things become really expensive. Unfortunately, architects and their clients usually want something completely different. Fortunately, they work on a completely different scale.

The main design feature of the new EPFL learning center by SANAA in Lausanne is an enormous hilly landscape. The single floor of the building is erected on a concrete slab of 20,000 square meters that smoothly undulates up and down over more than 5.6 meter in height difference. Reinforced concrete can be cast into almost any shape, but how do you build a formwork of this size to pour it into? Standard formwork systems are customizable to a certain degree, but they can not handle doubly curved surfaces. The solution, developed by the general contractor, the engineering consultants,

*Tool positions for 5-axis cutting Every tool position is marked with a line, color coded according to the cutting angle. Photo courtesy of designtoproduction*



*Process step 1: Input data. The basic geometry for the profiles was prepared by the engineers and handed over in a 3D CAD-file. Each profile is defined by three spline curves and a normal vector. Photo courtesy of designtoproduction*



*Rendering of the table structure. Photo courtesy of designtoproduction*

*Two-by-three table mockup on site overlay with rendered tables Photo courtesy of designtoproduction*

*Big shell formwork. Photo courtesy of designtoproduction*

*Formwork during assembly. On the left part the rebars are already in. Photo courtesy of designtoproduction*

*The small shell after taking out the formwork. Photo courtesy of designtoproduction*

and the formwork contractor, was to combine a standard table system with custom extensions. On a grid of 2.5 by 2.5 meters, scaffolding is erected to a height just below the intended concrete surface. The remaining space is filled by a wooden box that is custom built for every grid cell. The box is covered with a sheet of plywood, forced to the exact curvature by nailing it to six or seven vertical cleats, custom cut from plywood.

And now the scale effects kick in: the doubly curved portion of the slab has an area of 7,500 square meters. This area is divided into 1,458 tables, composed of 9,744 cleats. Since there are no two similar ones, every single one has to be planned and fabricated individually. After that, the logistics have to be solved: How do you ensure that the right cleat ends up in the right box and in the right spot on site? Quality management becomes an issue: how can you guarantee that the final shape of the formwork matches the design drawings? Changes become a threat: when is the very last point to change the shape before the formwork goes into production? Suddenly it makes perfect sense to invest a little time and look closely into every corner of the workflow. Because every extra minute needed to build a cleat adds up to an extra man-month of work when you have to do it 10,000 times over.

So the good thing with architectural projects is their scale. Contrary to the production of consumer goods, there is no need to develop solutions that fit a couple of thousand customers before they become cost-effective. The additional effort to implement an optimized process workflow can pay off within one single project. The sheer number of components needed to build a complex façade or formwork redeems a few weeks of thinking and programming. Then you move on to something completely different.

The next project.

## Summary

Fabrication methods do not scale and printing real size architecture from homogeneous materials like Styrofoam or gypsum powder is a tedious goal. Architecture is made from heterogeneous components and for budget reasons almost all the components have to be created from standard building materials, which are one-dimensional (straight beams) or two-dimensional (flat boards or sheets). Even the formless material concrete needs a formwork built from standard components. To efficiently create complex form from standard materials, the information (complexity) must be handed down the production chain seamlessly, which creates a certain effort. This effort can be minimized through parametric models and digital fabrication methods in a sort of project-specific mass-customization we call adaptive building systems. And this pays off because of the sheer scale of architecture. Sounds like circular reasoning? In the end, size matters.

**Fabian Scheurer** *seeks to interface the abstract order of digital systems with the creative chaos of design. He graduated from the Technical University of Munich after studying computer sciences and architecture and worked as assistant at the CAAD group of TU-Munich, as software developer at Nemetschek Programmsystem GmbH, and as new media consultant for Eclat AG in Zurich. From 2002 until 2006 he researched and lectured as a member of Ludger Hovestadt's CAAD group at the ETH Zurich. His scientific work focused on the practical aspects of artificial-life methods in architectural construction and has been applied to a number of collaborative projects between architects, engineers, and fabrication experts. In 2005 he co-founded designtoproduction as a research group at the ETH. Since 2006 he has been an associate in the company of the same name.*

**designtoproduction** *is a consultancy for the digital production of complex design. The company's interdisciplinary team integrates specialist knowledge from various fields to help architects, designers, engineers, and manufacturers bridge the gap between idea and realization. During the past years, the services of designtoproduction have been applied to renowned projects by Zaha Hadid, Renzo Piano, Daniel Libeskind, Shigeru Ban, SANAA, and UN Studio.*

*Following pages: Akpatok Island, Canada. One of Canada's most amazing arctic islands, it is ringed with steep limestone cliffs that rise high above sea level and its central plateau. Unsurprisingly, it is accessible only by air, which is pretty ideal for its cliff nesting seabirds called Akpatoks (or Thick-billed Murres as we know them). Image courtesy of the United States National Oceanic and Atmospheric Adminstration's Geodesy Collection*

**SITU STUDIO**

# Out of Control: Experiments in Participation

Constructed several times in several different locations, each with different and unknowable results, Solar Pavilion 2 is an experiment in indeterminacy. From the earliest stages of the design our goal has been to develop a local assembly system with a simple set of rules that would provide a high level of freedom for the configuration and reconfiguration of the Pavilion. Proceeding from this set of locally defined construction rules meant that we do not, and in fact cannot, produce images or drawings to coordinate the final outcome. The photographs and plans shown here are an attempt to document and communicate the work after the fact and, in a similar mode of reflection, this article itself is an attempt to articulate afterwards what has happened; to situate it within a genealogy of projects with similar ambitions and to think about the relationships between the use of images and the potentials offered by emerging fabrication technologies.

We have taken the occasion of this essay to look back at a series of projects which have similarly attempted to open up the design process; away from a top-down paradigm of form-giving towards processes that are more automatic or, at least, less deterministic. But in looking at these works from an historical distance we can see that although they share a similar desire to escape the totalizing ideologies of high modernism, they have often engaged a contradiction themselves through the conceits induced by their own use of images.

### Authoring the Unauthored

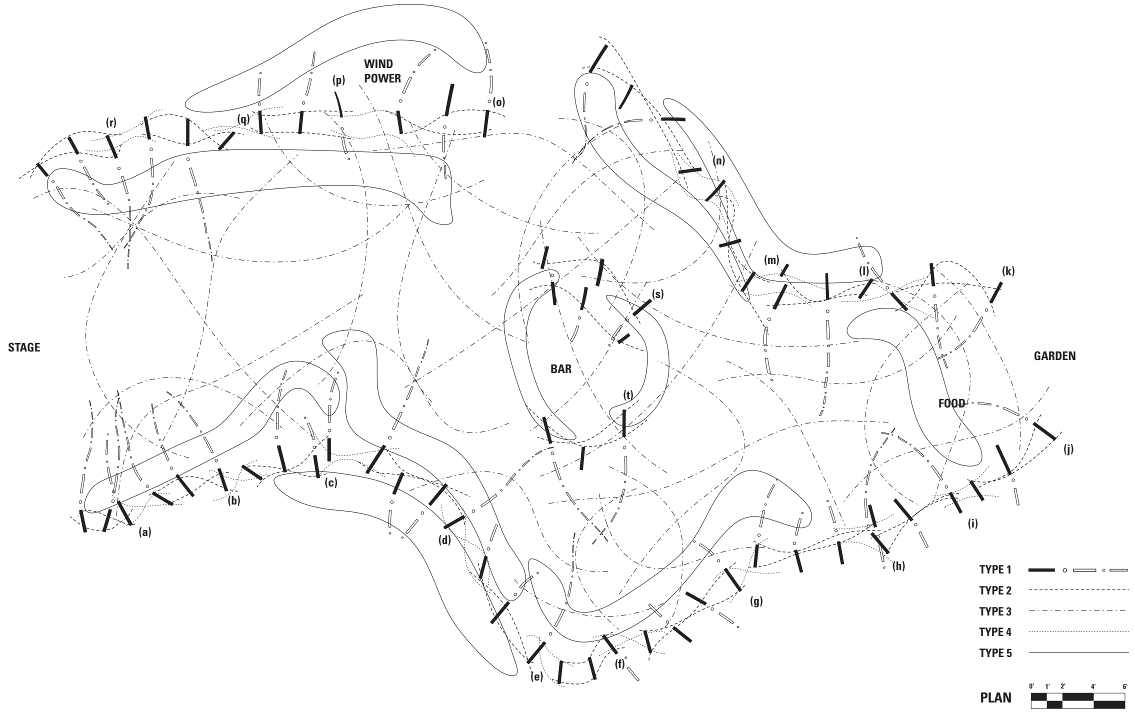
Many architect visionaries of the 50s and 60s were either seeking or celebrating indeterminacy in their work as a means of distancing themselves from the tendencies of much of the modern movement. Alison and Peter Smithson, Aldo Van Eyck, Bernard Rudofsky, Reyner Banham, Cedric Price, Archigram, Yona Freidman and Constant Nieuwenhuis all searched for ways of deriving form from exterior inspiration. They drew from divergent sources in the development of science and especially from biology, cybernetics, computation and linguistics, but also from cultural trends in pop culture and a resurgent interest in the vernacular or the "primitive." Whether it was the complexity of activity on the street, the biological motif of clusters and organic patterns, the infinite arrangement of activities in flexible structural networks, the inflatable, deployable, throw-away or plug-in, or the "non-pedigree" communal organizations of primitive settlements, what these tendencies shared was that they were a means of generating architecture that was seen to be automated and distanced from individual authorship.

The conceit that lay embedded within these intentions was that the dynamic changes these figures hypothesized had to be represented if they were to be communicated, and in this way were bound to be frozen in renderings of their projective futures. The images they produced fixed the constantly changing potential that they were proposing and channeled otherwise unpredictable outcomes into heavily composed pathways. New Babylon, for example, was a hypothetical urban game of continuous and active environmental participation, where all the walls were movable at the flip of a switch. But in all of the images and models of the project that Constant produced he had been forced to select an array of forms and shapes from the reserves of his own imagination which would be representative of the complex world that would emerge from the interaction of its imagined nomadic population. He was forced to be the sole author of an image which sought to communicate a principle of non-authorship. This problematic was evident in the tensions that existed between Constant and Guy Debord surrounding the paradox of what a Situationist Architecture might look like.[1] The same could be said of Peter Cook's *Plug-In City*, Cedric Price's *Fun Palace* and Yona Friedman's *Spatial City*. Although they were perhaps more utopian, aspirational or rhetorical in character, at some level, either by themselves or by others, the more specific characteristics of form foretold by their images would be literalized in later built works.

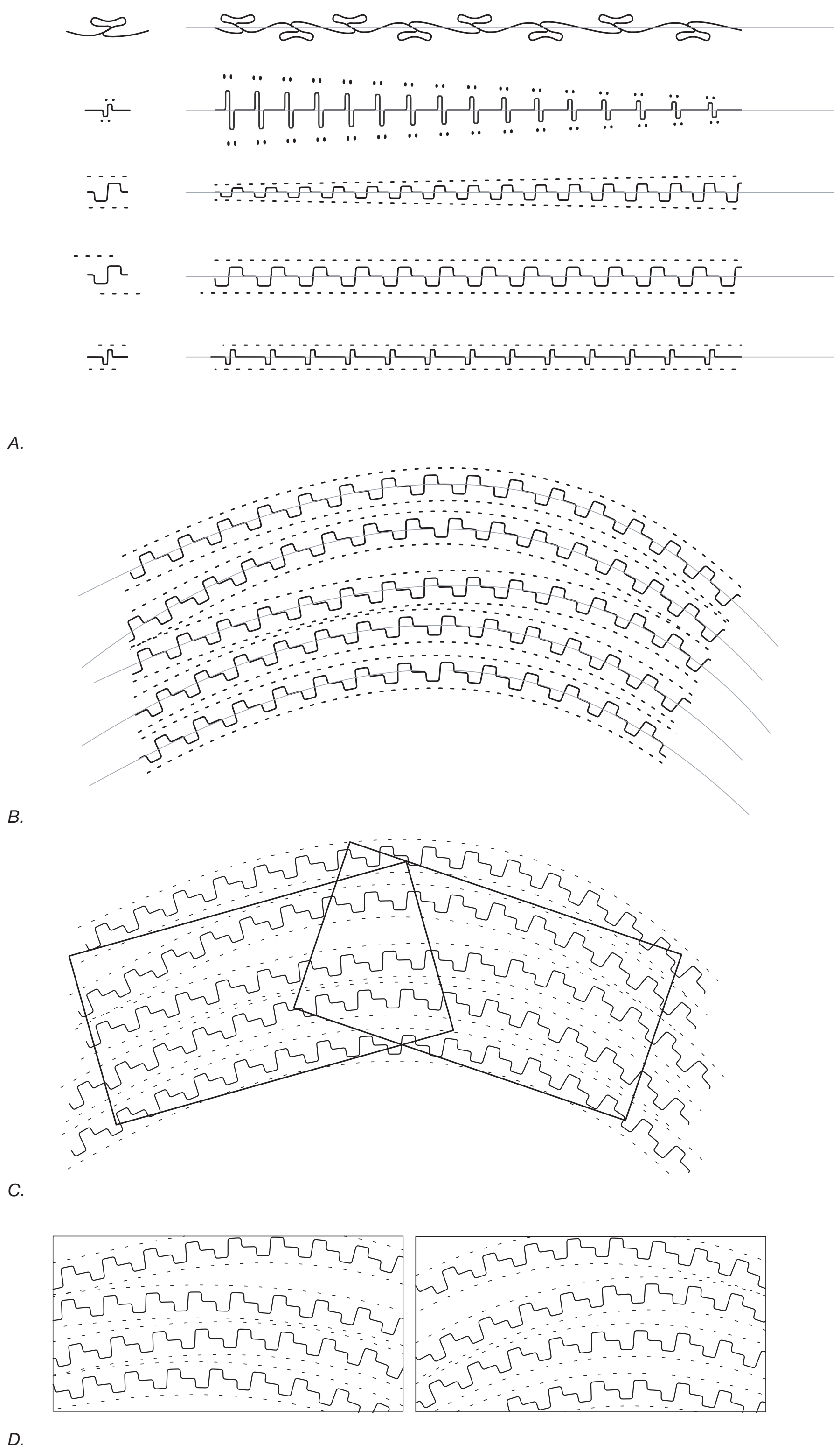
What belies the utopian role of these ad-hoc aesthetics is their direct translation into the forms of other projects. Alison and Peter Smithson's Sheffield University project, for example, was indicative of a Brutalist ideology which often sought to render the dynamic potential of the building in terms of an articulated distinction between over-emphasized structure and secondary and changeable units for inhabitation. Similarly, Kisho Kurokawa's Nakagin Capsule Tower was directly inspired by Archigram images. Although the capsule units were pre-fabricated and craned into place and even connected to the structural shaft by four high-tensioned bolts that could allow them to be moved, this gesture was never actualized and the project never evolved or changed as promised.[2] The variety of orientations and expressive articulation of each individual cell against the structural core, with its biological motifs of stem and branch structures, now appears to be primarily a frozen gesture of its own aspirations towards indeterminacy.

We can recognize the same conceit continuing throughout neo-avant-garde architectures to the present. The qualities of processes and transformation, in 1970s architecture inspired by the trace and the index ended up as an image of such transformative processes. Despite attempts to describe final forms with a dynamic vocabulary, such as "punctured," "compressed," "scattered," "interpenetrating," or "agitated," their dynamism was never a quality of the final object, but rather one of conceptual exercises that often took place in drawings and then overlaid upon the object as a metaphor.[3] The fluid architectures of the past decade have been similarly motivated, appropriating Deleuzian notions of smooth space and striated space. Despite the sociopolitical origins of this idea, it was more often represented as an image through variations on curvilinear shapes. In comparison to the original concept, the generation of such work gained traction through newly

*Solar Pavilion 2, Situ Studio, July 2007. CitySol Festival, New York, NY. Photo courtesy Keith Sichio*



*Plan, Solar Pavilion 2, Situ Studio, July 2007. CitySol Festival, New York, NY.*



*A. Joint profiles, B. Script to propagate joint profiles among given curves, C. Overlayed on 4 x 8 ft. plywood sheet, D. Toolpath for CNC cut sheets. Solar Pavilion 2, Situ Studio, 2007.*

available modeling software and developed a pedagogical role in the academy.

Another trend in recent design strategies, which builds upon a lineage of statistical and graphic representation going back at least as far as Hannes Meyer's Bauhaus, is the visualization and analysis of quantitative information. Earlier interests in program analysis using graph theory that once helped architects arrange rooms according to circulation calculations has, more recently, been extended to the mapping of broader phenomena such as geopolitical contexts and changing demographics. In architecture, the adoption of these strategies can occupy a curious relationship to the making of images - the traces of motifs, compositions and colors and their formalization in comparison to the graphs that one usually finds in a peer reviewed scientific paper often suggest an aesthetic sensibility at work in the layout if not also the compilation of data. An analog of this conflation might be found looking as far back as Marcel Duchamp's Coffee Grinder—a piece which, while driven by an ambition to overcome the retinal through the neutrality of the draftsman's tools and the banality of its subject matter, is nonetheless as seductive an image as any other. The graphs, statistics, charts of the more recent past tread a similar line—where ambiguities in the status of the images allow them to oscillate between the dispassionate and the highly composed.

The most recent incarnation of this conceit is in the adoption of advanced computation techniques from the biological and physical sciences, such as generative growth simulations, scripting and parametric modeling, to create non-standardized architectures which can potentially allow for local responses rather than universal impositions. The images produced by programs such as Maya are often purported to be natural, or at least to simulate natural processes of form creation. A typical generative process may involve creating a virtual cellular automata and then, within its digital environment, allowing it to grow according to programmed rules. The simulated moment of natural selection occurs intermittently throughout its growth according to a host of design criteria and then finally frozen at a specific moment within this ongoing cycle in which the design has evolved to be suitable for its task and ready for manufacture. Ultimately, the relevance of these processes to the final object often remains metaphorical and/or visual, while the strategies that govern their realization are of an entirely different logic.

The images produced by these projects highlight an affinity between the architect's intent and a general anxiety present in design culture regarding freedom and control. They figure this affinity towards greater freedom as an appeal towards a mode of creation that is sufficiently removed from subjective determination. It is as Colin Rowe said of "escapist myths" which he saw as "still active in endeavoring to relieve the architect of responsibility for his choices and which all alike combine to persuade him that his decisions are not so much his own as they are, somehow, immanent in scientific, or historical, or social process."[4] The difficulty seems to be in pursuing these ambitions without resorting to images that only serve intentions that could arguably be taking place at the level of spatial organization, constructional logic and production systems.

### Local Control, Global Uncertainty

Our recent experiments have been at a small scale and have only had to engage the limited logistical criteria of a temporary deployable structure, but by virtue of this modest scope of production the Solar Pavilions (both 1 and 2) have presented an opportunity to test hypotheses about local rules of assembly at an architectural scale. We aim to experiment with the output potentials of local digital fabrication (all the components of the pavilion were fabricated in our studio) and to create an open construction system that encourages participation and prohibits a repeatable configuration. The goal is to defer the aspect of indeterminacy to the actual on-site construction process, rather than to any point within the design process.

The Solar Pavilion 2 is the second of a series of structures that we originally designed and fabricated for the CitySol festival in New York and later installed at two other events. The pavilions are a kind of constructional game in which any number of players can participate in making local design decisions under our overall direction.

*CNC router cutting .5 in. plywood sheet. Solar Pavilion 2, Situ Studio, 2007, Photo courtesy Situ Studio*

*Deploying the pavilion at the CitySol Festival. Solar Pavilion 2, Situ Studio, 2007, Photo courtesy Situ Studio*

The forms that result are partly a product of the internal logic of the components, partly a product of our stewardship, and also partly a product of the unique human dynamic of each group of volunteers, and the particular circumstances of each site and program.

In our studio, using our CNC router, we cut 200 plywood sheets into thousands of component strips. The pattern cut by the router is generated by a simple script that propagates a connection profile along a series of curves and so provides each strip of plywood with a continuous interlocking edge. The basic elements of the pavilion are these arcing pieces of plywood that can connect to any other piece at any point of contact through the use of flexible tie straps. The pieces are grouped into five types—differing in curvatures, thicknesses and depths—that correspond to different structural conditions that may be present within the overall system. Minor variations within each group resulted in 30 unique pieces in total. The universal connection along their edge combined with the variety of curvatures and profiles provided a sufficient degree of freedom to force indeterminacy and variability in each assembly event.

In developing the design we focused on the local logic of the component pieces—the characteristics of each joint shape, the efficiency of a tie-strap—and were less concerned with how they would synthesize into a whole. Our initial decisions were based on factors including structural ability, efficiency of material, and ease of assembly. The overall structural behavior relied on redundancy, in which the weaving and interconnecting of pieces stabilizes the whole in a complex network of forces. Many hours were spent developing and testing the various properties of these components, always at full scale in our studio, in order to create a system that would adjust to a range of conditions. Computation was used in this process only to aid in the tasks that were either monotonous or difficult.

The role of 1:1 testing was critical at this stage. We played out scenarios of construction almost to the extent of mocking up the entire structure at full scale. The script that we developed allowed us to automatically produce zero-waste cut sheets beginning from a single joint shape. We experimented with the variations of their interlocking positions and stressed these to their breaking point in learning what possibilities were inherent within the pieces and what the critical environmental and material factors would affect them. For example, during this process we discovered that deeper notches on the profiles would be better suited to the task of securing the elements that would act horizontally; ensuring that they would maintain beam depth and not twist into a flat position. We also discovered that the forces in the structure would often take a few days to reconfigure themselves under slight changes in temperature and humidity. It was only through such full-scale testing that we could gain an awareness of how the macro characteristics of the whole depended upon the sequencing of construction and the time-scale of its various micro adjustments.

### Solar Pavilion 2

Solar Pavilion 2 has been constructed three times and each time the event has taken place on a different site, with different participants and different sets of programmatic requirements. The first deployment took place on the east side of Manhattan at Stuyvesant Cove Park in the summer of 2007. It accommodated a bar, a food counter and places to rest in the shade. The second event took place at the DUMBO Art Under the Bridge Festival in October of 2007, where the pavilion adjusted itself along a narrow site into a linear arcade that sat between the remains of two mid-19th century warehouses. The third construction took place at the SCOPE Art Fair in Miami, where the pavilion was reconfigured again to function as a filter to channel the flows of entry, egress, and VIP access into the larger tent structure behind it.

The construction of the pavilion begins with the arrival of a 20' shipping container on site that contains all of the pieces of the 2500 sq. ft. structure stacked flat. The assembly starts with the deployment of a number of self-supporting column clusters, type 1, around the site. These are made of a number of thicker plywood pieces that have been pre-assembled in a way that allows them to collapse into a flat bundle when a single tie-strap is removed, while all the others remains intact. A coding system that uses different colors of tie straps allows these bundles to quickly unfold on site and lock into rigidity. The construction expands and interconnects around these primary elements with the team attaching types 2-5 according to their respective structural roles. As different people select new pieces to add to the system, it begins to move, tilt and lean, often passing through points of instability before connecting to neighboring clusters. The process is akin to crystallization, as overall stability increases through the accumulation of pieces, one by one. At the early stages the structure is prone to slipping from apparent stability to instability and back again before settling into newer configurations. As the structure begins to weave together and become interdependent, initial pieces might be moved, or their connection points might be adjusted up or down one or two notches along their edge to tighten or release tensions that have been developing and moving around through the structural cage as it grows. This process relies heavily on human intuition as to the best selection of new pieces or the awareness of where forces are developing and so anticipating where a certain looseness of connection should be built in. Over the life of the pavilion, notations were made on the plywood parts to indicate certain configurations that worked especially well. In subsequent construction events, these notes, or traces, became suggestions to how one might go about placing a part in a similarly successful way. Each set of volunteers that has helped to install this pavilion has brought a different sensibility to its assembly and had a significant impact on its formation.

*Solar Pavilion 2, Situ Studio, July, 2007, CitySol Festival, New York, NY. Photo courtesy of Keith Sirchio*

After the plywood structure is complete a skin of overlapping flexible tiles of biodegradable corn-based plastic are hung from the underside to provide shade and cover for the events. Like the plywood parts, the skin was fabricated with a zero-waste mandate, in which two curved cuts in a square sheet produced four tiles with nothing left over. This simple, flexible shingle system could be raised in different sequences and tied to the structure at different lengths allowing the skin to adjust to the spatial outcome of any particular iteration of the structure's organization.

It is the simplicity of the pavilion's rules and the fact that small quantities of customized components can be both economically manufactured and assembled that offers a hypothesis for new systems of decentralization in the construction of local environments. The aspect of participation is extended beyond the design stage into, more significantly, the fabrication and construction stages. The basic question is whether decision-making power can be distributed to the builder and the user among other parties, as a means to allow a design to evolve. Is it possible for the construction process itself to be redesigned, allowing certain freedoms to be manifested in places beyond the architect's studio? The decentralizing possibilities of digital fabrication linked with such simplicity of use could potentially introduce these ideas where form emerges gradually out of a multitude of autonomous processes; processes that are not digital algorithms, but rather human ones. Granted, the limited structural and programmatic requirements of

*Solar Pavilion 2, Situ Studio, December 2007. Scope Art Fair, Miami, FL. Photo courtesy Situ Studio* a temporary pavilion readily allow for these experiments to occur, but their success implies a potential for implementation in more diverse situations.

There remains an opposite tendency for the use of digital fabrication and advanced computation that involves the privileged position of images in the process of design and manufacture. As one of the leading proponents of non-standard architecture, Bernard Cache has warned, “if, indeed, a non-standard architecture consists of generating more or less soft surfaces which will then be called a building by transferring them onto a battery of production software in order to create very expensive kinds of sculpture which no longer have any relationship with the historical and social sedimentation that makes up a city, then we are only perpetuating the Romantic myth of the artist-architect”[5] As the necessary translation from file to factory is often sold as a smooth process with little relationship to a contingent material world the Solar Pavilion 2 was, for us, an opportunity to explore these contingencies in the context of a set of tools that have fundamentally changed the relationship between form and representation.

## References

*1 Probably most Situationists realized the near impossibility of constructing true situationist architecture. Asger John apparently concentrated on the construction of Situationist theory rather than of genuinely Situationist works, and hopelessly ambitious Situationist projects rarely went much further than the written idea. Debord left his maps fractured and uncertain, without proceeding to depict a unitary urbanism proper, so it is unsurprising that he considered Constant’s projections of an uncontested future space to be highly improbable.*
*Simon Sadler,* The Situationist City *(MIT, 1999) p. 159*
*2 The tower currently faces imminent demolition due to fears concerning the toxicity of the materials with which it was originally built—the appeals of the architect at the end of his life to replace the plug-in units one-by-one with updated and safe capsules have been rejected by the building’s management association.*
*3 See Robin Evans, “Not To Be Used for Wrapping Purposes: A Review of the Exhibition of Peter Eisenman’s Fin d’Ou T HouS Shown at the Architectural Association, London,” (1985)* Translations from Drawing to Building and Other Essays *(Architectural Association Publications. 1997)*
*4. See Robin Evans, Not To Be Used for Wrapping Purposes: A Review of the Exhibition of Peter Eisenman’s Fin d’Ou T Hou S Shown at the Architectural Association, London, (1985) in* Translations from Drawing to Building and Other Essays *(Architectural Association Publications. 1997)*
*5. See Deleuze and Guattari, 1440: “The Smooth and the Striated,” in* A Thousand Plateaus: Capitalism and Schizophrenia, *(University Manitoba Press, 1987) p. 523*
*6. Colin Rowe, Introduction to* Five Architects, *(New York: Wittenborn, 1971) p. 6*
*7. Bernard Cache, and Patrick Beauce, “Towards a Non-Standard Mode of Production,” essay published in* Phylogenesis foa’s Ark *(Actar, 2004) p. 390*

**Situ Studio** *was founded in 2005 while its partners were studying architecture at The Cooper Union. Operating at the intersection of architecture and a variety of other disciplines, Situ Studio’s work has been enriched by close collaborations with geologists, writers, engineers, biologists, activists and artists. Recent projects include the design and fabrication of Solar Pavilion 3 and a demographic mapping project with Brooklyn Public Library that is focusing on the visualization of census information for the institution’s branch planning and analysis.*

*Solar Pavilion 2, Situ Studio, July, 2007, CitySol Festival, New York, NY. Photo courtesy of Keith Sirchio*

*Solar Pavilion 2, Situ Studio, October, 2007, DUMBO Art Under the Bridge festival, Brooklyn, NY. Photo courtesy of Situ Studio*

*Solar Pavilion 2, Situ Studio, July, 2007, CitySol Festival, New York, NY. Photo courtesy of Keith Sirchio*