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.

Burying the historic furrows of the peasant and the political 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 senescent circulatory system that is once parametric while inherently disconnected. By using his categorical maps, which include environment, population, synthetic inputs, outputs, natural resources, and economics, a notional 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 solitude or expression, they are not literal devices for evaluating our current or historic state of social/political/economic or condition, but rather the drawings offer unique non-spatial, non-territorial, yet qualitative landscapes of an invisible ecological world, synthesized by agrarian-to-use-of-policies, energies, production and the means of sustaining populations as imagined by Pete Sakes, an uneducated agrarian wanderer.

By tilling the historic furrows of the peasant and the political 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 senescent circulatory system that is once parametric while inherently disconnected. By using his categorical maps, which include environment, population, synthetic inputs, outputs, natural resources, and economics, a notional 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 solitude or expression, they are not literal devices for evaluating our current or historic state of social/political/economic or condition, but rather the drawings offer unique non-spatial, non-territorial, yet qualitative landscapes of an invisible ecological world, synthesized by agrarian-to-use-of-policies, energies, production and the means of sustaining populations as imagined by Pete Sakes, an uneducated agrarian wanderer.

**References**

2. Ibid.
3. www.economyprofessor.com
4. Ibid.
6. www.wikipedia.com
8. Ibid.
9. Ibid.
10. Ibid.

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 field conditions inter-relation environment, crop components and adaptive mechanisms, population and flows of energy via a senescent circulatory system that is once parametric while inherently disconnected. By using his categorical maps, which include environment, population, synthetic inputs, outputs, natural resources, and economics, a notional 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 solitude or expression, they are not literal devices for evaluating our current or historic state of social/political/economic or condition, but rather the drawings offer unique non-spatial, non-territorial, yet qualitative landscapes of an invisible ecological world, synthesized by agrarian-to-use-of-policies, energies, production and the means of sustaining populations as imagined by Pete Sakes, an uneducated agrarian wanderer.

**Scheurer, Fabian**

**Size Matters: Digital Manufacturing in Architecture**

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-locked entry 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 wind-screen 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 gumscript on their websites and occasionally build prototypes with 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 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 designproduction were asked to help realize Instant Architect’s design for Inventeering Architecture, a traveling exhibition of the four Swiss architecture schools. The newly built 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
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 that controls 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.

Complexity

Designproduction is founded on the firm belief that architecture is built from components. You can either use very similar, simple 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.gramazikohler.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
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 Paglitz 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 and 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 engineer 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.

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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,
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, even 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 at ETH Zurich. His scientific work focused on the practical aspects of artificial-life methods in architectural design 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: Alpatok 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 Alpatoks (or Thick-billed Murres as we know them). Image courtesy of the United States National Oceanic and Atmospheric Administration’s Geodesy Collection.