Gramazio & Kohler’s work in the faculty of Architecture and Digital Fabrication at ETH Zurich is renowned for its pioneering work with industrial robots. Here, Fabio Gramazio, Matthias Kohler and Silvan Oesterle describe how the integration of fabrication-relevant decisions into encoded designs enables the control of complex interactions between material elements and facilitates the direct generation of machine data, as epitomised by their West Fest Pavilion project.

The wood battens have been connected by screws, reducing the pre-tensioning, which results in thinner battens and less material consumption.
below: The Sequential Wall elective course investigates the architectonic and constructive potential of additive digital fabrication in timber construction. The interplay of many small parts results in a material system whose properties in terms of function and design go beyond the individual batten module.
We are in the midst of a period of major change in the production conditions in architecture. Over the last 20 years it has become possible to industrially manufacture individual, non-standardised elements according to their digital delineation. As a result, architects have started to integrate fabrication as a generative paradigm into the design process. During the period of early Modernism in architecture there were similar tendencies, for example the Bauhaus School’s principle ‘art and technology – a new entity’. This resulted in an architecture that exploited the possibilities of industrial production to achieve satisfactory design standards, regarding both functional and aesthetic aspects. It found an expression for the possibilities of the machine age and its control over fabrication information which was repetitive and standardised.

The use of computer-controlled production tools already available but typically underused in construction trades provides new opportunities for a freedom of design that is innovative and adheres to constructional logic at the same time. The material element and the fabrication machine inform the building process and provide the parameters and constraints for the design process. The integration of fabrication-relevant decisions into encoded designs allows the architect to control complex interactions between singular material elements and facilitates the direct generation of machining data. This implies the understanding of physical conditions of architecture as well as material properties as the foundation for design programming that develops from drawing geometric elements into defining material components and their assembly logic. Thus a design-focused relationship between the digital and the material can emerge.¹

The End-Effector

With direct access to the definition of material systems through programming manufacturing data, the question arises: Which are the relevant tools that allow the fabrication of building-scale elements and are flexible enough to adapt to different materials and assembly logics? The digital description of an object to be built can be extremely specific and can consist of a multitude of different instructions. Designing with assembly logic develops its full potential in combination with
a manufacturing machine capable of physically carrying out different actions. An industrial robot meets this requirement on an architectural building scale. It is a generic tool and not specialised for one specific activity. The robot has a universal arm that can reach any point in three-dimensional space. The actual tool, an end-effector that defines the material machining process, is attached to the end of this kinematic chain. The manufacturing process thus consists of the data required to control the robot and the respective properties of the tool being used. The design and development of custom end-effectors is important as it enables the architect to reach into the conception of material processes.

Expanding Design Information Content

The connection of digital fabrication and computation enables the immediate programming of production data and directly links the design with the making of architecture. As a result the architect can fully control the construction process down to the smallest detail. This enables increasing the building components' information level, which consists, first, of a large set of individual parts that make up the components and their joints. Second, it may include information about functional and material aspects. The question arises of how to deal with this on the one hand powerful, but on the other hand critical, direct relation of design and construction. If the programming of detail systems is within the control of the architect, new potential for the design is possible. The architect's design data does not need to be converted to construction instructions by a number of different parties involved in the building process, but can be used for fabrication as is.

A mere rationalisation of workflow might discard the creative potential that could emerge from the interdependence of design and fabrication. Only through the configuration of detail systems that encapsulate the increasing amount of material and fabrication parameters within simple and manageable methods can a new design space evolve. This allows designing with the specific characteristics of a building process and at the same time shaping the process itself. In this case, one should be aware that a major difference exists between the precise numeric design and the physical world – geometric and fabrication data do not contain information about physical conditions such as gravity or material properties per se. Conversely, this means anticipating physical requirements at the outset of the parametric design process and using material conditions as well as assembly logics as the basis for coding.

Design Information and the Structure of Construction

The West Fest Pavilion project (2009) explores which criteria of a material system are decisive for architecture and how the correlation of differing requirements can offer new design potential. Standard wooden battens are stacked up to form columns that transform into a roof. The robotic fabrication allows the modification of the length of individual battens during the production process before placing them in their final position in space. The columns constitute the spatial layout as well as the carrying structure of the pavilion, which are both determined by the architectural organisation of the programme, the structural performance and the assembly process.

The driving forces of the structural system are a minimal joining surface between the layers that transfers vertical compression loads, and an appropriate connection method that allows tractive forces coming from wind loads to be received. Through coding the assembly logic, the interrelation of the aforementioned constraints becomes possible and leads to new architectural solutions. For example, the overlap in the middle of a column's side maintains the minimum overlap required to transfer vertical loads and adheres to the maximum batten length. As a result the column's weight is reduced through dissolving the structure towards the top. This has several advantages. Firstly it reduces the self-weight on the lower parts of the column, and secondly it permits a larger cantilever to form the roof. Thirdly, and most important, it allows accentuating the wooden materiality through indirect lighting inside the column. The batten's overlap that shapes the ornamentation of the night lighting is a direct effect of the structural system and the way the vertical forces are transferred through the structure.
The columns were fabricated off site. Each column is individually rotated, producing a progression of subtly varied spaces. The detailing of the edges accentuates the rotation through the jagged overlap that at the same time prevents the wood from splintering under tractive forces.

The pavilion columns were fabricated from simple wooden battens by a robot that cut and stacked them. Three elements formed one column. Shown here is the topmost one where the element starts to dissolve towards the corners.

The pavilion was conceived as a temporary spatial structure for a major public event hosted by the canton of Zurich. The wooden structure consists of 16 contorted elements made from 372 wooden battens.
Gramazio & Kohler (Architecture and Digital Fabrication, ETH Zurich), The Sequential Wall, Zurich, 2008

bottom: Standard wooden battens are cut to length and stacked to form a building shell. Functional requirements of an external timber wall such as insulation and constructive weather protection had to be addressed. The gap between the inner and outer layer can be filled with insulation material. Individual protruding battens form a sacrificial layer and drain water off the external facade.

below right: The wall combines a shielding exterior surface with a girder-like structure. The rippling at the tip of the battens allows them to be connected to the load-bearing parts.
Expanding and Programming the Performance of Material Systems

Even when the number of functional requirements of a building element increases it is possible to address them with simple material components. Algorithmic design systems enable the selective manipulation of fabrication data whereby material can be structured according to its properties and functional requirements. The singular material elements are augmented with information that can enhance their performance. This results in more complex design and fabrication data. In order to operate in this ever increasing set of information, logical systems must be designed that define and codify the material and structural relationships of the individual elements to each other. In the elective semester course The Sequential Wall taught at ETH Zurich (2008), wood battens are stacked up to form walls. The fabrication process is similar to the West Fest Pavilion project, but the walls need to provide for the performance requirements of an exterior building shell: constructive weather protection and thermal insulation.

In order to increase the material potential of a system made from simple wood battens, physical experiments are exploited to define their arrangement and scope of variation. For example, watering tests define the possible range of overlaps and lengths within the water-bearing layer. This information is abstracted into design algorithms, which results in the interplay of many small parts that form a constructive system whose properties in terms of function and design go beyond the individual batten module. Although the controlled interplay of complex material arrangements cannot surpass the functionality of a highly specialised constructive layer, it can yield an effective combination of simple material parts to form high-performance building elements.

CNC: Crafting Numerical Control

Achieving a sophisticated building component with a simple material and connection through a high level of knowledge of construction techniques can be compared to methods used by manufacturers from pre-industrialised ages. Despite the similarities, today the action of material handling is indirect through the use of numerically controlled machines as opposed to the instant feedback about the work in progress the skilled manufacturer received through the tool in his hand. With computer-aided manufacturing (CAM), the tool is controlled through explicit routing data, which leaves no room for interpretation and adaptation. This change of workflow redefines the interface between architect and manufacturer. The manufacturer becomes a specialist in operating CNC machines and the architect designs control data for these machines. To derive solutions that effectively negotiate between beauty and construction without resorting to unmanageable complexity, the architect and the manufacturer must collaborate. The architect needs to be knowledgeable about the production conditions and able to integrate the implicit knowledge of the trades he or she is working with into the design of explicit machining code.

These changes in production conditions and working processes lead to the assumption that new forms of architectonic expressions will emerge. They require appreciation for the elegance of construction that is less based on demonstrating the perfected functionality of each singular building element, but should negotiate differing functional requirements of architectural components to form a coherent synthesis of material and design system.

Notes

1. For further reading, see Fabio Gramazio and Matthias Kohler, Digital Materiality in Architecture: Gramazio and Kohler, Lars Müller Publishers (Baten), 2008.