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DIGITAL WOOD CRAFT

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ABSTRACT: In 1995, Robin Evans points out in his book *The Projective Cast* how the development of techniques changed architecture and the space inhabited in times of Gothic and early Renaissance. We see a parallel phenomenon today, where the interplay of technology and tool gives shape to new design (Kolarevic 2005). Yet in opposition to the interwoven fields of design and craft of the late Gothic, today's building sector is enormously diversified, and a growing complexity in the building process and number of used materials can be observed. This gives an opposite point of departure into a more integrated field of design and innovation in architectural design and building industry.

KEYWORDS: Digital production, CAD/CAM, parametric design, complex form, mass customization

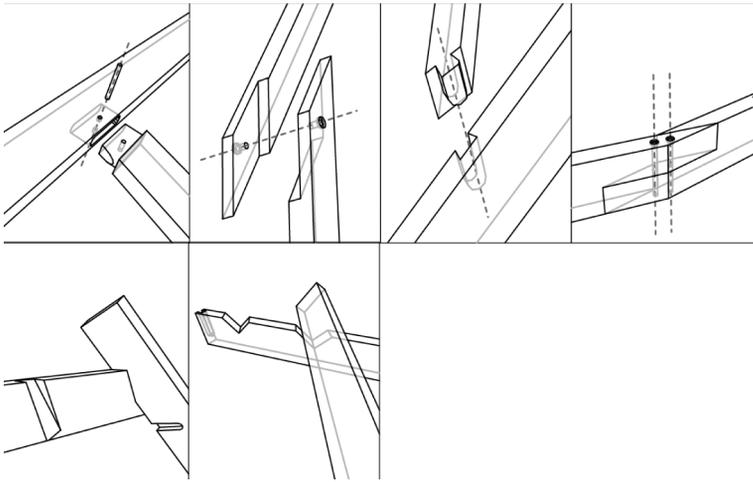
RÉSUMÉ: En 1995, Robin Evans souligne dans son livre *The Projective Cast* comment le développement technique a modifié l'architecture et l'espace habité durant la période gothique et le début de la Renaissance. Nous voyons un phénomène parallèle aujourd'hui, où l'interaction de la technologie et de l'outil donne forme à de nouveaux designs (Kolarevic 2005). Or, contrairement à l'imbrication des domaines de la conception et des métiers de la fin du gothique, aujourd'hui le secteur du bâtiment est très diversifié et d'une complexité croissante dans le processus de construction et par le nombre de matériaux utilisés. Cela donne un autre point de départ dans un domaine plus intégré de conception et d'innovation dans la conception architecturale et l'industrie du bâtiment.

MOTS-CLÉS: Production numérique, CAD/CAM, conception paramétrique, personnalisation de masse

1. A CRAFT BASED DEVELOPMENT

According to Evans the newly achieved skills in shaping the process were the key to innovation based on a synthesis of new design techniques, understanding of material and its behavior and new production methods. Experiences made in the realm of material and production process formed the basis for innovation which led to spatial solutions that could give better answers to emerging problems, as buildings for the ever-growing cities of the renaissance.

FIGURE 1. ILLUSTRATION OF THE DIFFERENT TRADITIONAL WOOD JOINTS USED IN THE PROJECTS 1:1 DEMONSTRATOR.



This was possible at exactly that moment, when craftsmanship met with new drawing techniques – this in the usage of *traits* for the construction of three dimensional complex shaped masonry. In addition the knowledge had to be found in person that was able to link the two sides, here Philibert Delorme in the 15 hundreds. The fusion of knowledge on process and material, the talent to vision and the skill to handle the newest techniques allowed improvement. Retrospectively this is understood as the start of a new architectural epoch. Thereby it was not a rational spirit that drove Delorme, but a will to find and overcome challenges in a novel way in order to create new aesthetic and spatial experiences. It was this desire for experiment and novelty that led to the development of new techniques which inspired a great number of intelligent applications in secular and religious buildings (Evans 1995).

The well known ways of design and production are today challenged by customizable digital design and fabrication tools, as parametric design software,

BIM oriented process management tools, intuitive to use 3dModelling technology and the enormous proliferation of different types of CNC machinery in almost all fields of fabrication (Kolarevic 2005). But at the same time the adaptability and ever increasing computational power allows new ways of design and a possibility to reintroduce the knowledge about material and its behavior into the design process—this in form of knowledge of materials behavior as well as the behavior of it in assembly, as in building construction.

Today digital tools form the basis of nearly all design, construction, fabrication and management tools in all profession related to the building industry. A digital basis for interfacing seems to be established, which might serve as general platform for an informed collaboration. Innovation could be unleashed, as the common ground of craft and design allows to inherit the complete set of information on material and process, its behavior and limitations (Schindler 2007); this not to make the craft obsolete in an Information society, but to reactivate the crafts grown knowledge on material and process as a means of design.

2. DIGITAL TOOLS

The digital toolset in design and production allows for new ways of making. As Catherine Slessor observed in 1993, “the notion that uniqueness is now as economic and easy to achieve as repetition challenges the simplifying assumptions of Modernism and suggests the potential of a new, post-industrial paradigm based on the enhanced, creative capabilities of electronics rather than mechanics.” The notion of non-standard production challenges the traditional building practice, which was oriented on the paradigm of Henry Ford’s industrial mass production (Holm 2006). In fact the model of mass customization seems to describe the building sector with its often singular outputs in a much better way.

FIGURE 2. CNC WOOD JOINERY MACHINERY ARE WIDESPREAD WITHIN THE EUROPEAN TIMBER INDUSTRY AND ALLOW THE FAST FABRICATION OF MASS CUSTOMIZED BEAMS. PICTURES BY HUNDEGGER MASCHINENBAU GMBH.



Architectural design based on computational methods allows per se mass customization approaches. Herein the focus of design shifts from the constitution of a solution (i.e. single elements), that already has the final overall output in terms of geometry and internal distribution of functions imbedded, towards the definition of relationships between the elements in play. It is the difference between the elements that informs a potential final geometry. As the constitution of every element may vary the formulated overall geometry is just one out of many – solely defined by the given parameters and the setup of the internal rules of interaction. Formulating this setup becomes the main design task (Burry 2005). The evolving systems oriented on a Deleuzian (Ansell-Pearson 1999) understanding allow new ways to think design. It allows for the easy exploration of a multitude of design solutions.

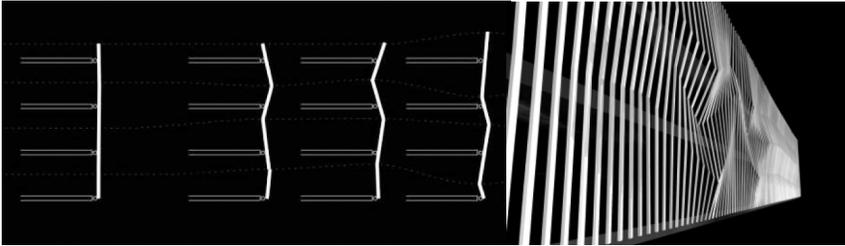
The system is thereby driven by outer parameters. This might result in a gradually or sudden change in local performance criteria, resulting in huge or small difference within the elements phenotype. This allows mass customization, to overcome the solely slight changes in appearance (i.e. colour, material or embroidery) as seen nowadays in customer products, such as sneakers (Reebok 2008), but introduce dramatic shifts. In addition to the examination of change over time, represented in a diagrammatic linear alignment as seen in the mapping of different states of an object due to movement of its parts, first examined by Eadweard Muybridge and Étienne-Jules Marey in 1890, topological change and its infliction with the designs overall appearance can become a driver design exploration, as the introduction of shift, rupture, definition of internal and external spaces, poche and openings to appear within series.

3. PRACTICE BASED RESEARCH PROJECT

Whereas the story of the creative use of mass customization and the capabilities of a (re)integration of material properties are quickly told, the actual facilitation of these techniques bears a lot of unresolved questions. These range from technical questions, as the identification of the relevant tools and the possible interfacing between them, over questions of management of production and assembly, to conceptual ones, as modes of integration of feedback loops in the process to include knowledge about later steps into the design.

In order to generate insights in the relation, dependencies and chances between and within the different parts of the process we started an practice based research project. Herein the role of material evidence and its making can be an as integral part as in architectural practice. The evidence acts as material research inquiries by which the concepts, technologies and applications of the project can be tested and evaluated (Thomsen and Tamke 2009).

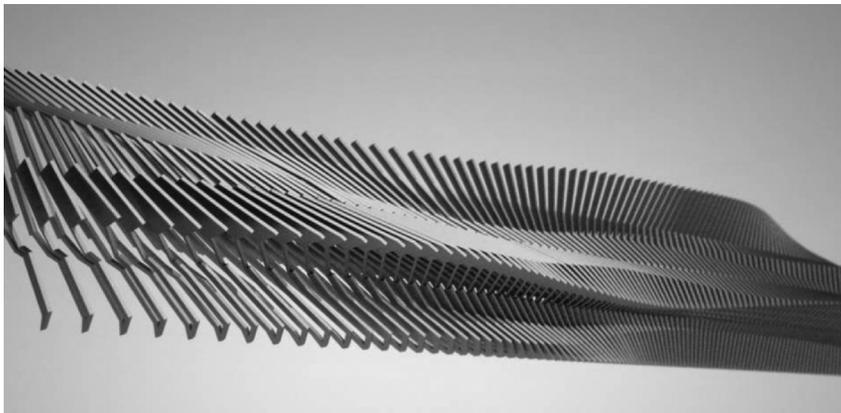
FIGURE 3. INITIAL DESIGN CONCEPT: A SERIES OF KINKED BEAMS CREATE AN OVERALL SURFACE.



4. DESIGN PROBES

The research took its point of departure from a real building project—the façade of a large scale multi storey Parking lot, wherein a parametric concept using CNC wood manufacturing processes was proposed (Figure 3, design: Blunck and Morgen Architects Hamburg with M. Tamke). The following research project looked at speculative modes of explorations in the link between design intent, formal and special expression and the realization process.

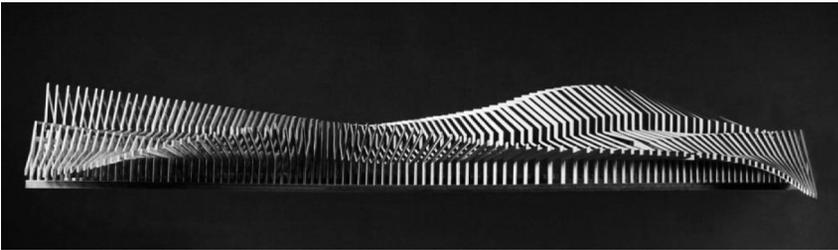
FIGURE 4. RENDERING OF THE THIRD GENERATION WITHIN THE DESIGN SERIES SHOWING THE VARIATION OF THE ELEMENTS DUE TO CREASING AND THE INTRODUCTION OF INTERNAL SPACES.



The basic idea of the design, consisted of evenly divided but differently kinked beams. Looking at the overall series wavelike patterns with changing transparencies and densities appear, whenever the observer moves along the façade. Parametric software was used to program a customized tool that allowed the exploration of several design variations until certain predefined or evolving performance parameters, as change in the structures transparency, were met.

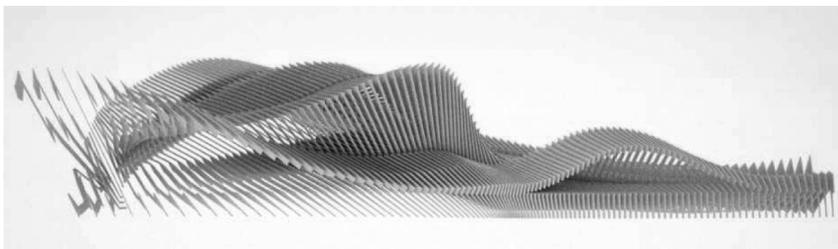
Furthermore the customization process allowed the introduction of fabrication parameters in the very first design process. The tools input parameters were linked to issues of tectonics, material, fabrication, formal concept as well as to a general idea of aesthetics and expression. The exploration was conducted in an iterative process, wherein we built several generations of design probes. By building these wood models the initial idea of a very direct link between design tool and fabrication could be examined at the same time as the parallel emergence of effects in the physical models as in the virtual design space.

FIGURE 5. PHYSICAL MODEL OF THE THIRD GENERATION WITHIN THE DESIGN SERIES SHOWING THE VARIATION OF THE ELEMENTS DUE TO DENSITY AND TOPOLOGY.



The idea of a series was not only met within the setup of the design, but as well in the design process. In a series of models the individual output of a certain design stage, its constituting elements and the emerging nature and its effects could be discussed. These would be distilled and emphasized in the next generation of models. By doing so an individual design language could be established. The structures level of complexity was raised for each generations leading to a model with enormous geometrical degree of freedom. This probed not only the custom made tool but as well the coherence of the established design language.

FIGURE 6. PHYSICAL MODEL OF THE FOURTH GENERATION WITHIN THE DESIGN SERIES SHOWING HIGH DEGREE OF GEOMETRICAL FREEDOM WITHIN THE BEAMS MOVEMENT AND VARIATION.



5. WOOD AS CONSTRUCTION MATERIAL

Wood is generally considered as one of the most sustainable building materials. It is as well connected to an enormous range of different ways of processing and joining. Especially the ability to easily process the joint directly from the material itself is remarkable. “The benefits of components with integrated attachments geometry are that the attachments can be designed and controlled as part of the generative process” as Larry Sass states in 2006. Based on a long tradition in the crafts wood-wood joints, especially those based on friction as dovetail joints, have advantages:

- Can be specific to certain geometrical and tectonic requirements.
- Parallel behavior of the joints part if exposed to changing temperature or moisture conditions due to the monolithic setup of the joints.
- High level of prefabrication.
- Inherit tolerance.
- Efficiency in assembly due to self registering joints and little or less secondary elements, as screws or bolts.

Precedent research has shown the advantage of implementing self registering joints that can adapt geometrically to specific local requirements in the construction. The required production capacity is given in the highly flexible CNC wood joinery machines, introduced in the typically midsized wood manufacturing companies. They enable not only the very fast production of individualized wooden beams but as well the efficient production of geometrical complex individualized joints that fit with little tolerances.

Taking into account that the material and production costs are usually not the main factor in the fabrication of constructions, as labor, production and transport are at most equally important (Guthrie 2003; Westney 1997), a reduction in costs for complex constructions in wood can be foreseen. This as the interplay of high precision and almost total prefabrication due to CNC manufacturing allows an easy assembly of elements with self registering joints, as shown in our research. Geometrical almost unrestricted joints enable furthermore new ways of design, as the traditional restrictions in fabrication and assembly are softened (Larsen 2007).

6. DEMONSTRATOR—INTRODUCING A BOTTOM UP DESIGN APPROACH

Taking a point of departure in the linkage of the parametric system used in the design probes and traditional wood craft techniques the final part of the research project was taking into account the whole process of digital design to production of a complex shaped geometry. In close cooperation with wood construction software- and machine industry we developed a design and fabrication approach, which combined the knowledge about the sustainable

materials properties, processing and joinery. The interplay of these attributes produced an intelligent system that could pose answers to complex situations in the spatial construction system of a 1:1 demonstrator.

FIGURE 7. DEMONSTRATOR BUILD UP AT THE EAAE EXHIBITION – JULY 2008 COPENHAGEN.



We knew already from the design probes that the key to design, fabrication and assembly of complex geometrical situations lied with the process of geometry generation. Within the series of design probes a tool was already developed that could handle design intent, material, processing and assembling properties and give instant feedback to the designer. These allowed an optimizing of the emerging complex spatial structure design on quantitative as well as on qualitative level. Within the making in real building size the ability to scale developed method and technique was tested.

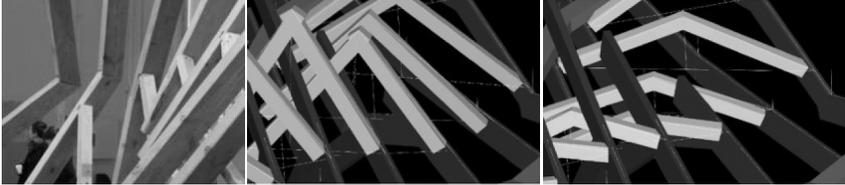
6.1. Parametric design strategy

The demonstrator aimed as well at testing the production limits of the wood joinery machines provided by our industrial partner and if these restraints could be implemented into our customized design tool.

In order to increase the complexity and as well raise the structures stability of diagonal beams were introduced connecting two respective beams. Which members met where and under which angle could be adjusted parametrically, whereas the precise meeting geometries derived from the given local status of the diagonal. The exact positioning of this element could not be easily calculated from their start and endpoint, instead the diagonal beams were measuring their and their neighbours dimensions, position and orientation and where adjusting themselves automatically in order to avoid intersection and fulfil the con-

structutive needs of the chosen dovetail connectors. The creation of autonomously operating second order geometry was interesting, as it was based purely on conditional statements and allowed design wise the introduction of spatial pockets in the structure.

FIGURE 8. THE DOVETAIL CONNECTORS POSED HIGH REQUIREMENTS ON THE GEOMETRICAL SETUP OF THE WOOD CONSTRUCTION, WHICH WAS MET BY THE AUTONOMOUS GENERATION OF DIAGONALS BY SCRIPTED FUNCTIONS.



At other positions solver algorithms were integrated into the structure to solve contradicting parameters. This as the underlying parametric model was based on the systems abstract axis system. While constructing the data for fabrication the implications coming with material thickness had to be taken into account. In the case of the joint between rail and beam, where depending on the geometric situation a double rafter cut or a notch was used, a solver algorithm, courtesy provided by Axel Kilian, limited the depth of the cut to 30% of the materials dimension in order to keep enough tectonic strength.

6.2. Local intelligence allows global design complexity

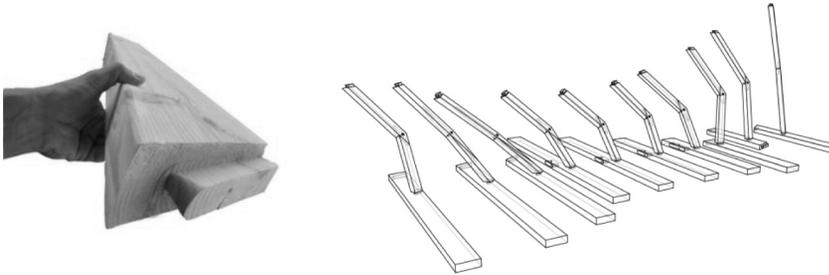
Whereas the overall structural system inherits a high degree of complexity, it was necessary to find easy ways of assembly. We found that traditional wood joints served well due to their self registering properties, this as a high degree of geometrical complexity was already bound in their making (Holzner 1999; Schindler 2007).

A high degree of planning was necessary to setup a system to control the complex fabrication of self registering joints, that allowed avoiding on site measuring and adjustment. Besides friction based joints, classical tenon joints with wood pegs have been used widely, whose exact position is as well geometrically defined. Solely the junctions between the beams and rails were not self registering as they were carried out as double cuts or notches. In order to provide guidance for assembly the insertion points were marked within the machine. And as this joints did not have an build in locking systems, metal connectors where needed—the only place in the construction.

In contrast to traditional modular structures, where joints are easy to assemble but not flexible in their geometrical setup (Wachsmann 1959; Herzog 1988) mass customization design strategies allowed variations within joints that allowed to fit to a diverse range of geometrical scenarios.

The combination of highly flexible CNC wood joinery machinery with parametric design tool allowed the production of individualized wooden beams and the rational production of geometrical complex individual joints that fit with little tolerances. The complex joint itself is thereby sculptured by a combination of simple cuts, drilling and milling operations out of the massive material allowing a fast production.

FIGURE 9. AS A MONOLITHIC WOOD JOINT DOVETAIL CONNECTIONS PROVIDE SELF REGISTERING PROPERTIES IN A CONSTRUCTION AND CAN BE FIT INTO DIVERSE LOCAL CONDITIONS, AS SHOWN ON THE LEFT, ILLUSTRATING THEIR APPLICATION IN THE DEMONSTRATORS STRUCTURE.



6.3. Integrating workflow and production parameters

The process development focused on the setup of a smooth and seamless workflow. We tried to use as much existing tools as possible and test their capacity before writing proprietary tools. As our parametric tools data could be read flawlessly, we used the Wood CAM tool HSB Cad. Its function was to define the different wood-joints on the predefined beam structure and write the instructions to the wood joinery machine. A colour-code, generated in the parametric modeller eased the identification of single beams and application of different types of craft based joints, as notches, cuts, dovetails and rafter joints.

In contrast to CNC mills wood joinery machines can execute a series of traditional operations, as cutting, milling, drilling etc. Therefore the code send from the CAM program to the machine consist merely of a set of tool operations and a special machine driving program is checking the plausibility of operations. As the CAM program used has no build in plausibility check—not producible wood operations could be sent from the parametric modeller to the machine driving program. As this slowed down the process to a great deal it was necessary to integrate the machines limitations into the parametric model. Learning and implementing the fabrications limitations in the constructions design and parametric model took just a few hours at the production facility with the operating staff on side.

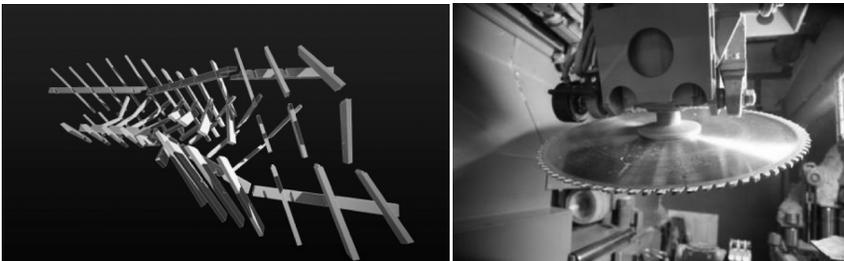
The machines requirements were introduced within the parametric model in two ways:

- either by algorithms limiting certain values;
- by real-time updating and observation of measured values in an excel sheet during the design process.

The last served for instance well for the control of the minimal length of beams. Similar to observation mad by Chris Williams (2003), too many interacting factors influenced the beams dimension to find a formula covering all occurrences. An iterative process triggering the influencing factors manually helped to find quickly a design solution that complied with aesthetic and production requirements.

The reading of certain parameters into an excel sheet helped as well to figure out further parameters as the overall weight and the centre of gravity. Those were defined by the given exhibition space and the fact that the demonstrator was to be suspended from the ceiling and should not tilt. Therefore an algorithm was integrated checking the centre of gravity. The resulting point could thereafter be displayed within the parametric modeller and give valuable advice in which way to adjust the design.

FIGURE 10. MODERN WOOD JOINERY MACHINERY STILL INHERITS THE BASIC TOOLING PROCESSES OF TRADITIONAL WOOD CRAFT: CUTTING, DRILLING AND MILLING. THIS ALLOWS THE PRODUCTION OF A GEOMETRICAL VERSATILE MONOLITHIC WOOD JOINTS AS SHOWN IN THE EXPLOSION DIAGRAM OF THE PROJECTS DEMONSTRATOR ON THE LEFT.



6.4. Production and assembly

The fabrication of the 65 individual wood beams on the wood joinery machine took 4 hours. As the pieces were not placed in order on the transport and due to an imprecise assembly plan and schedule sorting and discussion of assembly strategies took time. The assembly of the construction with 4 inexperienced students with no insights of the project and background in crafts took 10 hours. From this the careful tilting of the construction from its lying first state into the suspension took a great amount of this time. When the structure was build up a second time assembly was cut to 3 hours. Some tolerances had been set to small, which required force to make the pieces join. In general the joints fit well. Especially the introduction of the diagonal beams, led to a structural self centering system, as triangular relations where established within the system.

7. OBSERVATION

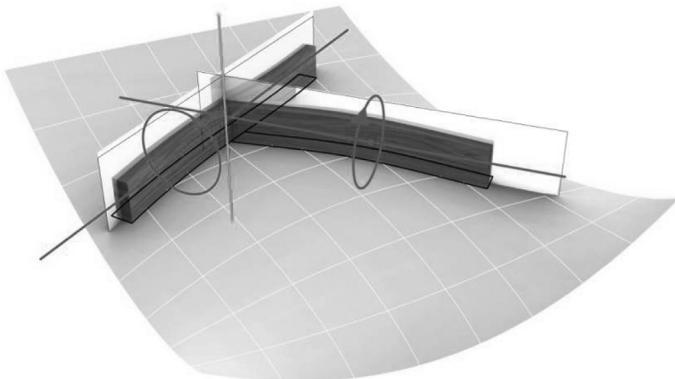
The successful integration of knowledge about material and fabrication into the design tool and the observation that this allowed to further the border for design was the key experiences made in the project. The ability to produce a customized tool allowed the combination of design intend with the possibility to realize it. In our example weaving in the limitations of the machinery and material (i.e. tolerances) did actually took not long (1 day), bearing in mind the result of a customized tool.

The precise creation of geometry can be identified as the key feature within the process. Geometrical information holds the knowledge of material and process. This precise definition and not additional information added as meta data, formed the basis of the following process. Information as the position and direction in space for tectonic calculation, dimension, material and type of joint for the highly precise fabrication and the position within the structure for the assembly could be extracted from this very data. The developed techniques can inform usage of similar approaches within structural wood systems in building size.

8. COMPUTATIONAL ASPECTS OF GEOMETRY GENERATION IN WOOD CRAFT

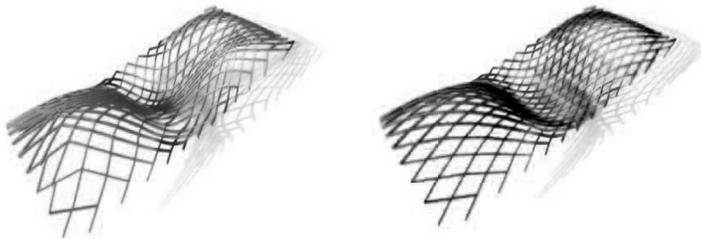
The focus of our ongoing research reflects the observed possibilities for design if parametric approaches are introduced in the generation of geometry. Elements are generated on the fly that can position themselves by measuring their position and negotiating their placement and orientation (Figure 8 and 11) with their neighbors through functions and solver algorithms can be observed as a start into the design of systems that autonomously structure themselves.

FIGURE 11. COMPUTATION ALLOWS DESIGNERS TO INCLUDE AUTONOMOUS BEHAVIOR INTO SINGLE ELEMENTS WITHIN A STRUCTURE—BY DOING SO, ELEMENTS CAN AUTOMATICALLY NEGOTIATE THEIR POSITION AND ORIENTATION ACCORDING TO MEASURED PROPERTIES OF THE ADJACENT NEIGHBORS. THESE PRINCIPLES WERE USED FOR THE CONSTRUCTED DEMONSTRATOR AS IN ONGOING RESEARCH.



Computational processes allow a novel understanding of a buildings setup for design. For instance the ability to describe a structure as a matrix allows the application of computational operations in its design. Matrix operations as the transformation of data between a three-dimensional and two-dimensional representation allows for instance the introduction of attractors and positions that repel on the structure. This operation allows the link of structural, programmatic or aesthetic performance in a design process.

FIGURE 12. COMPUTATION ALLOWS STRUCTURES TO ADAPT TO EXTERNAL DATA. IN THIS EXAMPLE FROM ONGOING RESEARCH, WORK BEAMS ARE AGGLOMERATED IN AREAS OF HIGH CURVATURE. THESE PROPERTIES ARE MEASURED AND USED FOR ATTRACTING AND REPELLING POINTS IDENTIFIED WITHIN THE GIVEN SURFACES. THE DERIVED STRUCTURE PROVIDES IMPROVED CONSTRUCTION PERFORMANCE, AS IT CAN FOLLOW BETTER THE PREDEFINED SURFACE.



Computation allows the integration of the knowledge of matter and it's processing into the design phase and by adding the possibilities specific to the virtual realm novel ways of design appear.

ACKNOWLEDGEMENTS

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