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## Generated Lamella

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abstract: The hierarchical organization of information is dominant in the setup of tectonic structures. In order to overcome the inherent limitations of these systems, self-organization is proposed as a means for future design. The paper exemplifies this within the research project "Lamella Flock".

The research takes its point of departure in the structural abilities of the wooden Zollinger system: a traditional structural lamella system distributed as a woven pattern of interconnected beams. Where the original system has a very limited set of achievable geometries our research introduces an understanding of beam elements as autonomous entities with sensory-motor behaviour. By this means freeform structures can be achieved

Through computation and methods of self-organization, the project investigates how to design and build with a system based on multiple and circular dependencies.

Hereby the agent system negotiates between design intent, tectonic needs, and production. The project demonstrates how real-time interactive modeling can be hybridized with agent-based design strategies and how this environment can be linked to physical production. The use of knowledge embedded into the system as well as the flow of information between dynamic processes, Finite Element Calculation and machinery was key for linking the speculative with the physical.

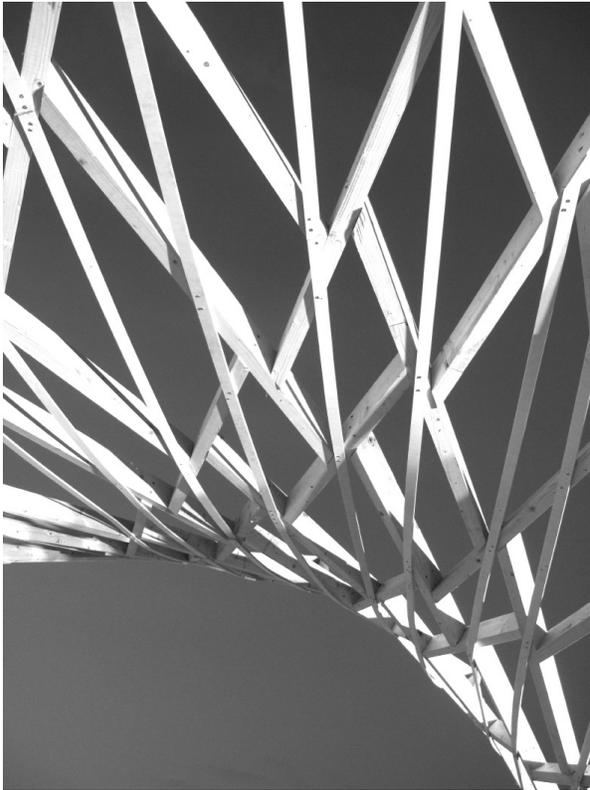


Figure 1. Detail of the 1:1 Lamella Flock demonstrator.

## 1 Questions of linear processes in architectural design

In a time when relational and generative tools become common in architectural practice and the design of information within projects gains significant attention, the questions that Herbert Simon raised in 1969 in his book, "The Sciences of the Artificial," gain new relevance. Herein he asks how (artificial) systems can be organized that can handle complex design tasks and which role computational methods as Artificial Intelligence or Genetic Algorithms have in this process.

Since Simons book, a new design practice has emerged in which architects become the developer of bespoke design environments that allow dynamic interfacing between design intention and contextual information (Kolarevic 2005; Schwitter 2005; Burry 2005).

Within this practice, the crucial step becomes the design of the system itself, or as Mark Burry calls it "the design of design". The common approach to dealing with the

complexity of architectural projects is to separate them into many levels of subassemblies with hierarchical interrelationships. Where in Simons theoretical model parts in the same hierarchical level can establish interrelationships, the common practice of parametric design leaves them independent. This top-down approach requires a high amount of specification on all levels. This causes problems in design projects, whose nature is that huge amounts of required information are to be developed within the process of the project (Rittel 1973). This insufficiency does not only apply to the content of information but especially to its relation to other parts. Every designer knows probably examples where information on a specific part clarified in the very last moment, such as prohibiting fire laws or production related restrictions, caused severe changes and delays to a project. Where parametric models may represent the geometrical dependency of a part on information of a higher level, this higher level may yet be affected by the parts properties. The appearing interdependencies cannot necessarily be defined in linear relationships but rather create networks of relationships with a high level of complexity. This level increases when parameters of very diverse nature as economical or time based constraints are taken into account.

Another field of questions concerns the depth of complexity in a project. This can be seen in architecture as the amount of parts in a subassembly. Kieran and Timberlake have shown in 2003 how other industries gained significantly in productivity by introducing several levels of prefabrication. This improved the quality of the final assembly as fewer parts had to be combined and allowed for better quality products as the parts itself could become more complex. On an architectural level, this can be either achieved by more preassembly or by the use of fewer parts that itself can establish more complex relations to their outer environment. This would not only reduce complexity on the parts level but offer chances for more efficiency on all resource levels.

As shown in processes of large scale Industries by Kieran and Timberlake, insight and control of all aspects from design to operation raises efficiency immensely. The reality in architecture appears yet somehow patchy. The downfalls of top-down strategies lead to a wide interest in alternative design strategies such as bottom-up methods (Kolarevic 2005) or evolutionary design in order to optimize towards multiple goals of diverse nature (Terzidis 2006).

It becomes obvious that design systems have to be developed that inherit the property to integrate continuously new knowledge, followed by a renegotiation of a satisfying solution on a certain level, while offering a flexibility on higher levels to cope with the emerging effects of this behavior.

Within our research we found this complex of questions while working on freeform lamella structures. We introduce the concept of an aware design model and use self-organization and bottom-up principles as means to allow design in environments that are characterized by multiple and circular dependencies. We furthermore combine traditional wood craft with digital information and fabrication techniques in order to gain efficiency by higher complexity on part level. The required prerequisites are shown in the next two chapters.

## 2 Zollinger – A Lamella Wood sSystem

The Zollinger construction is a type of Lamella roof construction (*JS Allen 1999*) that was invented in the 1920s in order to create wide spanning constructions out of short pieces of timber (Figure 2 and 3).

The lamellas structural principle consists of a crisscrossing pattern of parallel arches of relatively short members. These are hinged together and form an interlocking network in a diamond pattern. The ingenuity resides within two constituents: the efficient joint system that minimizes the amount of shared meeting points allowing for simple assembly, and structural strength given by the interwoven beams (Figure 4).

Where similar systems, as mutually supporting beam systems (*Popovich 2008*), usually form barrel or dome shapes work from the AA (*Hensel and Menges 2007*) and Shigeru Ban (*Tristan et al. 2007*) demonstrates the principal ability of the system to form different shapes using the flex of the material, tolerances in the joint geometries, and changes in the system's local orientation. In this bottom-up approach, each element is threaded individually as it acts autonomously in a larger formation.

Our own investigations revealed that freeform structures can be manually crafted from straight bamboo sticks by exploitation of tolerances in the joint. Yet this method relies purely on skill in crafting and negotiation with the physical model. The translation

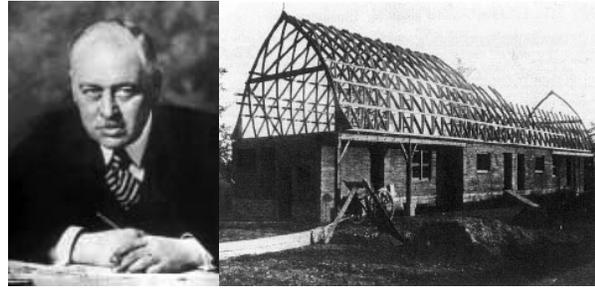


Figure 2 and 3. Friedrich Zollinger and a original Zollinger Roof system in Merseburg (Germany).

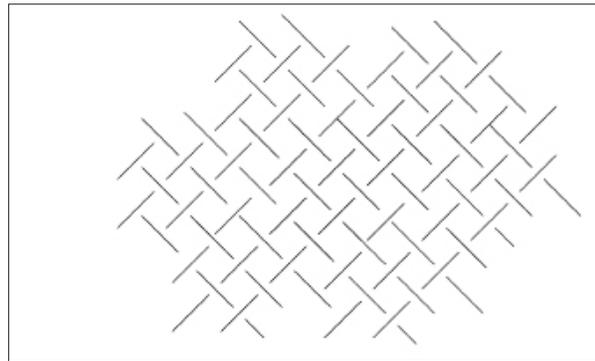


Figure 4. Principal pattern of the Zollinger lamella structure.

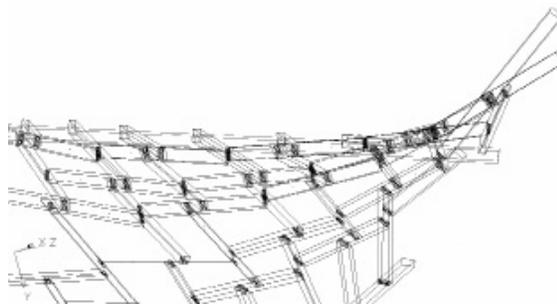


Figure 5. Wireframe view of the customized monolithic Tenon joints used in the construction.

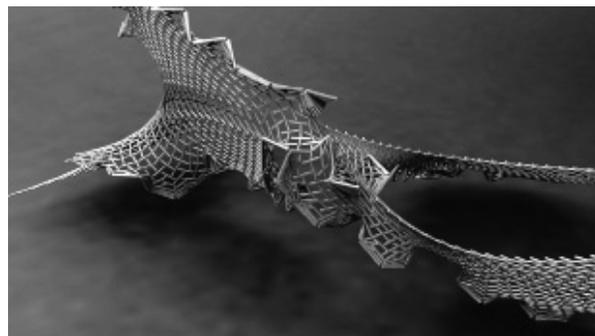


Figure 6. Output of a rule based distribution of lamella elements



of the craft-based approach into an architectural planning practice that would allow it to anticipate and fabricate geometry in relevant scale and tolerance became a main concern of the investigation.

### 3 Free form wood structures and previous experience

Previous research on mass customized parametric wood constructions (Tamke et al. 2008) indicated that digital production can provide the sought after flexible, effective fabrication of easily assembled wood beams. This approach is based on the conjunction of computation, digital fabrication, and traditional craft techniques. Herein modern CNC wood joinery machinery allows the cutting of monolithic joints in high speed and variable geometry (Figure 5). These joints allow for fast assembly as they incorporate self registering geometrical properties such as contemporary industrial snap fit joints (Schindler 2009). The improved understanding of forces within massive wood, in its monolithic joints as well as in its assembly as structural systems through Finite Element systems (Holzner 1999), allows for new applications of traditional wood crafts. The combination of computational capabilities with digital fabrication therefore allows the introduction of craft related knowledge into contemporary practice that was previously bound to the skill and knowledge of the executing craftsman.

### 4 Investigating freeform lamella systems

In the initial stages of the research, the distribution and computing of elements were investigated, looking for the most suitable method of controlling the system and the non-linear relationships within.

The lamella structure was at first distributed on preconceived test surfaces. This presented two problems: when following a free-form surface, all beam endpoints should be on the surface. Since all endpoints also connect to the midpoints of other beams, this criterion cannot be met. Secondly, this top-down approach lacked the possibility of exploring the performance of the structural principle. How would the rigidity of the reciprocal relationship between beams affect the scope of shapes possible?

The conclusion to use bottom-up approaches instead, gave, at first, problems in controlling the system. The elements were here structured through rule based linear distribution where elements were sequentially inserted. Due to the fact that in a networked lamella system, one element is affecting all its neighbors, this resulted in compelling morphologies (Figure 6) but impeded design control. The linear distribution led to extreme and unpredictable conditions.

We could now state the requirements of our system: a bottom-up process with the ability of dynamic non-linear interaction where different design possibilities could be explored. We introduced an understanding of the structure as a self-organizing system of entities possessing a simple set of behavioral properties and relations to each other.

### 5 An outline of self-organization

Theories of self-organization were originally developed in the context of physics and chemistry. Later it was found that these ideas could be extended to the simulation of social insects. Their colonies solve problem in decentralized systems, comprised of many relatively simple interacting entities (Bonabeau et al. 1999).

This relies on the anti-classical-AI idea that a group of agents may be able to perform tasks without explicit representations of neither environment nor other agents, and where planning may be replaced by reactivity (Carranza and Coates 2000). By recontextualizing this into numerous fields of knowledge, powerful tools for developing dynamic and intelligent systems emerged. The continuous negotiations within such systems are similar to the bespoke conditions needed to process material to achieve material performance within traditional crafts.

The advantages reside in flexibility to function, in changing environments and robustness through the ability to function even though some entities may fail to perform. The disadvantages can be located in the bottom-up approach to programming such systems. Here, the paths to problem solving can never be predefined but are always emergent and result from interactions amongst entities themselves as well as between entities and their environment. Therefore, using self-organization to solve a problem requires precise knowledge of both the individual behaviors and of what interactions are needed to produce a desired global effect (Bonabeau et al. 1999).

## 6 The generated lamella system, structure, and behaviour

In order to handle the complexity of the structure, we introduce a sublevel within the overall structure that consists of autonomous elements. These form an inner environment, acting on specific inputs from an overall outer environment (Simon 1996). These entities are based on the interaction of four line segments coming together in a spiraling motion. Each entity exhibits within itself the non-linear relationship that most unmistakably defines the global structure it is aiming at. The communication is sematectonic, as relevant interactions between entities occur only through modifications of the environment (Wilson 1975).

Initially, the amount of entities, their sizes, and a preliminary distribution of these as a diagonal grid in space are defined. This can either be coherent or fragmented. In both cases, entities are positioned by a distribution of point coordinates or loading a previously saved model into the system. This last feature also served for interfacing with other tools (Figure 7, 8).

While running, the system is controlled through four behavioral algorithms that accumulate vector information (Figure 9). A method that is inspired by the division into goal types as found in the simulation of flocks, herds, and schools (Flake, 1998). Each algorithm produces directions and velocities that interact to produce the overall movement and transformation of an entity:

1. Movement towards neighbors: If not representing a corner or an edge, each entity has four neighbors. By measuring the distance and direction from endpoints of line segments to a neighbor connection point, vectors are calculated. These vectors are added and weighted to calculate a mean vector by which all points in an entity are moved.
2. Orienting towards neighbors: By altering the configuration of angles between segments, each element tries to orient its segments towards their neighbors. A segment is in this way sought to be aligned with the trajectory towards its destination.
3. Stretching towards neighbors: Through the above orientation, a segment will, within a certain tolerance, be able to stretch to connect to a neighbor. This is allowed when the orientation is correctly aligned and if it is happening within a predefined size limitation of a segment.

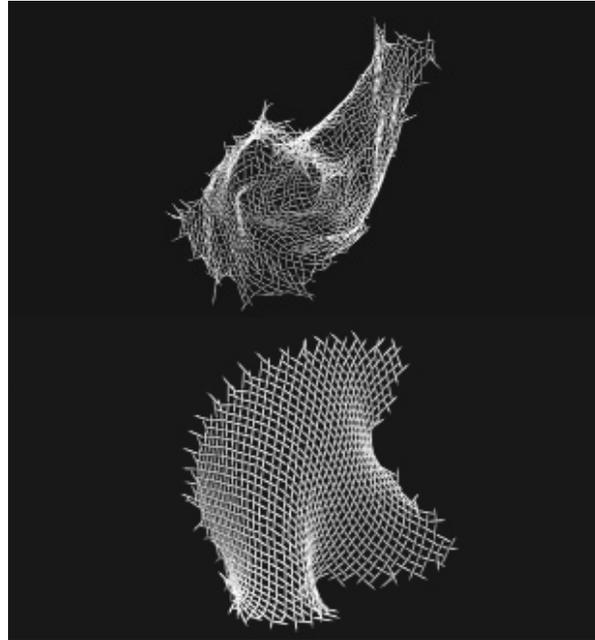


Figure 7,8. Renderings of two generated models with diverse characteristic

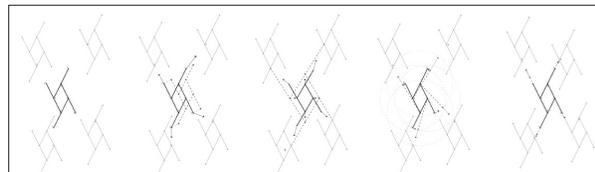


Figure 9. Initial state and the 4 main behavioral principles of Lamella Flock

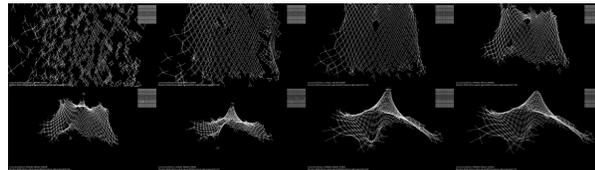


Figure 10. Formation and interaction of a lamella structure within the processing interface



Figure 11. Processing interface with model of the ROM exhibition site

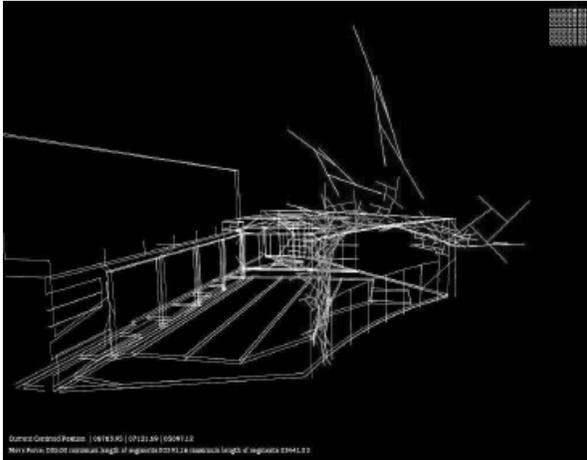


Figure 12. Labeled Non-standard wood beams ready for assembly



Figure 13. 1:1 Demonstrator at the ROM gallery Oslo / Norway

4. Scale entity: Each entity has the ability to scale up and down while keeping its proportions. This allows for a global push/pull effect within the lamella network.

Additionally, production related constraints, such as the limitation to producible wood joints and the ability to offset shared beam meeting points, were introduced into the program. The generative design process was informed by its implementation and realization in 1:1.

The global behavior occurring from these functions produces a network of entities that attempts to obtain the shape of a surface. The global configuration is continuously and non-linearly renegotiated until a stable result is achieved.

## 7 A hybrid system

It seems that already the early work within the use of Agent based systems in architectural design (*Carranza and Coates 2000*) favored an approach that analyzes a given environment with a set of given parameters in a time-based way and presents the designers solutions. The designer is hereby excluded from the actual design process in any other way than setting the initial parameters. The selforganization apparatus becomes a blackbox that offers a design approach alien to successful intuition based iterations of design praxis (*Simon 1996*) Our experience (*Tamke et al 2009*) has shown that in the context of architectural design, a combination of generative and interactive modeling is useful. We introduced manual manipulation of entities while the system is running. Changes in the configuration can be made by altering local conditions, while self-organization deals with the global consequences of these actions (Figure 10).

They include move, scale of entities or change of scale, as fixing its position to force the surrounding to adapt. Color coding of elements and a navigational diagram helps to maintain an overview of these manipulations. Precision and localization of the design model where given through a millimeter based unit space and the ability to link in 3D models of the site (Figure 11).

## 8 Implementation

The interface allows the model to interact dynamically with and inside an environment given by site, program, production and material. Changes to the environment through manipulation are instantly answered by the model through topological change. These changes appear to the designer as a result of an internal reflection rather than direct answer. In this way designing starts by learning about the distinct character of the model and its behavior.

The model exchanges through customized interfaces with different specialized tools: for structural FE-Analysis with Sofistik or for the generation of production data to parametric software. The output can be adjusted to different model scales ranging from design speculation to 1:1 realization through machine code for Hundegger wood joinery machines (Figure 12, 13). Intense communication and testing through prototypes were crucial to determine the adequate types and dimensions of joints, fasteners, bearing and bracing as fabrication and assembly strategies.

Feedback was integrated into the model which was becoming noticeably aware of its placement in the building process—its environment. The incoming information was handled in a pragmatic way where new insights were either encoded as internal conditions in the generative code or the visual interface was used for constraining the self-organization system.

The intense preparation allowed us to exploit the capacity of digital fabrication and self registering joinery, demonstrated by only 3,2 hours of cutting time and 2 days of overall assembly.



Figure 14. Detail of Lamella joint in 1:1 demonstrator in Oslo

## 9 Conclusion

Self-organisation is a valid approach in order to design within complex systems characterized by high degree of interdependencies on the same level of hierarchy. The hybridization of generative processes and interactive modelling proposes shows that non-linear systems can be used as a design tool.

Here the different modelling methods are not mutually exclusive but work in parallel rather than in succession. Where computation is able to structure processes and relations that are otherwise beyond human capabilities, the real time interaction offers space for design speculation. Various constraints can be easily applied and their effects studied. A learning process is initiated on the side of the designer that allows him to efficiently negotiate design intent with the systems underlying specifications. The interactive self-organisation model shows thereby an "adaptive behaviour that is directed towards an end" as Karl Popper calls it 1994. A "satisficing" (Simon 1996) solution is achieved in the abstract space to optimise the beams' positions. This behaviour makes the presented approach more efficient than optimising with evolutionary models (Genetic Adaption), where large numbers of options have to be created and later dismissed in an Darwinist act. Further research into the construction of customized user interfaces for hybrid dynamic-interactive processes might prove valuable for opening new territories for architectural design

The project shows that self-organization is capable of negotiating in an early architectural design context. It allows to implement global design intent as well as information regarding production, detail and material. The advantages of this is apparent in the speed and accuracy by which structures could be realized in 1:1 (Figure13). The open nature of the approach allows it to "learn" and become more aware of the overall process requirements. Further research in methods to include new knowledge faster and to handle the linked implications is necessary. This would allow to extended the awareness of the model to other environments and create new potential when gravity and tectonic stress become part of the initial design process



## Acknowledgements

The Lamella system was only possible through support by HSB Systems, Hundegger GmbH, Trebyggeriet.no, Knippers and Helbig Advanced Engineering and Prof. Christoph Gengnagel/ TU-Berlin.

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