# Connecting Intelligence


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## Introduction

The presented research project aims to investigate both the possibilities and the impact of integrating material behaviour and robotic fabrication in architectural design, using the example of lightweight plywood timber construction, as well as the possibilities of computational and biomimetic design methods for integrated and context oriented design strategies incorporating self organising material effects of form finding and the production logic of robotic fabrication.

In the first part, the current situation in timber construction and architectural design is analysed in order to gain an overview of their past development and possible research fields. The second part focuses on the use of an industrial robot and its design space for developing geometrically differentiated, curved finger joint connections for planar sheets of plywood, which induce elastic bending through their inherent assembly logic. Subsequently, on the basis of material behaviour and fabrication requirements a bending active, multi layered material system is being developed, incorporating fabrication and material constraints as well as structural and architectural demands. Finally, this leads to the development of a computational design tool showing the performative capacity of the developed material system in an architectural context, as well as of computational design processes in general. The project concludes with a discussion about the potentials of integrated computational design as well as the role of the designer throughout such processes.

## Project Intention

New developments in computational design as well as in digital fabrication are currently leading to a rethinking of architectural design, material science, engineering and fabrication. While these processes were separated and detached during the industrialisation (Kieran & Timberlake 2004), the present development shows that there is yet again the possibility of interweaving them in a particularly performative way through computational design methods. The project aims at showing that novel possibilities of integrating material behaviour and biomimetic design can lead to truly performative architecture when the design process is clearly separated from classical well established form oriented design methods and is instead an open, undetermined and explorative process (Menges 2012).

Current research in the field of digital fabrication in architecture is characterized by a shift from CNC machinery designed for a specific task towards more generic fabrication equipment such as industrial robots (Menges & Schwinn 2012). Leading to an increasingly open design space robotic fabrication offers the opportunity for computational design to explore the design space for particularly promising areas. In evolutionary biology, the term morphospace is being used for describing the morphological characteristics of individuals compared to the theoretically possible outcome and thus offers the concept of seeing the morphological features of a specimen as actuations within a solution space. While this systematic can be transferred in order to conceptualize the space of robotic fabrication possibilities (Menges & Schwinn 2012), the performance of possible designs populating the machinic morphospace also depends on its material behaviour integrated in both the fabrication process and the subsequent assembly intelligence. The project therefore aims at proving that through computational design methods it is not only possible to determine areas of the robotic design space with the most promising performance, but also that in this context only the integration of material behaviour in the fabrication intelligence will lead to truly performative and ecological architecture.

In the context of mass customization in digital fabrication it is also important to distinguish between areas in the morphospace of robotic fabrication and the actual possible morphological differentiation of produced pieces in the developed fabrication process. As wood has been one of the most economic and available building material throughout the preindustrial era it easily makes advances in production technology visible (Schindler 2007). Many traditional wood jointing techniques were developed and refined over a long period of time in the context of material behaviour, connection performance and labour input. However, through the industrial revolution and the development of efficient, yet simple mass production processes, most of the wood joint's intelligence was lost due to the machine's disability to produce geometrically complex connections. The project will focus on the development of robotically fabricated finger joints for plywood sheets, which constitute themselves a generic platform for connecting plates at varying angles. Here, the possible morphological differentiation of each plate is linked to the fabrication method's constraints, which will ultimately describe the fitness of this particular area inside the machine's morphospace.

Another profound change through robotic fabrication and mass customization compared to fabrication processes developed during industrialisation is the apparent possibility to finally use materials and other finite resources more efficiently. In biology, material is expensive, but shape is cheap, whereas until today the opposite was true in the case of technology (Vincent 2009). However, it is not sufficient to only enable morphological differentiation through the design and fabrication process without taking the material's specific performative capacity into account.

Therefore the project also aims at integrating material behaviour during the development of a material system in the context of robotic fabrication. Bending active structures are curved beam or surface structures that base their geometry on the elastic deformation of their initially straight or planar elements (Lienhard, Schleicher & Knippers 2011). In these structures residual stress caused by elastic deformation is used to act against external forces such as load bearing, while their advantage also lies in increasing their geometrical stiffness.

The intention therefore is to include the performance of bending active structures through the finger joint connection's geometry and thus in the connection and assembly intelligence.

It is the project's goal to show that through the research in robotic fabrication and material behaviour it is possible to efficiently and thoroughly expand the use and performance of computational design, especially when integrated in an architectural context. This also includes the ability to prefabricate and transport parts of the structure as well as an easy assembly on site. It will therefore be necessary to develop a modular material system that includes not only fabrication constraints and material behaviour, but also structural and architectural demands, and finally to develop a design tool integrating those parameters in a form finding process through the adaption of natural behaviour and biomimetic principles in the context of an architectural and urban surrounding. While such principles in general are amongst others heterogeneity, anisotropy, hierarchy, multifunctionality, redundancy and adaptability (Knippers & Speck 2012), a biomimetic top down research process for specific principles will also be necessary. Ultimately, it will be shown that through this integrative computational design process the fields of design, material science, engineering and fabrication are again inseparably interwoven as only their intense and direct information exchange enables performative architectural design.

## Timber Construction in Architecture

Although timber has gradually been replaced with other materials in architecture as well as in other industries during industrialisation, it still is the lightest, most ecological and most efficient material. While fibre reinforced polymers are specified with a higher durability, their density lies above 1500Kg/m$^3$ (Knippers, Cremers, Gabler & Lienhard 2011), compared to wood with densities well below 1000 Kg/m$^3$. Although fire resistance and durability are issues for many construction materials, this is also true in timber construction in all industries and thus constructional wood preservation is of a high importance during the whole research.

## Methodical Approach

The stated arguments are being validated through an exemplary context sensitive case study following the development of geometrically differentiated finger joints through the possibilities of robotic fabrication. After a research in timber construction and material behaviour the possibilities of curved finger joint connections inducing elastic bending during assembly are investigated through the development of a modular material system. Therefore, a decision oriented catalogue of geometrical possibilities in plate arrangement is being laid out, which is in reciprocal influence with the development of a global system. During this process biomimetic and physical principles are analysed and extracted from natural systems acting as role models for elastic bending and curved folding on a local level, as well as for context sensitive form finding principles on a global level. The system's fabrication and geometrical constraints, as well as its behaviour against system internal and system external influences will then be integrated in one design tool and tested in a given context and programme.

## Expected Insight

The project shows the potentials of context aware modular lightweight timber constructions, which are, through their inherent ability of morphological differentiation, capable of adapting to internal constraints and external influences. As these performative capacities are only achievable through an integrated computational design process, it is expected to raise the awareness for the paradigm shift in architecture from a hierarchical process to an integrated design without a separation of "material" and "structure" (Knippers & Speck 2012), and thus the importance and possibilities of fabrication methods and material behaviour in architectural design. The developed fabrication method as well as the research in material behaviour promises new insight in the integration and performance of elastic deformation in the design, assembly and fabrication process, subsequently leading to a construction system with far less material and energy input than needed for traditional solutions. In the course of the project it is also expected to identify the performance of such a system in the context of a nondeterministic process following biomimetic design principles.

## References


Lienhard, J., Schleicher, S. & Knippers, J. (2011). Bending-active Structures Research Pavilion ICD / ITKE. Symposium of the International Association for Shell and Spatial Structures 2011.

Kieran, S. & Timberlake J. (2004). Refabricating Architecture. How Manufacturing Methodologies Are Poised to Transform Building Construction, McGraw-Hill, New York.

Knippers, J., & Speck, T. (2012). Design and construction principles in nature and architecture. Bioinspiration & Biomimetics, 7(1).

Knippers, J., Cremers, J., Gabler, M. & Lienhard, J. (2011). Construction Manual for Polymers + Membranes. Birkhäuser Verlag, Basel.

Menges, A. (2012). Biomimetic design processes in architecture: morphogenetic and evolutionary computational design. Bioinspiration & Biomimetics, 7(1).

Menges, A., & Schwinn, T. (2012). Manufacturing Reciprocities. Architectural Design, 82(2), 118-125.

Schindler, C. (2007), Information-Tool-Technology: Contemporary digital fabrication as part of a continuous development of process technology as illustrated with the example of timber construction, ACADIA Conference 2007 Expanding Bodies. Proceedings of the International Conference, Halifax.

Vincent, J. (2009). Biomimetic Patterns in Architectural Design. Architectural Design, 79(6), 74-81.