COMPLEXITY OF PERFORMATIVE ARCHITECTURE

Ever since the implementation of the directive 2010/31/EU in the European Union, which was adopted in order to strengthen the energy performance requirements on buildings, performance criteria have become a big topic in architecture. Unquestionably, the directive will have a huge impact on the way buildings are designed. While architecture by its very nature has always had to respond to a variety of complex demands and regulations that are difficult to reconcile, the energy performance requirements step up the number of restrictions to an unprecedented level. Although the current situation is diverse in different EU countries, presently architects do not have the tools to deal with this new level of complexity. As a consequence, buildings that aspire to fulfill the new energy performance requirements are typically very limited in their formal vocabulary. So far the tools available to designers as well as to the building industry to address the energy-concerns spelled out in the directive simply don’t provide any means for formal experimentation. They consist of simple rule-of-thumb prescriptions or calculations for standard cases and don’t allow for specific reactions to a given context nor to explore possible alternative strategies at reaching energy-efficiency. Not surprisingly, energy-conscious designs developed with the help of these simple tools are often aesthetically lacking. Thus, the performance criteria have a negative impact on the architectural quality of our environment.

This need not be the case. There are some high-profile projects like the European Central Bank that demonstrate that unusual formal approaches can yield large gains in energy performance. But average architectural projects don’t have the budget to bring the specialists on board that are needed to develop such complex solutions with current technology. The challenge, therefore, is to create tools that allow designers to deal creatively with these more complex requirements as part of a normal design process. The fast feedback of the tools could also significantly speed up the design process (Fig. 1), especially in cases of complex geometries.

Parametric Design System for Passive Houses

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Abstract. The intention of this research is to develop a design system for geometrically complex passive houses. Research focuses especially on the link-up of the CAAD (Computer-aided architectural design) and the CAM process (Computer-aided manufacturing) and deals only with timber structures. The aim of the project is to develop a system that would automate a creation of the computer model of the geometrically complex timber structures and link it to fabrication process. It should be possible to use the system for houses of the size of a family house up to an apartment house. The advantages of the system ought to be the fabrication preciseness, economical availability, high speed of construction, eco-friendliness and above all absence of geometrical constraints.

Keywords. Parametric; passive house; timber; CLT; geometry.
CLT IN FREEFORM CONSTRUCTION
The coupling of digital design with fabrication opens the perspective for so-called mass customization: low- or same cost production of individually different pieces. Therefore, the step towards the mass customization of massive timber construction seems to be the appropriate step, and not just because of the economical aspects, but also because of the possibility of greater design freedom.

To investigate these issues in depth we focused on just one particularly interesting type of wood construction: cross-laminated timber (CLT). CLT is a material with very positive characteristics in terms of energy-efficiency and sustainability and it has large potential for customization through digital fabrication. The CLT boards can be also easily machined by CNC milling machines. Massive timber construction has many well-known advantages over other types of construction. The small amount of embodied energy is one such advantage, as is the fact that it enables relatively large freedom of design. However, with increasing geometrical complexity the price increases, mostly due to the complex detailing (labor intense work).

There are only few examples of freeform structures build out of massive timber. For example the Laboratory for Timber Constructions IBOIS has conducted a research of folding plate structures using cross-laminated timber (Buri and Weinand, 2010). Another interesting research with CLT and freeform structures was done by the Institute for Architecture and Media at TU Graz (Schimek et al. 20112). They introduced not only an interesting discretization strategy for approximation of freeform shapes, but also employed a timber-to-timber joint system capable of transferring the tension loads of the structure. It is also a rare example that integrates into its design strategies the anisotropic characteristics and behavior of wood.

DISCRETIZATION OF FREE-FORM SURFACES
The use of discretization strategies in the process for approximating freeform shapes in not new, many attempts have been performed with different kinds of construction strategies and materials, mainly steel and glass, but there are just a few examples of freeform structures using solid wood panels like cross-laminated timber (CLT).

Double-curved forms have been difficult to manufacture. If the building elements are not planar, the production requires extensive labor, such as milling or custom formwork for each building part. This significantly increases the price of construction. Therefore, it is desirable to discretize the shape into planar elements, which requires techniques that have been researched in the last decade (Eigensatz et al. 2010, Pottmann et al. 2008a, Shelden 2002).

The most common and the easiest way to panelize double curved surface is triangular meshing. This method has been used with success in number of projects, such as the roof of British Museum by Norman Foster and Partners. However, the triangular panels are less economical then panels comprising more than three sides (Glymph et al. 2004). In terms of having less waste material and needing fewer cuts are better four sided - quadrilateral panels (Tsikkari 2006). However, there are only certain types of geometrical shapes that can be tessellated fully into quadrilateral mesh. One such type is translational surface and the other is rotational surface. Architecture based on these types of surfaces has been successfully built with four sided panels; an example is the Berlin Zoo's Hippopotamus House (Jörg Gribl with Schlaich Bergermann and Partners) or the Sage Gateshead (Foster and Partners).
Another approach to panelize a freeform surface is to only approximate the surface geometry with planar four sided panels (Liu et al. 2006). The disadvantage of this method is that there is a degree of deviation from the original form. Another disadvantage is the need of inserting more than four sided panels in “singularity places.”

The deviation in form could be reduced by reducing the panel size. However, this corresponds to increase of fabrication and building times.

The main focus of the research is the design of the construction system of the geometrically complex passive houses (including, and above all, buildings with double curved surfaces) while keeping the costs relatively low. We decided not to use any curved members of the construction system in order to cut costs down. However in order to keep the original curvature both on interior and exterior finish, the last outer and inner layer is rendered as curved (e.g. curved timber cladding or curved plasterboard). Thus only the structural part of the curved wall/roof is panelized into polyhedral surface where each member of the construction system is flat.

**ENERGY CONSUMPTION**

The energy consumption of a building depends on several aspects, such as the geometry of the building (A/V ratio), building orientation, percentage of glazing, and thermal properties of the envelope or heat recovery efficiency. There is already software that can calculate the heat and primary energy demand (EnergyPlus, PHPP, etc.). However, what is missing is the immediate feedback. Yet, there is neither single software that would allow to quickly test countless number of variations (see Fig. 3) nor the software or tool that would provide recommendation how to improve the design or even automatically optimize it (see Fig. 4). Such a tool would be very beneficial both in early stages of the project when critical decisions are made and also in later stages when architect deals with cost related issues on one hand and environmental performance on the other hand.

**SYSTEM INTEGRATION**

This research aims to provide an effective and fast method for form finding of passive houses. Standard software that is available on the market and custom written scripts are used for this purpose. If followed, then this method allow for fast exchange of information among different software and almost immediate feedback for countless number of variations. Therefore, the design can be quickly optimized to meet aesthetic, energy related, structure and economic criteria. This is especially helpful for geometrically complicated buildings where intuitive and empirical knowledge becomes insufficient. The method is divided into eight steps and the relation among those steps can be viewed on Fig. 5.

**Design criteria**

There are usually many aspects of the assignment unclear or at least imprecise during the first (conceptual) design phase. Those aspects are either de-
pendent on each other or simply unknown. Typically this includes the volume of the building, size or even number of rooms in the house, building costs, heat/cooling demand, primary energy or the building materials. In order to test all possible combinations the boundary conditions need to be set up. These boundary conditions then define the range for experimentation.

**Variables**

1. **Extensive variables**

An extensive property is a physical quantity whose value is proportional to the size of the system it describes. Minimum and maximum values (boundary conditions) are defined over here. Typically these are the volume of the house, sizes of the rooms or the offset of the house from the boundary of the building site.

*Figure 3*  
Fast massing study of different geometry with different envelop area while the floor area and volume are always constant.

*Figure 4*  
Fast massing study of dependency of energy consumption on building orientation.
2. Intensive variables
An intensive property is a physical quantity whose value does not depend on the amount of the substance for which it is measured. Again minimum and maximum values (boundary conditions) are defined over here. Typically these are the specific space heat demand, specific primary energy, material properties (cost, U-value, g-value, exterior absorptivity, exterior emissivity, etc.).

**Parametric model**
Parametric is a term used in a variety of disciplines from mathematics through to design. Literally it means working within parameters of a defined range. Within the field of contemporary design, it refers broadly to the utilization of parametric modeling software. In contrast to standard software packages based on datum geometric objects, parametric software links dimensions and parameters to geom-
etry, therefore, allowing for the incremental adjustment of a part, thus affecting the whole assembly (see Fig. 6). For example, as a point within a curve is repositioned, the whole curve comes to realign itself. If the building is modeled in parametric software, then countless number of scenarios could be tested just by varying the selected parameters.

There are simple modeling rules defined for any parametric software for this purpose.

**Building cost**

Building cost is one of the out coming parameters of the parametric model. The result is then compared to the original criteria and if necessary again optimized by variation of preferred parameters.

**2D layout**

Similarly countless number of layouts can be generated from the parametric model and compared to the desired criteria. This is especially helpful if the geometry of the building is extremely complicated.

**3D CAD model**

The parametric model is imported into Rhino software (Fig. 6). The geometry must be divided on layers into several categories such as: exterior wall-ambient, exterior wall-ground, windows, doors, floors, roofs or shading. These categories can be perceived as temperature zones or cost defining zones. There are the same simple modeling rules defined for Rhino in the case that the step 3 (parametric model) is skipped and house is modeled directly in Rhino.

**Descriptive data**

An executed VB script takes CAD model, calculates from its geometry descriptive data and writes them into Excel sheet. This data is for instance: surface area, surface north deviation, surface angle, surface temperature zone, door area, window width, window height.

**Building physics analyses**

Another VB script takes this data and automatically transfers them into excel based software for energy calculation (PHPP). Furthermore other relevant parameters (intensive parameters) are automatically transferred here (Fig. 7). Specific space heat demand and primary energy is calculated and then again compared to the design criteria (Fig. 8). The process could be repeated until the desired values are met.

**CONCLUSION**

The automated process is fragmented into several steps at the moment. These steps need to be integrated together. Generally the system performs well but many tests are yet to be executed. Interlocking connections need to be verified on scaled models and physical prototypes; economy of production should be optimized and family of possible singularities is to be developed.

*Figure 6  
CAD model imported into Rhino 3D.*
However, the system proved to be effective during the initial design where the architect can receive almost immediate feedback during the form finding of his/her building (Fig.9). Later on, the system can be used for fine tuning of the design (Fig.10), which is valuable especially in case of passive or zero carbon houses.

REFERENCES
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