Lattice Spaces

Form optimisation through customization of non developable 3d wood surfaces

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Abstract. This paper discusses a collaborative project by RDAI architects, Bollinger+Grohmann and the timber construction company Holzbau Amann. The project is located in a former swimming pool in Paris and it is part of the new interior of a flagship store of the French fashion label Hermes. In late 2009, Rena Duma Architects, asked Bollinger+Grohmann to collaborate as structural engineers on a challenging design proposal within a very short timeframe. Three wooden lattice structures, the so-called “bulle” and one monumental staircase with a similar design approach characterize the interior of the new flagship store. The lattice structures are dividing the basement into different retail spaces. They vary in height (8-9 m) and diameter (8-12 m) and have a free-form shaped wicker basket appearance. Wood was the chosen material for these structures to strengthen the idea of the wicker baskets and to create an interior space with a sustainable and innovative material.

Keywords. digital production; parametric design; mass customization; wood; digital crafting.

INTRODUCTION

The French fashion label Hermès had entrusted the RDAI agency, which is responsible for designing most of the Hermès stores worldwide, with the design of a new space, in Paris. In the discussed 1930’s swimming pool building Hermes’s new ‘La Maison’ furniture line is being displayed.

Three pavilions with an organic design, are forming the main interior of the new shop. The staircase that naturally leads the visitor towards the pool and forms the link between the entrance and the open space of the swimming pool is the fourth naturally shaped object in the space.

These shapes of different form and dimensions are constructed in wood to support the philosophy of Hermes as a sustainable fashion label with a high-quality approach.

Starting with that vision the architects worked in a close collaboration with Bollinger+Grohmann to
turn this concept into a feasible, self-supporting “object”. Considering the deadlines, the complexity, the multi-formats exchanges and the communication with collaborators on the project, it was necessary to organize a smooth workflow between visual aspect, geometry, structural properties, structural optimization and execution process.

**Digital Wood**

Who would have thought that wood would become a high-performance material that is used in the most complex geometrical and structural way that we can imagine. Due to custom made programs that are describing not only the geometry and the structural performance but also calculating the most efficient way of producing and fabricating the wood elements, this material got a renaissance in the building industry. This “old” material offers us a broad range of beneficial properties; it is easy to work with, affordable and accessible to many, a new way of engagement with the material through digital design and fabrication processes. Joining, laminating, carving, bending, cutting and finishing become sources of design ideas (Robert Woodbury, 2007). Within the last few years wood has become a construction material for advanced complex geometries in architecture, examples for this material revolution are the Korkeasaari Lookout Tower in Helsinki, the roof of the Centre Pompidou in Metz or the recently produced Parasol pavilion in Stuttgart.

The understanding of the material behaviour and its properties is becoming more accurate with the development of new analyses techniques in various realms. Material scientists and biologists are looking closer and understanding the complex structure of wood at a nano scale, engineers and architects are shaping the geometry according to the performance of wood.

The Hermes project is following that trace and shows new possibilities of working and designing with wood.

**Material specifications**

The basic design of the here-described “bulle” was thought as a kind of a wicker basket structure that reflects the concept of sustainability and natural beauty with its appearance. In order to develop such a structure that is on the one hand self-supporting and on the other hand will meet the high design criteria of Hermès and RDAI, we had to look first to the possibilities of creating double curved wooden elements.

Since the mid. 60’s the knowledge of different approaches to control and bend wood is available. The following example explains the various techniques that were published in the book: Principles of Wood Science and Technology/Solid Wood (Kollmann, Franz F. en Côté, Jr Wilfred A., 1968)

To be able to complete the project in the given tight timeframe we decided to collaborate with a timber construction company from an early design stage. In order to develop a solution for the rationalization of this complex design while integrating the understanding of execution principles as well as structural, geometrical, visual and time wise elements five variants for the execution were seriously

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*Figure 1*

Impressions of the architecture (first design)
considered, tested and discussed with different possible wood construction companies:

1. The steam bending process was too labor-intensive and besides that fact no one was able to produce 12m long laths within the short construction time frame.

2. The two-dimensional bending approach with single curved laths. This process did not answer fully to the aesthetical requirements because the aesthetical understanding behind the design was more related to a fully 3 dimensional curved line that describes the geometrical shape of the bulle.

3. Bending and milling the laths was designed to bend manually the elements in two directions until they met the required boundaries for the final milling process. The process has the advantage that it is simple for the manufacture since everything is numerically controlled. The process is also relatively fast but in the end this process was considered too industrial for the craft tradition of Hermès and for this project and it would lose the quality of the design of the wood because the grains are not continuous if you are cutting extreme curved wood laths.

4. By carrying out the bending and gluing of the wooden laths directly on site and adapting the length and thickness of the elements to the curve was after a short discussion with the fabricator not satisfactory. Aesthetically and structurally the solution would not fit into the criteria of the architects. The structure would consist out of too many end pieces and small elements. The work exclusively on site was also considered too dangerous in terms of time, structural quality and aesthetic quality (example; La Chapelle des Diaconesses in Versailles).

5. The Laminated bending approach was the last construction method that was considered. The process consists of gluing several laths together in the right shape. This is very labour-intensive and time consuming but offered the possibility to optimize all aspects of construction, form, structural performance through adapted geometry.

**GEOMETRICAL ANALYSIS AND FORM FINDING**

To fulfill the design wishes of the architects and the short construction period the parametric design software was linked to our structural solvers. The advantages of using a parametric strategy are that all element parameters can be manipulated while constraints and dependencies between elements are maintained. The dynamic models that result are able
to respond to changes and offer a degree of flexibility and coordination. These processes of “anticipation and response make up the dynamic of life” and apply equally to everyday consideration of design, fabrication, and construction and to conceptual explorations of dynamic conditions like Weinstock (2004) is pointing it out.

Equipped with a rough 3d model based on a pure volumetric model by the architects, because they developed the appearance of the wicker baskets with a bitmap pattern, we started to analyze the shapes in order to develop the first scripts to create 3 dimensional shapes of each lath.

The 3 “bulles” were following no particular geometrical rules and had therefore no continuous curvature or dependencies between each other. To be able to create producible elements that we could analyze we developed certain “rules” and created a reparameterized geometry that we could work with. A script that was developed within the scripting environment of the 3d-modeller Rhinoceros by Mc Neel automated that process.

**The reparameterization**

A set of curves was created with a certain distance to the original surface. This results in a set of horizontal curves that could be analyzed in terms of their curvatures. We optimized the curvatures wherever necessary. From these horizontal Bézier-curves, we could reconstruct and improve the surface close to the original geometry. This operation permits the creation of a vertical regular surface. This nurbs-surface is built up from two-dimensional parameters in U and V direction, which are represented as lines on the surface. These U and V “lines” serve later as guiding lines for the definition of the axis of the laths.

**Tessellation**

The wicker-basket pattern was created by the division of every constructed horizontal curve through a number of points. By introducing an offset at each horizontal curve of the division points we are able to design and control the diagonal pattern.

The crossing of the curves in two directions creates a lozenge pattern. Since the aim was to have the impression of regular shaped and equal sized diamonds on the whole surface, we thought of the diamond pattern as a tessellation. The creation of the curves creates an actual 3D-tessellation on the surface, eg.; a diamond pattern of tiles on an irregular surface. Several scripts controlled and equalized each enclosed diamond on its size of surface, parallel lines, etc. This script ensures the regularity in size and density of the diamond pattern over the irregular shape!
Laminated bending approach
The Laminated bending approach was chosen to realize the bull and the stair cladding for two reasons.

It combined high-tech technique and mathematics with high skilled woodworking. All laths were perfectly pre-designed in a CAD-model and precisely cut including all necessary holes. This approach ensures a full digital control of the final result. The digital approach reveals any unforeseen effects in an early stage and control of all necessary parameters; what you draw is what you get!

However this process required advanced material skills to bend and glue these elements together. The developed technique provides an almost continuous wood grain from the natural solid wood which is advantageous both in structural and aesthetical sense.

To obtain the laminated bending approach the geometrical optimisation had to be clearly described. The optimization consists of a mathematical phenomena; a double curve of a rectangular section can be designed through the sum of two simple curves combined with some twist.

Each single curvature is describable and thus developable; this means that the laths can be cut out from a simple flat panel. This operation on its own would not create an ever-changing non-describable double curvature of a rectangular section. To obtain the real form and to obtain that laths perfectly lay onto each other at the nodes the rectangular section needed to be twisted. Since wood, cannot be infinitely twisted, we also gave restraints to the twist in the laths. Due to the nature of wood bending and twisting is directly manually possible and this material behavior inspired us to choose this solution!

**STRUCTURAL ANALYSIS AND EXECUTION PARAMETERS**
Fast modifications and updates of parameters were made possible by the development of programmed parametric geometries to be able to control the overall shape of the guiding surfaces and different design partners/parameters.

The input parameters for the code were such as slats curvature tolerance, slats intersection angles, intersection area and slat dimensions, braiding density, alignment and torsion tolerance. The evaluation and optimization of the generated models were based upon: structural analysis results, visual...
appearances and execution techniques and discussion with the different design partners.

With the introduction of a whole set of analysis scripts we could now optimize the bulle structurally and aesthetically. Already in this phase, the geometrical model communicated with the structural geometry via Excel and a Com-interface in order to gather necessary information for the optimization.

Typical scripts for analysis include curvature control and the distance to the initial surface.

The developed surface of each “bulle” is horizontally regular; a horizontal offset of two curves and the surface created between them remains a controlled surface. Every surface can be developed within a certain tolerance by simply unrolling the elements.

The initial scripts are related to flat slats lying on the surface. The structural analysis gives the input of the necessary thickness and width of the laths. To obtain geometrically the thickness of the laths and bearing in mind the execution process we considered the following; the developed surface can immediately be used and cut out of a wooden panel.

An extra script was introduced in order to twist the laths exactly at the right position around the nodes. The neutral surface of each lath (=middle of the lath) was used to do this.

In a second iteration of the offsets, we built in an extra step to control the curvatures and the maximum allowable torsion or twist of the laths. This was introduced as an iterative design process in order to be flexible and precise at the fabrication stage of the project.

The slats are produced at the factory on false work. Three wooden elements with 14 mm thickness and 60 mm width are cut from flat plates and placed on false work. The slats have to be slightly bent and fixed in the correct geometry manually. After placing and aligning the laminates, these are glued and held together with bar clamps, so as to produce the composite carrier.

The set of customized parametric tools was also used to develop an exchange-feedback platform between 3D models, structural models and Excel sheets. All involved parties were using different software packages and had varying interests into different scales of information. Here a customized workflow was necessary and the whole collaboration was optimized by data exchange files. Hence a close communication between the different members of the project could be introduced.

**Detailing**

The structures are assembled by four connection details which are all load bearing elements and will be briefly explained.

The crossing points of the rods: They are connected to a central shoulder bolt with a diameter of d = 8 mm and two eccentrically placed dowels in order to be able to absorb the torsional moments occurring in the node.

The center shoulder bolt is integrated within the laminated wood elements.

The connection of the bars on the door consists of steel swords, which are welded to the profile of the door. The bars are slotted after the swords, to hold the sword in the central axis. Fixing is by means of two shoulder bolt itself, which thus form a double-shear connection.

The compression ring is placed in the plane between the two bar levels and is connected in the intersections of the wooden slats. To ensure the load transfer between the pressure ring and rods, arranged shoulder bolts are also connected to the steel section.

The supports are made out of flat steel feets which are oriented according to each slat with unique angles. Those feets are welded to a flat steel plate following the outer curvature of the bull.

**Customization**

To realize the project, specific solutions for braiding joints, openings and foundations have been conceived and discussed with the architects. Both our work on digital and physical models helped us defining the execution process. Following the principle we adopted for our physical model, the idea of a specially adapted scaffolding system to control curvature of the wooden slats was developed. Eventually
the production established a high-end process of CNC cutting, scaffolding, bending, glueing and assembling of wood pieces to create the final double curvature wooden slats.

Every single wooden sculpture shows a different curvature of non-developable surfaces. Various alternatives for the construction were seriously considered and tested: steam bending, bending in combination with milling and assembling smaller pieces to continuous slats. The final manufacturing process was defined due to the concept of easy production of the single slats, a fast mounting solution and to have an invisible node.

The pavilions and the realized monumental railing of the staircase show the possibilities and opportunities of the digital workflow in the context of design and structure with complex geometries. The key here is to adapt the targeted free forms and the structural system until they meet the demands of the architectural approach. This requires a very close cooperation of those companies involved in planning and construction.

**CONCLUSION**

The understanding and the knowledge of the construction and design material, in that particular case wood are identified as one of the main indicators for the success of the project. Digitally simulating the right material behavior was impacting not only the geometrical form finding but also the structural performance of the overall shape of the four different bulle. This understanding of the material was the common thread that also connected the involved planers and partners. The architects with there ideas about a sustainable emerging interior for the fashion label Hermes, the engineers with the knowledge about the geometrical constrains and the load bearing abilities of wood and the expertise of the fabricator Holzbau Amann could establish a workflow and a collaborative framework around the material properties.

Not only had the material defined the collaborative work around the implementation of the properties of the material into the parametric design and optimization process. It led also to a variety of design
options and proposals. Equipped with this clear advantage an optimum of design and fabrication in a short design and construction period was possible.

These insights of the project and the relationship between material behaviour and geometry in order to create optimised constructions and fulfil promising design solutions will be a focus of future projects.

REFERENCES