Advances in Material Performance of Solid Wood: Loop, the Environmental Summer Pavilion II

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(insert Figure 1 here)

Fig1. New Meets Old, Loop Pavilion (photo: Okamura 2014)

Loop is a solid wood pavilion that adsorbs the moisture during night and evaporate it during hot summer days. Its panelling is warping in the sun and low relative humidity, thus supporting the circulation of humid air in its environment.
Loop is a contribution to the Research by Design on Responsive Wood started by Michael Hensel and Achim Menges at the AA School of Architecture in 2005 and is a second prototype of the first author's Environmental Summer Pavilions project that developed the previous one, pareSITE Pavilion, further. By spatial organisation of its panelling and the shape of the overall structure, we reached much higher performance. The design was accomplished in Grasshopper for Rhino 5 and digitally fabricated.
The project is a result of a transdisciplinary, one semester lasting, studio course at the Faculty of Art and Architecture at the Technical University of Liberec and the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague lead by Marie Davidová, Šimon Prokop and Martin Kloda. Architect, environmental design and wood engineering students were involved in the project as transdisciplinarity is crucial in the field of Performance Oriented Design in general. The pavilion served as a stage for EnviroCity festival in Prague during the summer 2014.

Research questions:

• The main area of our occupation lies in the material performance of solid wood: Wood - Humidity - Temperature Interaction. Can design push the performance further? (see section 'Material Performance').

• A second topic is the question of parametric possibilities of the design and production of CNC fabrication data: Section 'Grasshopper for Rhino 5 and Fabrication').

• To finish, we ask ourselves over the structural possibilities of parametric design from wood (see section 'Structural Design').

Material Performance:

The studio course took an advantage of the first author's Research by Design in Responsive Wood that aims to be applied in building industry. The research covers facades and screens for non-discrete spaces that breathe and operate the indoor and outdoor environment. The data from samples and prototypes observations were shared among overall team. Loop is a second prototype in Environmental Summer Pavilions project, following the pavilion pareSITE.

'The Paresite - The Environmental Summer Pavilion designed for reSITE festival, is a möbius shaped structure, built from torsed pine wood planks in triangular grid with half cm thin pine wood triangular sheets that provide shadow and evaporate moisture in dry weather. The sheets, cut in a tangential section, interact with humidity by warping themselves, allowing air circulation for the evaporation in arid conditions.' [1]

(insert Figure 2 here)

Fig2. pareSITE Pavilion (photo: Zapletal 2013)

Concluding the project of the pareSITE pavilion, we asked the question, if the specific design may heighten its performance. Both of the pavilions are inspired by the concept of oriental screens, so called 'mashrabīyas'. Among other properties mashrabīyas absorb moisture at night, when the relative humidity of air is high and evaporate it during the hot summer days. This performance was studied by Michael Hensel:

'….. these (mashrabīyas) consists of wooden lattice work and are characterised by a range of integrated purposes or functions: they regulate in a finely nuanced manner the passage of light, airflow, temperature and humidity of the air current, as well as visual penetration from the inside and the outside' [2]

According to Fathy:

'Water will evaporate from a wet surface if it is exposed to air with a dew point lower than the surface temperature. The rate at which water evaporates from the surface depends on the relative humidity of the neighbouring air, the surface temperature, and the velocity of air movement. Thus, for a wet surface at a given temperature, a reduction in relative humidity or an increase in air velocity both increase evaporation.' [3]

PareSITE pavilion was reaching better performance of this concept by warping of its panelling from plates, cut in tangential section in triangular shape. The concept of wood warping has been originally used in traditional Norwegian panelling [4] and has been further on explored by many authors in this century. The first recent century prototype was published by Hensel and Menges in Morpho-Ecology publication with a comment:

'Study by Asif Amir Khan commenced from an analysis of pine cones and the way they open and close in relation to changes in the relative humidity level, which informed the design of full scale prototype of a screen that deploys the selforganisational capacity of thin timber sheets under changing humidity conditions.' [5]

Compare to Norwegian origin based on tangential section of the trunk, the current research, except the one of the author, is using either laminated timber sheets or plywood. The LCA comparison, made for similar prototype in Czech conditions, by Vladimír Kočí from the University of Chemistry and Technology Prague, Dept. of Environmental Chemistry with the first author clearly talks for the use of solid wood for its environmental sustainability.

From the samples observations, the triangular shape warps twice as much as the rectangular one. [6] In the Loop pavilion we tested the spatial organisation of the panelling and combination of left and right side of the plates which resulted in propeller when warping. The sheets were also shortened by solar analysis to equalize the wood shrinkage and expansion. However, extreme conditions were not considered. The expansion data were also not taken from the samples of identical material used for the pavilion as this was impossible to arrange with the material supplier due to the industrial processes of the production as well as the evaporation of sap from former green wood material.
The looping shape of the overall structure was speculated to support the performance next to the spatial organisation of panelling.

(insert Figure 3 here)

Fig3. Panelling (photo: Davidová 2014)

Within this task, the architectural students took the main part in the design of performance and the wood engineering students in the discussion on wood properties, structure, fabrication and building.

Design Process in Grasshopper for Rhino 5 and Fabrication:

The pavilion was designed and built by all the team, including students and tutors. Its concept was a result of competition among the students, where the students were asked to deliver a concept sketch model and a concept research diagram. The winning concept sketch model, designed by Antonín Hůla was based on double curved folding of paper. Once the design was selected, all the members picked their responsibilities in the project, such as panelling, structure, shape, analysis, blog, the GIGA-map, photo documentation and so on.

After the introductory Grasshopper workshop a group of students started with modelling the whole pavilion. All the students were new to Grasshopper, but some of the architectural and environmental design students were familiar with Rhinoceros 5. Further design research was dedicated to finding the exact curves which the physical model exhibited after curved folding. However thanks to the parametric approach in modelling other students could work parallel on the structure as well as the panelling even though the exact shape wasn´t yet found. Finally a precise paper model was scanned by Micro Scribe to Rhinoceros 5 and further on parameterized and developed in Grasshopper for Rhinoceros 5.Due to the parallel work of different students on some areas of the design, some difficulties appeared mostly in data structuring. This was partially caused by the nature of scripting in grasshopper where visual control slightly overbalances other more thorough ways, speaking particularly about beginners.

Numerous versions of the structure and panelling were tested and discussed in the team and consulted with structural engineer. The code was shared by online file sharing and discussed in Facebook group next to the regular meetings over a physical GIGA-map. The concept of GIGA-mapping was introduced by Birger Sevaldson for mapping the complexity of the overall design from the study to the design outcomes. The decisions to be taken in design were printed out and pinned to the board so all relevant specialists could comment on it. By plotting time on the x axis of the GIGA-map deadlines and time organisation was apparent at all times.

(insert Figure 4 here)

Fig4. Antonín Hůla with Micro Scribe (photo: Pokorný 2014)

For structural analysis the team used plugin called Donkey developed by Lukáš Kurilla. It utilises Final Elements Method (FEM) to evaluate efficiency of usage of each profile. Outcomes from this analysis guided the decisions about number of elements in the structure and also provided important insights regarding stability and seating of the pavilion. Even the author of Donkey doesn´t aim to replace detailed structural assessment methods [7] rather to provide architects and designers with a simple tool to be able to understand structural behaviour in early stages of design.

(insert Figure 5 here)

Fig5. FEM Analysis in Donkey (Prokop 2014)

A plugin called Ladybug developed by Mostapha Sadeghipour Roudsari was used to predict exact positions of the sun and then the solar gain analysis. Again the analysis has to be done early in the design process to harness its true potential. [8] Each individual panelling plate was resized accordingly to its maximum possible solar gain.

(insert Figure 4 here)

Fig6. Lady Bug Analysis (Prokop 2014)

During construction the team faced several difficulties. One of which was maintaining order in the 1082 different pieces of the pavilion. The problems appeared already in the design phase. Because the script was created in a collaborative way by up to four people some irregularities emerged in data organising. Also the production numbering of elements at the 5-axis CNC sawmill was very different from the numbering the team used. After delivery of cut pieces manual measuring had to be done on a fraction of pieces to maintain order.

During the fabrication the team faced a challenge of putting two main skew wooden planks of every rib of the pavilion together in precise angle. A pair of unique „rulers" with fitting slits had to be fabricated prior to the assembly of each rib. The fact that the CNC machine was to be operated exclusively by an antique Windows XP based PC with no maintenance over a few years was significantly user unfriendly.

Structural Design:

The structure had rather complex fashion when it comes to forces. After the FEM analyses was processed, several different prototypes of joints were tested at FLD CZU by Universal Testing Machine 50kN with software TIRA by Ing. Vlastimil Borůvka, Ph.D. at the Faculty of Forestry and Wood Sciences at the Czech University of Life Science in Prague to find the most suitable solution. The results from FEM analysis and joints prototypes' tests were coming out well. However, we experienced problems in reality. In one of the most stressed planks appeared cracking and most stressed joints were losing.

We were performing weekly the pavilion's structural behaviour checks with structural engineer and placed steal belts over each joint. The problems seemed different than in the FEM simulation. Compare to WIP Version 2015.11.5.0 of Scan and Solve plug in for Rhino released in 2015, FEM analysis by its nature does not consider neither fibre orientation nor joints.

As a first test, we built the single structure in front of the workshop before bringing it to the festival site. At that point, we didn't realize any problem. The cracks appeared after two weeks on the site which is also tricky wood's structural behaviour that was experienced by the students as well as by the tutors in practice.

(insert Figure 7 here)

Fig7. Vlastimil Borůvka is Testing a Joint Sample (photo: Davidová 2014)

(insert Figure 8 here)

Fig8. Physical Structural Test (photo: Davidová 2014)

Conclusions:

The design can support wood's material performance. The circulation of humid air was way much higher than at the previous prototype of pareSITE pavilion. This fact was clearly perceived by all the visitors of the festival who had experience with both of the pavilions. However, better attention has to be given to wood extension. In extreme storms, some of the panels extended more than expected, which resulted in their cracking due to its spatial organisation. Better combination of sampling for extreme conditions and solar analysis has to be achieved.

FEM analysis for solid wood is not yet that advanced which is most likely for its anisotropic nature as we experienced structural difficulties. The recently released WIP plug in Scan and Solve for Rhino that considers fibre orientation might lead to the solution. The physical structural test proved the importance of the fact, that wood's structural stability is time based. The pavilion's observations in time was a great learning tool for all the participants among the disciplines where everyone took her/his part to certain profession.

The transdisciplinary cooperation among the architect, environmental design and engineering students worked very well even though the schools were in different cities. All the files were shared and discussed online which enabled us to develop the design any place – any time.

Thought the roles were not divided at the beginning, the architecture and environmental design students were more advanced in the design tasks while wood engineering students in structural design, joinery and the work in the workshop. This way we used all the talent of the students. It is a satisfying fact, that the students who chose responsibility which involved Grasshopper scripting became fully capable of using the tool to an intermediate level. The same happened with the site analysing, panelling design development, structure, detailing and joinery, fabrication data or, experienced by all fabricating and prototyping, GIGA – mapping and Systems Oriented Design in general and the most targeted topic of the course, the Material Performance was adopted by whole team.

List of the Participating Students:

Alena Novotná, Anna Hrušová, Antonín Hůla, Barbora Slavíčková, Jakub Kopecký, Jiří Fáber, Jiří Pokorný, Petr Tůma, Tereza Jílková, Radim Sýkora, Eliška Antonyová, Tereza Lišková, Filip Janata, Tomáš Kytka, Marie Kortanová, Vojtěch Holeček, Martin Vaníček, Jakub Hlaváček and Petr Havelka

Studio Course Leaders:

Marie Davidová, Šimon Prokop, Martin Kloda

For further information, please, follow our blog at: http://environmentalpavilion.tumblr.com/

References:

[1] Davidová, Marie, Šichman, Martin, Gsandtner, Martin. "Material Performance of Solid Wood: Paresite, The Environmental Summer Pavilion" *Fusion - Proceedings of eCAADe 33*(2014): 139-144

[2] Hensel, Michael. *Performance-Oriented Architecture: Rethinking Architectural Design and the Built Environment*. Winchester: John Wiley & Sons, 2013

[3] Fathy, Hassan. *Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates.* Chicago and London: The University of Chicago Press, 1986

[4] Larsen, Knut E. and Marstein, Nils. *Conservation of Historic Timber Structures: An Ecological Approach*. Oxford: Reed Educational and Professional Publishing Ltd., 2000

[5] Hensel, Michael & Menges, Achim. *Morpho-Ecologies*. London: AA Publications, 2006

[6] Davidová, Marie. "Ray 2: The Material Performance of a Solid Wood Based Screen".*Fusion - Proceedings of eCAADe 33*(2014): 153-158

[7] Svoboda, Ladislav, Novák, Jan, Kurilla, Lukáš, Zeman, Jan. "A Framework for Integrated Design of Algorithmic Architectural Forms" *Advances in Engineering Software 72*(2014): 109-118

[8] Roudsari, Mostapha, Pak, Michelle, Smith, Adrian. "Ladybug: A Parametric Environmental Plugin for Grasshopper to Help Designers Create an Environmentally-Conscious Design" *Proceedings of BS2013 - Conference of International Performance Simulation Association 13*(2013): 3128-3129