Ray 2

The Material Performance of a Solid Wood Based Screen

Marie Davidova
PhD research fellow at FA CTU / member of Collaborative Collective
http://www.fa.cvut.cz/En
marie.davidova@fa.cvut.cz

The wood - humidity interaction of solid wood has been tested through generations on Norwegian traditional panelling. This concept has been further explored by Michael Hensel and Steffen Reichert with Achim Menges on plywood and laminates in basic research. Plywood or laminates are better programmable but they are less sustainable due to the use of glue. This research focused on predicting the performance of solid wood in tangential section which is applied to humidity-temperature responsive screen for industrial production. With the method Systems Oriented Design, the research evaluated data from material science, forestry, meteorology, biology, chemistry and the production market. The method was introduced by Birger Sevaldson in 2007 with the argument that the changes in our globalized world and the need for sustainability demands an increase of the complexity of the design process. (Sevaldson 2013)Several samples has been tested for its environmental interaction. The data has been integrated in parametric models that tested the overall systems. Based on the simulations, the most suitable concept has been prototyped and measured for its performance. This lead to another sampling of the material whose data are the basis for another prototype. Ray 2 (figure 1) is an environmental responsive screen that is airing the structure in dry weather, while closing up when the humidity level is high, not allowing the moisture inside.

Keywords: *Material Performance, Solid Wood, Wood - Humidity Interaction, Environmental Performance, Parametric Design, Prototyping*

BACKGROUND

Larsen and Marstein (2000) introduced traditional Norwegian panelling cut in a tangential section of solid wood. They explain the principle on the example of Traditional wooden panelling in boathouses, Nordmøre, Norway: "*The boards are nailed towards the upper edge, just below the joint where they overlap. In dry weather, the lower board ends bend outwards, allowing dry air into construction. In wet weather the boards close again*".

Further on Larsen and Marstein (2000) complain that such craft skills have been forgotten and con-

Figure 1
Ray 2 Prototype

temporary panelling is designed to not allow such performance.

This challenge has been taken by contemporary basic research which focuses on plywood and laminates. Plywood and laminates are allowing greater performance and are more controllable than solid wood but my ongoing Life Cycle Assessment analysis, in cooperation with Vladimír Kočí from the Institute of Chemical Technology, is leading to the answer that the use of solid wood is more sustainable due to the use of glue in plywood.

In 2004 Asif Amir Khan at the AA School of Architecture presented his screen based on pine plies which was published in the Morpho - Ecologies publication: "*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*" (Hensel and Menges 2006).

In 2007 Steffen Reichert, under the leadership of Achim Menges, introduced their Responsive Surface Structure. The project was further developed into several prototypes. Reichert's and Menges's research focuses on laminated veneers which are far too fragile for industrial solution but reach very good performative capacity. They address the programming of wood behaviour by the arrangement of the composite: "*The dimensional change of wood is directly proportional to changes in moisture content. Hence, a specific increase in moisture content will always result in the same swelling or shrinking dimensions of a particular piece of wood. However, in combination with another synthetic composite, this linear dependency can be expanded to achieve highly specific yet diverse shape changes. In other words, the veneer-composite elements can be physically programmed as a material system to perform different response figures in various humidity ranges. For example, the ICD's experiments in a climate chamber have shown the following. Using the same veneer as a starting point, two veneer-composite elements can be produced - one entirely straight and the other acutely curved at a humidity level of 40 per cent. When relative humidity rises to 70 per cent, the initially straight element will change to an acutely curved shape as mentioned above, while the other will become straight. Exposed to the very same environmental changes, the two test pieces geometrically respond in exactly the opposite way*" (Reichert and Menges 2012).

In my observations on the samples, such behaviour can be also controlled by the wood moisture content when the wood is cut. Also the material is not fully programmable - approximations have to be done.

In 2008 Matthew Hume at the Centre for Architecture and Situated Technologies Department of Architecture, University at Buffalo in New York produced a humidity responsive screen called Warped which is based on plywood. The screen seems to be very solid. Omar Khan refers to the project in his text in Architectural Design: "*Warped (2008) examines the elastic potential of wood grain as it responds to moisture. Taking existing plywood as the starting point, the project develops elastic plywood cells that do not resist moisture but use it to perform work. Some convincing surfaces using these cells have been developed that demonstrate how a small expansion at the scale of the wood grain can be multiplied to mutate large architectural surfaces*" (Khan 2011).

Since 2008 Responsive Wood Studio is held by Michael Hensel and Defne Sunguroğlu Hensel at the Oslo School of Architecture and Design. In 2010 student Linn Tale Haugen examined the potential of plywood. She developed a double curved surface out of the combination of veneers directions. Hensel explains it as follows: "*In a typical laminate consisting of an odd number of layers, the layers are rotated so as to utilize the fibre direction to stabilize the laminate. Likewise, in a laminate with an even number of layers, the fibre direction of the various layers can be utilized to warp the laminate in a controlled way. Single or double curvature can be attained with a specific fibre direction in the different layers and with the related directions caused by the swelling and shrinkage from the moisturizing and drying of the wood. It is then no longer necessary to derive such curved elements by means of machining, such as routing, which results in a large amount of off-cuts or sawdust, or, on the other hand, the costly production of moulds*" (Hensel 2011).

Mark Weston and Dan Greenberg (2013) developed composite wooden Microloop panels that serve as a passive lighting control: "*This research is centered on a novel perforation technique for flat, bi-material sheets which are carefully attached at elongated tabs, but arranged to slide past one another just slightly when mechanically actuated. The movement of the two sheets causes the tabbed attachments to bend into endless recursive material loops which appear to erupt from the face of the panel; the resultant microloop perforations allow diffused light to pass through the panel while maintaining visual privacy and blocking direct light*".

Except Weston and Greenberg (2013), who claim the industrial production strategy, the mentioned projects are basic research not covering the complexity of application. Instead they perfectly study the possibilities of the performance of the composites in the depth of material science. While Weston and Greenberg (2013) follow the production, their explanation of the sun shadings doesn't follow the building's overall performance. It seems that the shading has rather aesthetical reasons presenting the wood performance. Furthermore, it is not clear in which cir-

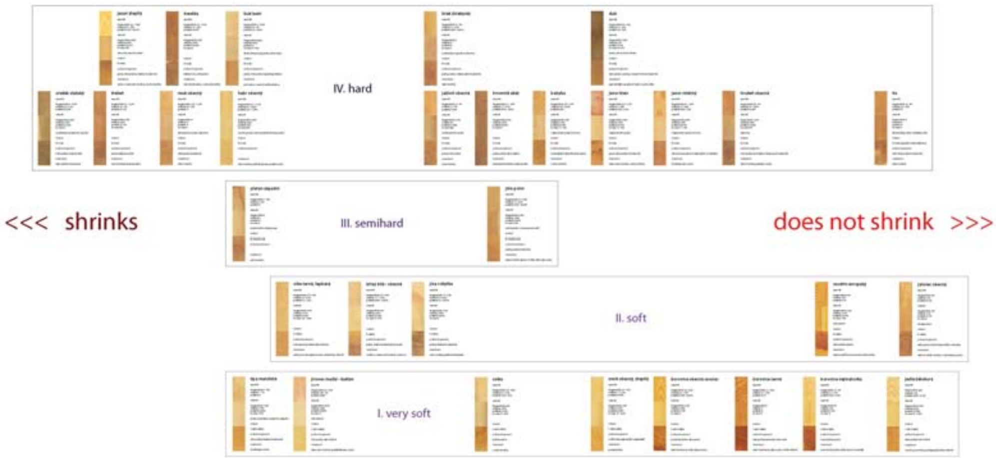

Figure 2
Map of Shrinking and Warping of Different Local Wood Species (data: Němec 2005)

cumstances the complete closure is wanted, not allowing any sunlight into the building.

The conducted research has been done on laminates or plywood not considering the environmental impact of the use of polyurethane glue.

MATERIAL PERFORMANCE OF SOLID WOOD

According to Hoadley (1980) wood always remains hygroscopic (Hoadley 1980). Which means that it is adsorping or releasing water in relation to relative humidity and temperature.

Based on that fact the wood shrinks, swell or moves and warps. If the wood always remains hygroscopic, I expect, that it also remains warping, though Skaar (2011) explains the hysteresis effect. That means, that the wood is less hygroscopic after the first desorption from the green wood when the initial resorption is the lowest (Skaar 2011).

Wood shrinks and swell or moves in relation to relative humidity based on the specie and the grain orientation. The greater shrinkage is associated with greater density (Glass and Zelinka 2010). Dinwoodie explains that wood is anisotropic in its water relationships. It is due to the vertical arrangement of cells in timber and to the particular orientation of the microfibrills in the middle layer of the secondary cell wall between tangential and longitudinal shrinkage. And due to a) restricting effect of the rays on radial plain, b) increased thickness of the middle lamella on the tangential plane in comparison with the radial plane, c) difference in degree of lignification between the radial and tangential cell walls, d) small difference in microfibrillar angle between the two walls, and e) the alteration of earlywood and latewood in the radial plane, which, due to the greater shrinkage of latewood, induces the weaker earlywood to shrink more tangentially than if it would be isolated, between tangential and radial section (Diwoodie 2000). From green wood to air dried, the pine shrinkage is 6,8%, 3,8% and 0,201%, and swelling is 5,72% 3,04% and 0,076%, in tangential, radial and longitudinal section, respectively (Němec 2005, also see figure 2). Reaction and juvenile wood may shrink even 2% in longitudinal section from green wood to oven dry (Glass and Zelinka 2010).

Diwoodie (2000) specifies three cases of moisture flow in timber. Which is a) free liquid water in cell cavities giving rise to bulk flow above the fibre saturation point, b) bound water within the cell walls which moves by diffusion below the fibre saturation point, c) water vapour which moves by diffusion in the lumens both above and below the fibre saturation point. Generally, the pines are much more permeable than the spruces, firs or Douglas fir (Diwoodie 2000).

The effect of change in moisture content, and thus of movement in wood that differs in different section, is warping. There are four cases of warping. a) The most common warping occurs in the tangential section, a cup, which is caused by higher shrinkage on the left surface, b) a bow, which is not that common, occurs for the reason that the grain that is closer to pith shrinks more in the longitudinal direction, c) a crook, which is caused by reaction wood, d) a twist, that is caused by the spiral grain (Knight 1961).

Hoadley demonstrates, that the wood cut in tangential section from the centre of the tree warps more than the boards cut from its border (Hoadley 1980). This fact was proved on my prototype of Ray 2 which is using such condition for generating water resistant system.

THE DEVELOPMENT OF RAY 2

From the analysis of the forest management and material science, the pine wood was selected as the most suitable for the task. Several samples of different shape and thicknesses were measured for its performance. This data has been integrated into parametric models in Grasshopper for Rhino 5 of two selected concepts. The airing gap for 10%RH and 21°C was simulated for both cases.

System Sponge (figure 3) was water resistant in case of sudden rain but according to the simulation it was failing in its performance. Also its interdependency could generate huge problems due to wood's uneven behaviour.

System Ray (figure 4) avoided such problems but it failed to be water resistant in case of sudden rain. In this case, the moisture would enter the structure, then it would close and keep it inside.

Figure 3
Concept „Sponge“ - Parametric Model

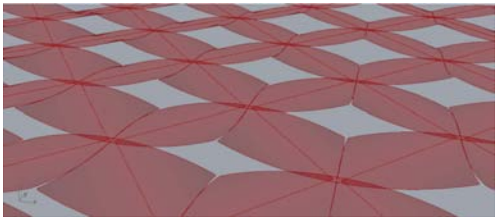

Figure 4
Concept „Ray“ - Parametric Model

Figure 5
Concept „Ray2“ - Parametric Model

Figure 6
System „Ray2“ - Layering

Thanks to the Hoadley's (1980) demonstration, that the wood from the centre of tree trunk warps more than the wood from its border, the system Ray 2 (figure 5) was developed. This fact enabled the overlapping on the diagonals' crossing, by its layering (figure 6).

The system was further on prototyped. It was found out that it behaved in similar way as the simulation but the moisture content of cut wood was not considered. The structure closed just in the case of extremely high humidity level. Samples cut in different moisture content were recently measured to suit the task.

Figure 7
System „Ray2“ - Prototype Detail

CONCLUSION

The data integration of physical and digital has to be involved in dealing with realistic context. The digital simulations can fairly help in evaluation of the concepts performance. But the attention has to be paid to the complexity of the simulation. The samples fairly helped to evaluate the performance of the system but the parametric model has to be confronted with the physical reality of the prototype (refer again to figure 1).

Except of the wood's moisture content of cut wood, that made the system close later than expected, the prototype performed in a similar way as the simulation (figure 7). The system opened in dry weather with the same results but it closed just in extreme humid conditions. According to the observations it was caused by the cut of green wood. Lower moisture content of wood has to be explored for further development.

ACKNOWLEDGEMENT

The project was accomplished with the kind support of Defio, s.r.o.

REFERENCES

Dinwoodie, JM (eds) 2000, *Timber, Its Nature and Behaviour*, E and FN Spon, London

Hensel, M 2011, 'Performance-oriented Architecture and the Spatial and Material Organisation Complex', *FORMakademisk*, 4(1), pp. 3-23

Hensel, M 2013, *Performance-Oriented Architecture: Rethinking Architectural Design and the Built Environment*, John Wiley and Sons, Winchester

Hensel, M and Menges, A (eds) 2006, *Morpho-Ecologies*, AA, London

Hoadley, RB 1980, *Understanding Wood: A craftsman's Guide to Wood Technology*, The Tauton Press. Inc, New Town

Knight, E 1961, *The Causes of Warp in Lumber Seasoning*, Western Pine Association, Oregon

Larsen, KE and Marstein, N 2000, *IJAC, Conservation of Historic Timber Structures: An Ecological Approach*, Reed Educational and Profetional Publishing Ltd, Oxford

Menges, A (eds) 2012, *Material Computation, Higher Integration in Morphogenetic Design*, Willey, London

Němec, J 2005, *Dřevo - historický lexikon*, Grada, Prague

Ross, JR (eds) 2010, *Wood handbook-Wood as an engineering material*, Forest Products Laboratory, Madison

Skaar, C 2011, *Wood-Water Relations*, Springer-Verlag, Berlin

Spiller, N and Armstrong, R (eds) 2011, *Protocell Architecture*, Willey Academy, London

Stoufs, R and Sariyildiz, S (eds) 2013, *Computation and Performance*, Delft University of Technology, Delft

[1] http://www.systemsorienteddesign.net