ARCHITECTURE IN-PLAY CONFERENCE 2016
CHOOSING THE MATERIAL FOR ENVIRONMENT RESPONSIVE SCREEN RAY:

The LCA comparison

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Abstract: Wood performs based on its material properties by shrinking, expanding or warping due to the changes in relative humidity and temperature. This property intends to be utilized in architecture for purposes such as ventilation or thermal comfort. This concept was developed in the design of Ray 2, a screen that airs in dry and is resistant in humid weather. Two material options are available. Following the contemporary research, a plywood could be used performing on 'bi-metal' principle of different shrinkage of different wood species. In reference to the past, the tangential section applied in traditional Norwegian panelling, where different fibre density on opposite sides of the plate cause warping was proposed for the prototype. The plywood research shows better programmability. However, our paper claims that the use of solid wood, at least in the Czech context for the particular product of Ray 2, is more sustainable and therefore it is in our best interest to explore past knowledge in the field. The data from the local manufacturers, as well as from the related universities, were utilized to compare both of the cases in LCA analysis among all showing the energy savings and lower carbon emissions for solid wood.

Keywords*: performance oriented architecture; responsive wood; life cycle computer modelling; simulation of production complexity; solid wood versus plywood; sustainability****.***

1. Introduction

Wood is the main renewable and recyclable building material that has been tested over generations, though administratively rejected due to the fire issues in many countries. Our study compares two ways of its use for design of performative screen Ray 2 that reacts to relative humidity and temperature of the environment. It is worth noting that no analysis is able to predict the future and account for all the circumstances. However, we decided to compare solid wood and plywood material in LCA analysis for this particular design. The screen is designed to be used on buildings and therefore is not a conventional product. This difference for Life Cycle Assessment is explained by Bribián et al., stating that LCA was mainly targeted at other low environmental impact products than buildings. Reasoning the difference in long life span, frequent changes, multiplicity of functions, inclusion of many different components, local production, uniqueness, causing of local impact, integration with infrastructure, unclear system boundaries, etc. (Zabalza Bribián et al. 2009). All these facts have to be taken in consideration when discussing our results and utilized data. Our focus was in the comparison of two materials for one product in a certain location over an established period of time. The following summary explains the application for both of them.

1.1 State of art

While the current research in the field has been conducted on laminates or plywood, the traditional architecture was applying solid wood, cut in tangential section, for the performance. Therefore the paper's research question is which approach is more sustainable for the particular first author's design in certain location.

The natural property of wood is warping. When the material is cut in the tangential section it generates a so-called 'cup' across the grain (Knight 1961). Humidity responsive panelling systems based on the tangential section used in traditional Norwegian architecture were described by Larsen and Marstein:

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'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 the construction. In wet weather the boards close again.' (Larsen & Marstein 2000)

The first example in today's research, when the installation of Asif Amir Khan illustrated pine wood laminate-humidity interaction at the AA School of Architecture under the supervision of Michael Hensel and Achim Menges under Morpho-Ecologies project (Hensel & Menges 2006). The prototype provides more extreme performance in the organisation of the system towards openness and closeness, also showing the relation of scale/size in two directions. A Master thesis of Linn Tale Haugen supervised by Michael Hensel at the Oslo School of Architecture and Design proposed a way more durable plywood, performing on the different shrinkage of plies of different wood species (Haugen 2010). Ray 2 (see figure 1), the design by the first author, returns to the roots of Norwegian traditional panelling. It uses the fact observed on the samples that the tangential cut panels in the shape of triangles warp twice as much as squares. The system was explained as:

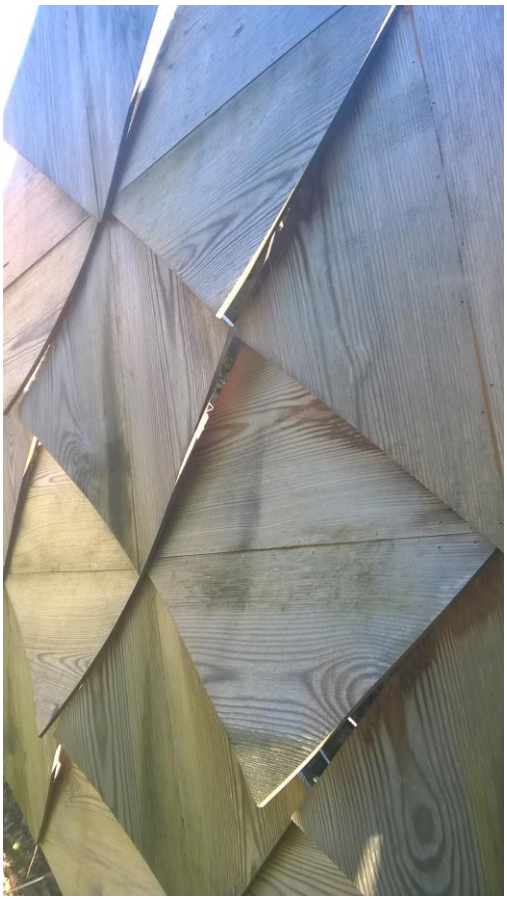

Figure 1. Ray 2 – Prototype after Three Years of Being Exposed to Weather (photo: Davidová 2016)

‘…. wooden environment responsive screen system that reacts to changes in relative humidity. Based on the material properties of wood cut in the tangential section, the system opens in dry weather, thus airing the construction, whilst in the humid conditions it closes, not allowing the moisture into the structure.’ (Davidová 2014)

This refers to Berger et al. (Berger et al. 2015), stating that moisture has an impact on the indoor air quality and the hygrothermal comfort of the building's occupants. From their observations on laminates, Holstov et al. (Holstov et al. 2015) conclude and suggest that the thickness of the active layer (means wood) is also the main factor affecting the response speed. Composites with comparatively thick active layers can be applied where the response to longer term changes in the surrounding conditions is required (i.e. daily, monthly or even seasonal changes), whilst thinner composites can react rapidly to hourly changes of ambient humidity or sudden rain. The thickness of the panels was selected at 0.8 cm as a compromise between amount of warping and reaction speed contra durability of the panel.

Samples observations prior to the decision were made hourly within 24 hours with the changes ranging from 10% to 90% RH on plates with the thickness of 0.3; 0.5, 0.8 and 1 cm when 1cm was considered to perform too little and too slow and 0.5cm was considered too fragile during the summer storms.

1.2 Conclusion for Material Selection Chosen for Comparison

This resume shows that current research at the other institutions has been done on laminates and plywood. Compared to the laminates, the plywood seems to be much more durable when it comes to vandalism, as it can combine the directions of the fibre. The laminates are very thin veneers with textile laminates that break very easily. Therefore, the plywood option was used for comparison with solid wood in Life Cycle Assessment analysis on the case study of the Ray 2 concept.

From the forest analysis of Central Bohemia, where the research is located, it became reasonable to use the combination of pine wood and false acacia. The solid wood model comes from pine wood. Pine wood is native to

Central Bohemian forests (or Czech forests in general, as it grows there in all the places with low nutrients), therefore it is good to support its growth and harvest. At the same time it has very high performance when it comes to warping in the tangential section. On the contrary, false acacia is a dangerous, invasive species with no local enemies. False acacia should be harvested and its roots excavated, as it is the way it reproduces, poisoning the soil, thus disabling natural biodiversity. Pine wood and false acacia have reasonably different tangential shrinkage, therefore its veneers would perform well on the concept of so called 'bi-metal'. As a result, the species for both of the Ray 2 concept products were chosen, on one hand for its suitable material properties, on the other hand for its positive impact on local ecosystems with low carbon footprint during its transportation.

The speculation of the advantages of solid wood considered the energy and carbon emissions, but also the evaporation of poisonous chemicals. As Wójcik & Strumiłło puts it:

'Today, remanufacture of timber, i.e. the production of timber derived sheet components and glulam beams, is a way to meet the needs of modern economy. That is not without an impact on the environment. Processing a material means energy expenditure and may have an impact on health risks posed by this material, and also on its recycling.' (Wójcik & Strumillo 2014)

2. Method - LCA:

The methodology of life cycle assessment used in this project was based on ISO 14040 (Anon 2006a) and ISO 14044 (Anon 2006b) with detailed specification according to EN15084 (Anon 2014), that can be used as product category rules for construction products. For detailed evaluation of environmental impacts, not only were impact categories required in EN 15804 was calculated, but additional impact categories based on USETox (Henderson et al. 2011) and ReCiPe (Goedkoop & and coll 2009) were calculated as well.

The aim of the Life Cycle Assessment based comparison of the panelling compared to the Ray 2 design concept was to evaluate

environmental burdens and/or benefits of having the panelling made of solid wood and or plywood. The functional unit chosen was one square meter of panelling possessing its fully-functioning ability for a reference lifetime of 20 years. In this study, the Life Cycle Assessment was principally performed on the production of panelling, its application including repair, and finally on waste management and energy utilisation of used wooden parts. Used system boundaries include wood production and atmospheric CO_2 utilisation and incorporation into wood biomass, panelling production, transportation, production of the ancillary materials and energy carriers, consumption of fuel and water, as well as atmospheric, aquatic, and soil pollution produced. The end-of-life phase of the panelling Ray 2 concept was modelled as in solid wood and/or plywood-contained energy recovery and its use for avoiding emission related to the production of the same amount of thermal energy.

LCA methodology was used to calculate the possible environmental interventions (inventory profile) and characterisation profiles (results of impact category indicators) (Koci & Trecakova 2011). The pollution from diesel consumption and electric production, as well as the relevant processes dealing with polyurethane glue, were derived from use of the GaBi 6 Professional database (thinkstep).

3 Results and discussion

Outputs of inventory analysis are summarized for following modules of life cycle: upstream module; transport; core module; energy recovery and end of life (EoL) module. Within upstream module all processes dealing with production of materials and energy carriers are included. Transport module covers production of during transport consumed fuels and emissions dealing with transport within all life cycle. In core module in site manual production of Ray2 panels and its estimated repair during 20 years of use. EoL summarizes inputs and outputs within waste management and Energy recovery demonstrate potential benefits of use of wooden parts as biotic fuel during end of life of panels.

Solid wood Ray2 needs a lower amount of all consumed resources and, in the case of the energy-carrying resources and water, avoids consumption of a higher amount of resources (expressed as numbers below zero). The main resource consumption is due upstream module and end of life module. Although during the core module there is principal consuming of Pine and/or False Accacia wood as a biotic resource.

The assessment of possible environmental impacts was conducted using CML IA. USETox characterization was used for evaluating toxic and ecotoxic impacts of both scenarios. The ReCiPe characterization method was used for sensitivity analysis.

Similarly as in the evaluation of resource consumption results in impact categories due to the energy recovery of end-of-life wood and plywood express negative values, meaning the positive effect on the environment- so called avoided emissions/impacts. As the values decrease, the amount of avoided emissions rises. It seems that both of the products would be truly sustainable as the environmental impact of wood and wood products in general seems to be lower than other materials used in the building industry. This has been also concluded by a literary study comparing the results for cca. twenty years in Europe, Northern America and Australia by Werner and Richter (Werner & Richter 2007). The LCA results argue for the use of solid wood with negative values in most of the categories. Therefore it seems that solid wood is more suitable for Ray 2 product for Czech Republic.

4 Conclusions

The experience of vernacular carpenters, accumulated throughout generations, has been overlooked during modern times and must be revisited through ‘Research by Design’ in transdisciplinary teams by samples observations and the construction of prototypes in 1:1 scale. The Life Cycle Assessment of wood and plywood panelling clearly demonstrated that solid wood-based panelling of Ray2 exhibits substantially lower environmental

impacts than plywood, having lower results in almost all the values for the Czech Republic. This statement is valid for all applied impact categories and is not sensitive to the selection of impact assessment methodology. Therefore, research on performative wood should also consider the direction of solid wood.

From the designer's perspective, it is an important fact that Life Cycle Assessment is utilizing the most up-to-date data even for the calculations of the future and not the speculations of its possibilities. In this way, the system avoids failures of predictions in development, but on the other hand, it is unable to be precise in its life cycle nor accurate in the evaluation.

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