Creation of new markets and applications for native hardwoods – Research activities in Göttingen

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1. Introduction

New approaches to silviculture call for a maximum increase of biodiversity in forests through the creation of mixed forests. Therefore, more hardwood will be available in the near future. It is the declared political will to introduce these hardwood resources into the building sector for a non-energetic use.

In 2012, softwoods covered more than 75 % of the total 70 Mio. m³ annual felling in Germany. While 80 % of this total amount were used in wood and wood products, 20 % were processed for energetic use. For hardwoods, the proportion was the opposite, only 35% were used in the building sector. Therefore, in the future it will be necessary to use hardwood more extensively in a non-energetic way to meet upcoming demands. To ensure future resources for the wood industry, new strategies for the utility of unused, thus mostly energetically used hardwood are needed.

German forests are at present stocked (11.4 Mio. ha) with approximately 54% of coniferous tree species and 43% of hardwood tree species. Hardwood forest area grew around 7.3% from 2002 to 2012, while softwood forest area shrunk by 4.3% in the same time period. Most wood species are used according to the "sustainability rules" what are followed in Germany since hundreds of years: not more wood is harvested than it is regrowing. However, for spruce the use of wood was 15 % higher than the stainable growth rate. While the available softwood in German forests is used extensively, there are still considerable potentials for the use of hardwood. Beech and oak wood is widely used by its potentials (beech mainly energetic) whereas species like birch and ash have possibilities for more applications (Spellmann 2013).

Since the turn of the century more and more funds for hardwood research have been made available to overcome this gap between growth and utilisation rate. The above-mentioned situation with respect to the raw wood market was also the starting point for different national and transnational research activities at the University of Goettingen, Department of Wood Biology and Wood Products. The first focus of the research was on identifying criteria of the underrepresented use of hardwoods, why is hardwood only poorly used or rather difficult to introduce to certain markets. Therefore, different interviews were carried out as part of an ongoing PhD-thesis (Increasing the resource efficiency within the value chain of low-value sorts for chosen hardwoods from sustainable managed mixed stands). The interview partner were all kind of people of the forest and sawmilling sector in all over Germany. Based on the interview results different reasons could be screened out (see Figure 1).

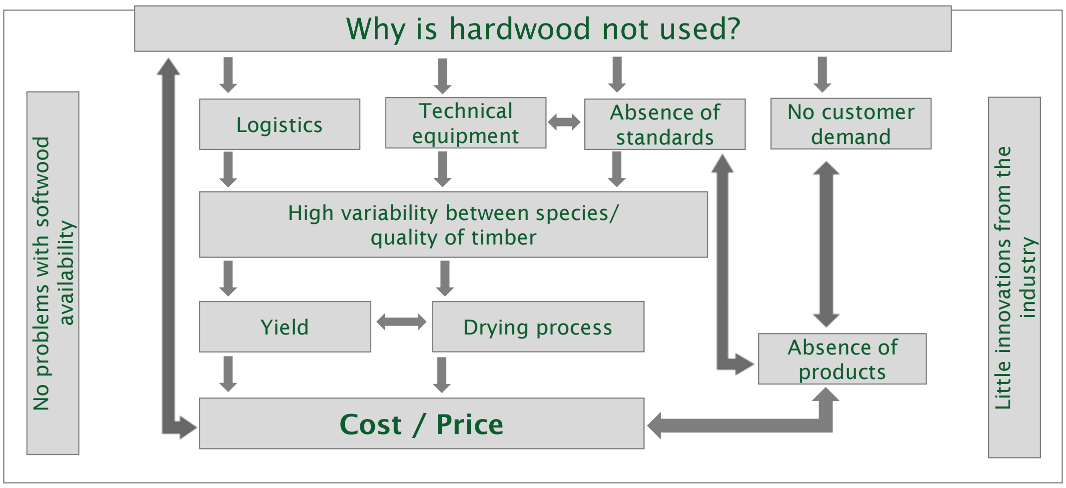

Figure 1: Flow chart "Why is hardwood not used?"

One of the main factors is that, at the time being, there is still sufficient softwood available. This has maybe the strongest influence on this topic. Furthermore, most interview partners mentioned that they have a logistic problem when it comes to hardwood. Beside beech and oak, hardwoods usually grow in mixed forests with several tree species and not in monocultures like spruce. The trees are mostly in single stems all over the stand and therefore harvesting is more problematic. The technical equipment is also different harvesting hardwood and often machines that are used for softwood will having problems with hardwood (e. g. harvester). Besides there is still an absence of standards. Most of the sorting standards are just for beech and oak (DIN 1316-1:2012) or the standards for softwoods are just transferred to hardwoods (DIN 4074-5:2008). Standards for the usage for construction timber are still missing. All these points are highly influenced by the high variability between the species and also by the quality of timber. In contrast to softwood (which is more or less homogenous) hardwood is heterogeneous. Therefore, the requirements for logistic services and the technical equipment are challenging. And the heterogeneous material is also challenging for establishing new standards because of the diversity of the hardwood species. Additionally, there is almost no costumer demand except in the well-known markets like furniture, parquet flooring industry or stairs. On the other hand, we have the fact that there are little innovations from the industry and therefore also an absence of products. After all most of these factors are affecting the economics.

In view of these points, the research activities at UGOE were clustered depending on the different key issues. During the last years, different research projects were started such as:

- NaWoTech: Creation of new markets and applications for native hardwoods. National research group, funded by the Federal Ministry of Food and Agriculture
- CreoSub: New protection technology to substitute creosote for the protection of railway sleepers, timber bridges, and utility poles. European joint research project, funded by the WoodWisdomNet
- GerLau: Possible uses for low value hardwood. National joint research project, funded by the Federal Ministry of Food and Agriculture
- Dauerbuche: Development of a dimensional highly stable and durable laminated veneer lumber (LVL) from European Beech (Fagus sylvatica) by impregnation with low molecular weight phenol resin. National research project, funded by the Federal Ministry of Education and Research

The key issues of these different research projects will be described in the following chapters.

2. Research activities

2.1. The use of hardwood for structural purposes

During the last years, research activities together with efforts made by private companies has led to a number of European and German Technical Approvals for hardwood glulam (oak, beech, sweet chestnut, beech LVL). A further result was the inclusion of the hardwood species beech, oak, maple, ash and poplar into the European standard EN 1912:2012, which allows the use of these hardwoods as solid wood product in construction. Nonetheless, a widespread use of these products cannot be witnessed at present.

Therefore, the goal of this research part was to identify reasons for this development. Next to market driven causes like a still sufficient availability of softwood and high prices of hardwood products, technical reasons (problems) regarding hardwood glulam and solid wood were identified. In the last five years, it was aimed to answer some of these technical questions, in order to work towards a more reliable and cost reduced (etc.) hardwood construction product.

First, the market and standard situation was identified and put together. Afterwards, three technical work fields were determined together with the industry:

(A) Strength grading,

(B) Surface gluing, and

(C) Yield.

Special emphasis was set on the work field (A) strength grading, since here a raised improvement potential was seen. For the six European hardwood species oak, beech, ash, maple, lime and birch the distribution of sawn wood characteristics (of a typical, market-available assortment) were determined and the timber availability examined, in order to evaluate the suitability of the species for a wider use in construction. For the species ash and maple, a yield analysis from round wood sections to sorted glulam lamellas was carried out (work field C), which pointed out the need for an improved sawing technique (incl. sawing pattern), an optimised drying technology and adapted sorting schemes. When it comes to timber sorting, the grain angle is highly correlated with the final tensile strength of the glulam lamella. It is technically complicated to determine the grain angle on hardwoods in a non-destructive way. In the course of this project, it was proved that for all six above-mentioned hardwood species it is possible to determine the grain angles by machine use. Also in the field of work package (A) falls the topic "size effect", which was examined for bending, tension and compression parallel to grain (for all six species) as well as tension and compression perpendicular to grain (for ash, maple and beech). In addition, compression and tension tests on glulam lamellas were carried out and the results correlated with the sorting results. These experiments revealed the unused potentials (in standard strength values) of some of the hardwoods, but also pointed out the difficulties in raising the final yield (e.g. lower production costs). The evaluation of the suitability of commercially available gluing systems for surface gluing (work field B) was carried out for the species ash, maple and beech. An (in most cases) unsatisfactory delamination resistance was detected.

2.2. Hardwood for exterior uses

Most of the native hardwood species are without any further treatment not suitable for exterior use because of their low natural durability and poor dimensional stability. To improve the resistance against wood destroying organisms and the swelling and shrinkage behaviours the use of conventional wood preservatives as well as different wood modification systems were investigated.

2.2.1 Treatment of hardwood with conventional wood preservatives

In Germany in the past, mainly softwood was treated with wood preservatives. Therefore, the adjustment of the wood preservatives, limiting values for their effectiveness as well as the impregnation processes are oriented on softwood. However, due to the different anatomical and chemical structure between hard- and softwood, impregnation and fixation mechanisms could differ essentially. Hence, the following research questions are of great interest:

- Penetration and distribution as well as fixation in different hardwoods
- Protective effectiveness against brown and white rot fungi (investigation of the limiting values in comparison to softwood species)
- Impact on mechanical properties of treated hardwood

Wood specimens of beech, oak, poplar and birch were used in this study and impregnated with different water based wood preservatives. The results have shown that the wood preservatives, which are already approved for softwood, cannot be used without any adaption and optimization for hardwoods. This study is ongoing. Further investigations will be carried out to understand the different effect mechanisms and to optimize the impregnation processes and distribution into the wood.

2.2.2 Wood modification of different hardwood species

This research part dealed with different wood modification systems for the use of hardwood in exterior use, mainly under use class 3 conditions such as cladding or decking elements.

In the first part two wood modification systems (heat treatment and wood modification with methylated melamine formaldehyde resin) were applied, adapted and combined to produce competitive materials for outdoor applications made from native hardwoods. In close cooperation with the industry the scope of the investigation was the development of a solid wood based substitute for tropical wood species. This two steps modification process was chosen to find technical and optical equivalent wood for this purpose.

Beech, ash, lime and poplar were chosen because of their good availability and treatability. The results have shown that a combined treatment in a twostep process (first heat treatment and afterwards chemical modification with the melamine formaldehyde resin) increased dimensional stability and hardness. The modulus of elasticity (MOE) and modulus of rupture (MOR) are rather unchanged, whereas the work in bending was negatively influenced. The results also showed that an adjustment of the process parameters is necessary in order to improve the crack resistance as well as the embrittlement of the modified wood. Therefore, different tests were carried out to modify the parameter of the modification process as well as to optimize the modification process. The influence of the different parameters and the quality of the modification process was controlled by the determination of the nitrogen content, fixation of the modification chemical into the wood, work in bending and the determination of the formaldehyde emission.

The second part of the research program was to investigate the feasibility of acetylating German hardwoods to enhance their performance. The investigations were carried out in cooperation with Accsys Technologies (Arnhem, The Netherlands). Accsys Technologies is working on the development of commercially viable acetylation processes for additional wood species.

Beech, alder, lime and maple were acetylated in an adapted industrial process at Accsys Technologies to high loadings in commercial sizes. The resistance against fungal decay was investigated in a laboratory test against the brown and white rot fungus *Rhodonia (Poria) placenta* and *Trametes versicolor*. The results showed very low mass losses for the acetylated woods as would be expected based on the literature about the potential of acetylation to improve durability. Also cyclic dimensional stability tests were carried out. The results indicated that acetylated wood species are highly stable in changing moisture conditions. In addition, the mechanical properties (hardness, bending properties) of acetylated woods were determined.

The results overall are very promising and upscale efforts to demonstrate uniformity and reproducibility of the acetylated hardwoods would be the next step.

2.3. Potential substitute products for the use of creosote in railway sleepers made of Beech

An important field of application for beech wood in Germany are railway sleepers. Standard track sleepers are made of creosote impregnated beech. Creosote as an oil based wood preservative is one of the oldest industrially used wood preservatives for products in heavy-duty applications (use class 4) like railway sleepers, timber bridges, utility poles and piles in marine applications. Because of its high variety of chemical compounds, creosote provides a wide spectrum of efficiency against wood destroying fungi (especially soft rot), insects and marine borers. Additionally, the hydrophobic character of the oil reduces the water uptake of impregnated timber. However, creosote was classified as harmful to the environment and health. Therefore, the use is restricted for selected products and the use of creosote in the future is questionable. This leads to the necessity of finding alternative products for a potential banning of creosote.

Therefore, these investigations are part of two research projects. They were carried out within the above-mentioned national research group for hardwood applications and within the European joint research project CreoSub.

Substituting products for creosote should have comparable product properties to creosote impregnated material regarding the biological effectiveness or mechanical properties, particularly concerning the effectiveness against soft rot and copper tolerant fungi, which are the main causes for insufficient protection of conventionally impregnated products in heavy-duty applications.

Also, the Deutsche Bahn AG in Germany has requirements towards new alternative wood preservatives such as:

- The performance of the environmental compatibility must be given
- The active ingredients must show a low leachability
- Detection of biological target activity in lab- and field test
- Mechanical properties comparable to creosote impregnated sleepers, mainly bending, tensile and fatigue behaviours
- Fulfilment of required standards for electrical conductivity
- Corrosion resistance
- Further use of conventional impregnation plants

Different copper organic wood preservatives as well as oily products for their potential for the use in railway sleepers were investigated. The focuses of research work at the University of Goettingen are:

- Optimization of impregnation processes for railway sleepers
- Examination of physical-, mechanical- and biological properties of the impregnated wood
- Examination of application-typical properties like corrosion or electrical conductivity.

2.4. Possible uses for low value hardwood

Different research institutes in the field of wood science are working together in this project to improve the use of low value hardwood. Beside different Departments of the University of Goettingen also the Northwest German Forest Research Institute and the Fraunhofer Institute for Wood Research (WKI) are part of the project. Aim of this research is to find an ecologically acceptable, non-energetic and sustainable solution for the use of low value hardwood timber. Along the value chain of the potentially useable hardwood species developments are on their way.

First interviews with different partners from the sawmilling and forest industry show very different regional aspects of availability and demand for different hardwood species. The reasons are diverse, e.g.: Wood species like ash are expected to show a major decrease in the next years (parasites). Species like birch are available but only in single stems in the stands. Some tree species are not harvested, because their wood is not "en vogue" at the moment. Many trees of low value are still in the forests due to expensive costs of felling and little payment for the quality. Moreover, the species and assortment range of hardwood trees is higher compared to softwood trees, therefore sorting and storage is more complicated and more expensive.

The Department of Wood Biology and Wood Products at the University of Goettingen is working on low value hardwood timber in the sawmill industry with special focus on yield and drying. The wood species oak and birch were chosen for first investigations – mainly because of the availability and demand in the future. Studies in the past (e.g. Van de Kuilen et al. 2014) show a huge optimisation potential regarding the process of producing hardwood gluelam. During first experiments, yield analysis with maple and ash were carried out. The logs were sorted according to German round wood standards and cut to lamellas. After technical drying the lamellas were planned. The yield for maple was 13.6 %. That indicated that one important point to make hardwood products competitiveness with softwoods products is the increase of the yield. Recent experiments showed that the biggest problems are caused by multiple curved stems. They have a major influence on the yield while sawing and processing boards. To overcome this drawback, different cutting methods will be tested (shorter cutting dimension) in combination with different sawing types such as rift, quarter or plain sawn. Furthermore, improved methods for planning the boards will be investigated. Additionally, hot steam drying and alternating climate drying are promising options in order to reduce drying time and or improving drying quality. The experiments for the drying processes shall be held at the semi industrial kiln at the Department. So far, there are hardly any drying schedules for low value hardwood timber available. Nevertheless, for an optimal use of low value hardwood timber, drying schedules are necessary and should be developed. Alongside with mechanical tests, a conclusive picture for further usage of low value timber of these species will be given during this research project.

2.5. Laminated veneer lumber (LVL) made of beech wood

Beech-LVL, and derived products from it, are already used and accepted for structural purposes, e.g. fabrication halls and multi-store buildings, though they benefit from its higher mechanical properties compared to softwoods. The Pollmeier Company started in 2014 their production plant in Creuzburg (Germany). Today many reference objects prove the applicability of this product. However, the susceptibility to biological decay and possibility of dimensional changes limit the applicability to dry climate conditions. Therefore, it is the aim of this research project, in close cooperation with the Pollmeier Company, to achieve durability against fungal decay, increase of weathering performance and dimensional stability. As modification of the cell wall is a promising way to provide dimensional stability and durability to protect wood and wood products against these corrupting influences, a modification on basis of phenol formaldehyde was chosen. This seemed to be more attractive than other chemical treatments or thermal treatment, because earlier work showed a sufficient preservation of the mechanical properties, which is crucial for building applications. The aim of the treatment was to decrease the water uptake and the extent of dimensional changes by incorporating the phenol formaldehyde resin inside the cell wall polymers to achieve a permanent bulking and a resistance against fungal decay. Therefore, rotary cut beech veneers were treated with low molecular weight alkaline phenolic resins with the aim of an optimal cell wall modification. The process contained a two-step impregnation, within a vacuum was followed by atmospheric pressure, and a pre-drying. The final curing of the resin took place while gluing the veneers in a heated press to form LVL-boards. The used resins are water-soluble alkaline types with a low molecular weight and commercially available. First results have shown that LVL from the PF-modified beech veneers is highly durable against the wood degrading white rot fungus *Trametes versicolor* and at the same time dimensionally stable. The cell wall modification with PF also provides a higher compression at relatively low production pressures, which is why increased modulus of elasticity (MOE) and modulus of rupture (MOR) are achieved. On the other hand, it has to be dealt with an increased stiffness and a reduced impact bending work. Thus, it will be the issue to identify the needed material characteristics for a specific product application and to adapt the process. Even though there is still research to be done concerning natural weathering and other corrupting influences, it is believed that the modification with PF at low and moderate WPGs can lead to durable products in structural and outdoor application.

3. Literature

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