DokIn'Holz

Zusammenfassung
Wissenschaftlicher Zwischenbericht

1. Jänner 2014 – 30. April 2015

Doktoratsinitiative *Holz – Mehrwertstoff mit Zukunft*

des
Bundesministeriums für Wissenschaft, Forschung und Wirtschaft
gemeinsam mit der
Kooperationsplattform Forst Holz Papier

F1: Innovative Laubholztechnologien und Produkte

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Solid hardwood industry faces major challenges in Europe and beyond. It has to find its stability and market place once again. The increasing hardwood timber stock in forest is still in contrast with a stable to slightly decreasing utilisation in the wood-based industry. A gap is evolving between resource growth and material utilisation. One reason for the issue concerns the missing links in the supply chain from resource to product and customer. Those links are essential parts of a supply chain network (SCN). SCN members produce products step by step. Every single manufacturing and processing step within SCN changes the quality of the ready-made product. Each business, which is involved in the product transformation process, is responsible for the product quality. Knowledge of those quality influencing processes require extensive information. In order to obtain that information about the hardwood manufacturing and processing SCN, methodologies with structured holistic approaches are needed. Quality management and product development methodologies provide such an approach. They are informative about a company´s processes at a very detailed level.

Our approach uses the Quality Function Deployment (QFD) and Value Stream Mapping (VSM) methodology for a better understanding of the interaction and reaction of upstream and downstream companies in the SCN and their specific process functions. The QFD provides the user with a high density of functionally dependent information. In addition, the application of QFD affects parameters and processes through the cross-divisional and company-wide business processes. The expected results from this approach are the analysis of key processes of the solid hardwood supply chain network and a holistic possibility to evaluate the actual system on resource-efficient capacity utilisation as well as redundant and limiting process chain elements. In general, we will equip decision-makers with a decision support tool which delivers a quality process function analysis for their network system.

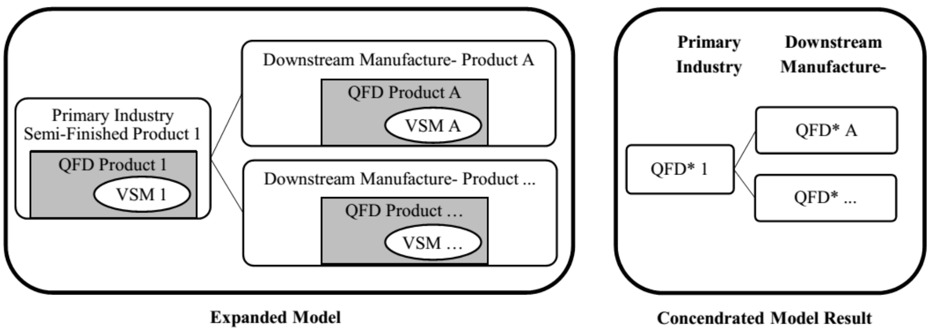

Figure 1: Model of the Integration of VSM into QFD.

F2: Sicherung der Rohstoffversorgung: Produktionsplanung und Ertragsregelung unter Berücksichtigung von Risiko und Ungewissheit

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Long-term production planning and yield regulation are the core elements of forest management planning. The approaches and tools applied in practice mostly refer to concepts which ignore any risk and uncertainty irrespective of the fact, that risks of production and market risks are of great significance and the long time horizon of timber production implies a high degree of uncertainty. The project aims at explaining as well as bridging the gap between the state of the art in science and practice.

The general guidelines for risk management postulate, that effectiveness and efficiency of respective approaches hinge on a comprehensive as well as balanced concept. Consequently, a framework for risk management in forest enterprises has been developed, thereby taking into account the peculiarities of forest enterprises in general and timber production in special and highlighting the role of management planning within the overall system. Figure 1 illustrates this concept which comprises also a checklist specifically addressing crucial aspects of risk management at the different levels of decision-making.

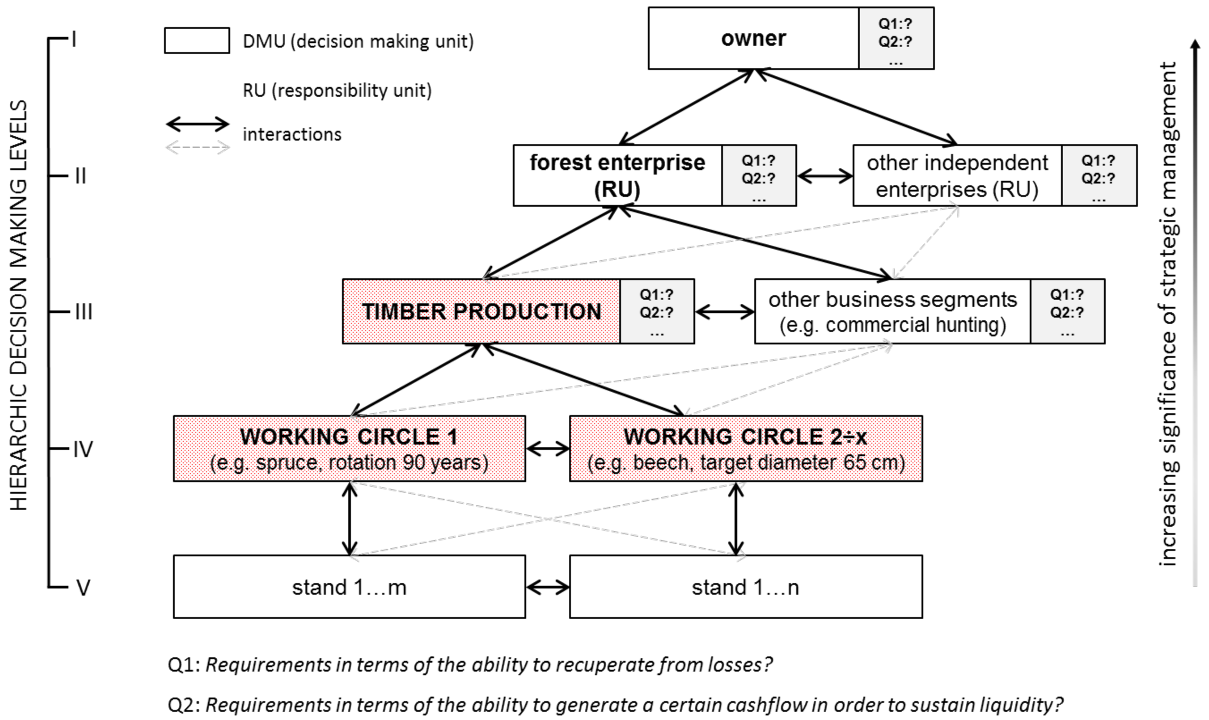

Figure 1: Framework of a comprehensive system of risk-management (the focus of subsequent research is highlighted in pink)

H1: Numerische 3D-Modelle zur Ermittlung von Biegefestigkeiten, Festigkeiten und stochastischer Informationen von Brettschichtholz und Brettsperrholz unter Berücksichtigung von Material- und Strukturnichtlinearitäten

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This work aims at a new approach to understand and estimate failure mechanisms and strengths of wood. Since failure initiation and crack formation are strongly influenced by the complex material system of wood, exhibiting cellular and layered structures on different length scales, a mechanical concept, in which these different microstructural characteristics are incorporated, appears to be necessary. Thus, the division of wood into meaningful scales of observation is the first objective of the proposed work. At each scale, failure modes and failure stress states (strength properties) are to be determined by means of numerical methods, and the obtained information is to be transferred - and will serve as input - to the next higher scale of observation. For this so-called upscaling, at the Institute for Mechanics of Materials and Structures, a numerical concept based on the extended finite element method is currently in development, which is able to describe failure (even cracking mechanisms) of wood very accurate. For a comprehensive description of the strength behavior over several levels of observation, however, this method alone seems to be insufficient and inefficient. For this reason, within this work, finite element limit analysis approaches are developed and applied for the first time to wood, complementing the overall multiscale 'damage' concept successfully. This method is exclusively focused on the time instant of failure, and delivers lower- and upper bounds for the ultimate strength of the considered material structures. Compared to conventional finite element approaches, where the com- plete load history has to be considered and, in order to predict the correct failure mechanisms, proper regularization techniques must be used, limit analysis approaches are much more stable and efficient. Within the first project year, orthotropic failure criteria as well as periodic boundary conditions have been implemented into existing limit analysis formulations, allowing their application to wood cells. Through the investigation of numerous loading states, effective failure surfaces for early- and late-wood cells could be obtained. First comparisons with conventional finite element analysis show a very good agreement of the effective failure surfaces, qualitatively as well quantitatively, although, the computational effort is much lower using finite element limit analysis formulations.

H2: Das akustische Verhalten von Wand- und Deckenverbindungen im Massivholzbau

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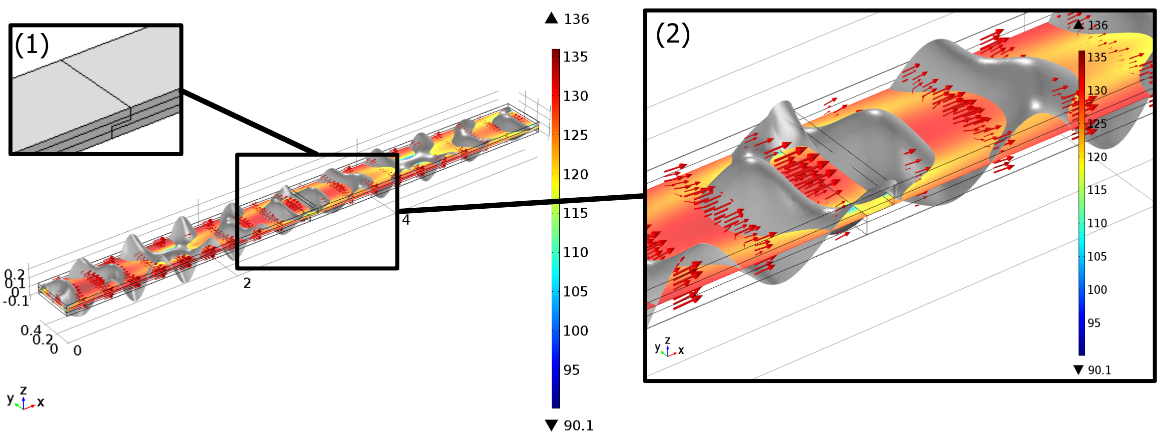
Current prediction methods for sound insulation between adjacent dwellings are of limited applicability for timber constructions. Measurement and calculation standards are based on homogenous, isotropic materials like concrete. Timber constructions show a different acoustic behaviour, especially in the junctions of the involved components. As a consequence, the competitiveness of the material timber compared to other building materials is significant decreased.

The PhD-project deals with a basic research of the acoustic behaviour of the junctions to get this problem under control. Essential physical effects are identified and their influence on the acoustic energy transmission between adjacent components is studied. Based on new findings, proposals for additional calculation methods are developed. General designs of junctions shall be improved. The competitiveness shall be increased and the need for expensive measurement procedures may be reduced by the use of alternative prediction methods.

First results based on computer simulations show that the analysis of the structure-borne sound intensity allows comprehensive investigations. It allows an insight into the acoustic energy distribution within a component and a determination of the energy flow from one component to another one. This is shown in the following figure displaying a simulation of two coupled plates of cross-laminated-timber. A typical junction is implemented (1). Red arrows show the structure-borne sound intensity vectors (2). The colored surface shows the intensity in the horizontal cross-section and the gray surface shows the displacement of the elements. A variable connection stiffness of the plates controls the transmitted energy. Values of connection stiffness of common junctions should be identified by measurements and implemented in simulations. In terms of practical aims this should allow a calculation of the resulting acoustic energy transmission.



H3: Grundlagen für einen neuen mechanischen Holzaufschluss als Basis für verbesserte bzw. neue Holzwerkstoffe und Engineered Wood-Products

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In a pre-project alternative cutting technologies for disintegrating wood were identified by a cross innovation patent research. In total approx. 28.000 patents were screened and 250 were selected for close investigation. From this number 50 patents were evaluated during a workshop. At the end 6 technologies were selected by the industry partners for further investigation in the DokIn Holz programme i.e.: Lasercutting assisted by a Wedge, Waterjet assisted by a Wedge, Roll-Squeezing, Chipless cutting knife, Pressure Wave debarking and Shockwave. During the reporting period a detailed literature research of all these alternative cutting technologies was performed. Open questions from the literature research were answered by performing expert interviews. The contents of the literature research and the expert interviews were summarized in a presentation and in a detailed report. Main limitations, chances, risks and potential of the different technologies were outlined. During a meeting on 4th of December 2014 it was decided by the industry partners to lay the future focus on squeezing as a pre-treatment for the refiner process and on shockwave technologies.

Analysing pressure wave and cavitation it was shown that both technologies are based on the same physical principle “shockwave”. Therefor both technologies were merged. The shockwave is easily produced when the expanding medium has lower density however this shockwave has lower pressure. The pressure of a shockwave depends mainly on the density of the medium and the speed of propagation. On the other hand the expert interviews pointed out, that a shockwave will cause similar effects than the impact of a solid body into the wood material (high energy instantly crash on a steady material). Due to the viscoelastic properties of wood high differences between static and dynamic insertion of a solid body is expected. Systematic test runs have been started to investigate the effect of total energy absorbed and the speed of the solid body smashing the wood material. Further investigations will point out if smashing of wood can be used as an alternative method for disintegration of wood into strands and particles as well as for debarking or pre-treatment of wood chips in the refining process.

H4: Innovative Laubholzverwendung

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Wirtschaftspartner:	Fachverband der Holzindustrie Österreichs (FVHÖ)

The purpose of project H4 "Innovative Hardwood Applications" is to show up new possibilities for hardwood utilization focusing on innovative product and connection solutions meeting the demands and requirements of contemporary timber engineering. In order to achieve these objectives three work packages are defined: (i) preliminary study and conceptual basis (ii) development of hardwood products and (iii) development of hardwood connections.

(i) Based on a comprehensive literature research two hardwood species (beech and birch) with potential for building construction applications were identified.

(ii) A preliminary study, regarding a new and innovative approach for utilizing mentioned hardwood species, was carried out and presented in [6]. The innovation features forming processes to produce Ultra High Performance Plywood elements with special focus on load-bearing optimized cross-sections for light-weight constructions (Fig. 1). In contrast to common planar and straight products (GLT, CLT, LVL, Plywood) UHPP combines high mechanical properties of hardwoods and high yield production processes (peeling of logs, forming process). UHPP is going to open new fields of hardwood applications.

(iii) The performance of light-weight constructions such as trusses and space frames strongly depends on the used connection technology. Hence, the purpose of the studies already performed in the frame of project H4 is to investigate relevant parameters for end-grain joints, with special focus on screws and glued-joints. The main findings on screw connections were presented in [12], allow assessing the load bearing capacity of the mentioned joints and provide a basis for further research, regarding efficient hardwood connections.

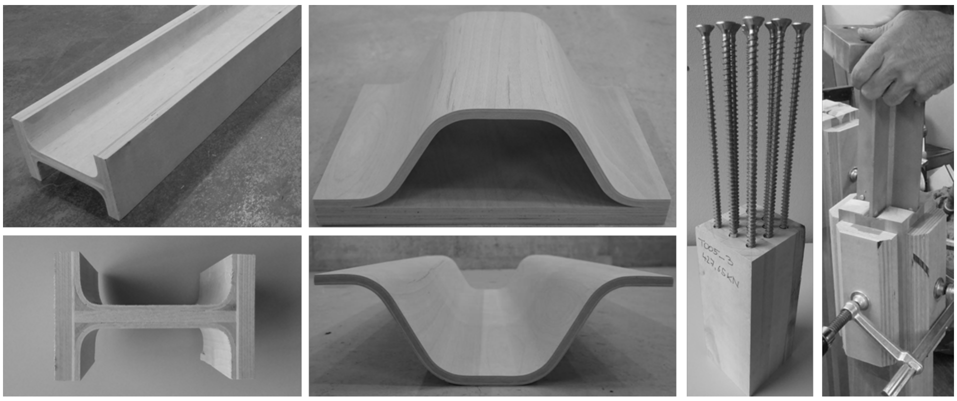

Fig. 1: (ii) hardwood products, (iii) hardwood connections

bmwfw FHP FORST HOLZ PAPIER DokInHOLZ

H5: Grundlagen für ein vorgefertigtes und integriertes Fassadensystem zur thermischen Sanierung an bestehenden Gebäuden mit variabler Geometrie

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Ko-Betreuer:	Anton KRALER (Uni Innsbruck) Wilfried Konrad BEIKIRCHER (Uni Innsbruck)	
Wirtschaftspartner:	proHolz Tirol Cadwork Informatik GmbH Schafferer Holzbau GmbH Freisinger Fensterbau GmbH	Harrer GmbH Saint Gobain Isover Austria GmbH Isocell GmbH

The refurbishment of the building stock is one of the most important challenges of sustainable urban development. Particularly the use of natural and local materials gets an increasing relevance, regarding the embodied energy. The focus of this work is the development of systematized high-precision precast timber framed elements and its fastening technology on existing buildings. A façade-system-connector is evolved, which can be adapted to variable building types and geometries. This mounting system ensures multifunctionality, short assembly time, simple utilisation, maximum in precision and absorbance of tolerances in all directions. Part 1 is fixed on the existing building by a concrete screw or adhesive anchors and part 2 is pre-mounted on the façade element. After assembling on site the connection between part 1 and 2 will be provided by a high-tension bolt and is able to transmit vertical and horizontal loads.

To reach low production costs the connector is made out of steel sheets, which are stamped, bent and welded and consists of standard components. At the moment the Dok'In Wood project partner Harrer GmbH is looking for a producer in order to conduct further investigations with a prototype.

In laboratory the mounting properties will be tested with a test façade. Also the load capacity and serviceability will be checked and compared to design models and FEM calculations.

Figure 1: Prefabricated test façade to simulate element joints with prefabricated external rendering

At present an extensive refurbishment program of districts is ongoing in Innsbruck and Bolzano in context of the Smart City project SINFONIA. The building promoter NHT (Neue Heimat Tirol) has decided to retrofit three residential buildings with prefabricated façade elements furthermore the IIG (Innsbrucker Immobiliengesellschaft) is convinced to use it for two retrofit operations. The department of timber engineering at the University of Innsbruck provides the technical support and scientific attendance. Currently timber construction companies have to prepare and submit an offer. Holzbau Schafferer (Dok'In Wood project partner) produced a first prototype façade, where construction details, as element joint solutions and the assembling procedure, can be tested and verified. It is planned to prefabricate the elements inclusive external rendering to avoid additional work on site and the need of scaffolding. Therefore special solutions have to be developed for the element joint to ensure that the requirements in regard to the fire safety guidelines for building class 5 are respected.

P1: Experimentelle Bestimmung und numerische Modellierung von Festigkeiten von Einzelfasern und Faser-Faser Bindungen in Papier

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The first half of the project was devoted to the deciphering of the microstructural interactions governing the mechanical properties (in particular elasticity and strength) of paper. Our scientific hypothesis is that this will allow us to eventually predict overall paper strength from the strength properties of pulp fibers and/or the bonds between them.

In order to cast the aforementioned microstructural interactions in a clear and efficient mathematical form needing only such input parameters which are directly accessible from experiments, we resorted to the theoretical framework of continuum micromechanics or random homogenization.

We resorted to micromechanical formulations based on infinitely many material phases oriented in all space directions, a concept which turned out as particularly successful and efficient for modeling the mechanical behavior of porous polycrystals made up of needle- or disc-shaped solid elements′.

As regards adaptation of these theoretical concept to the case of paper, the basic idea was to restrict the orientation directions from those possible in the three-dimensional Euclidean space, to those possible within a plane in such a space, namely the paper plane.

First model predictions compare well to experimental results.

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It is well known that the strength of paper mainly depends on two factors, the strength of individual fibres as well as the strength of fibre-to-fibre bonds (Page 1969). Another important factor that influences paper strength is the force per unit area also referred to as specific bond strength. To the present day, studies dealing with the determination of the mechanical properties of individual fibres and bonds only focused on softwood pulp. Despite their importance as papermaking fibres hardwood fibres and fibre-fibre bonds have not yet been in the focus of investigations resulting in a significant lack of understanding of these fibres basic properties. In the effort to obtain data for hardwood fibre-fibre bonds and hardwood fibres, further bond strength measurements using eucalypt kraft pulp fibre-fibre bonds have been performed with the micro bond tester (Fischer 2013) developed at the Institute of Paper, Pulp and Fibre Technology at Graz University of Technology. Figure 1 shows a comparison between the forces needed to break softwood bonds (Fischer 2013) and those of hardwood bonds (Jajcinovic et al. 2015).

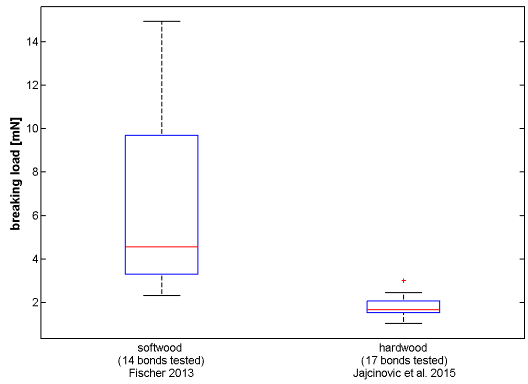

Figure 1. Breaking force of softwood and hardwood bonds

The mean breaking load of hardwood bonds is 1.82 mN (Jajcinovic et al. 2015) which is about 3.6 times lower than the one for softwood bonds (6.58 mN; Fischer 2013). In order to estimate the force per unit area, the optical bonded area (OBA) was determined using polarized light microscopy according to Kappel et al. (2010). The OBA for hardwood bonds (293.26 mm^2) is 81% lower compared to softwood bonds (1562.93 mm^2). The force per optical bonded area for softwood bonds is 3.10 N/mm^2 and for hardwood bonds 6.32 N/mm^2 (Jajcinovic et al. 2015).

Another important factor that has an influence on the formation of bonds is the bending stiffness, which is the reciprocal of the fibre flexibility. The bending stiffness values of unbleached softwood kraft pulp fibres measured using a method based on a beam fixed at both ends with a concentrated load at the center of the beam range from $8.45 \cdot 10^{-10}$ to $1.36 \cdot 10^{-9}$ Nm^2 (Fischer et al. 2014).

Fischer, W.J. (2013). A novel direct method for mechanical testing of individual fibers and fiber to fiber joints. PhD thesis, Institute of Paper, Pulp and Fiber Technology, Graz University of Technology, Graz, Austria.

Fischer, W. J., Lorbach, C., Jajcinovic, M., Hirn, U. and Bauer, W. (2014). Measured and calculated bending stiffness of individual fibers. Progress in Paper Physics Seminar, September 08-11, 2014, Raleigh, NC, USA.

Kappel, L. (2010). Development and Application of a method for fiber-fiber bond area measurement. PhD thesis, Institute of Paper, Pulp and Fiber Technology, Graz University of Technology, Graz, Austria

Page, D.H. (1969). A Theory for the Tensile Strength of Paper. Tappi Journal, 52(4):674-681

Jajcinovic, M., Fischer, W.J. and Bauer, W. (2015). Investigating the mechanical properties of individual hardwood fibres and fibre to fibre joints. In preparation for publication in Cellulose.

P2: Auflösung, Regeneration und Funktionalisierung lignocellulosischer Formkörper

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Ko-Betreuer:	Antje POTTHAST (BOKU) Markus BACHER (BOKU)
Wirtschaftspartner:	Lenzing AG

The starting materials studied in this PhD work are micro- and nanostructured celluloses, with a focus on Tencel® Gel, which is provided by the industrial partner, Lenzing AG.

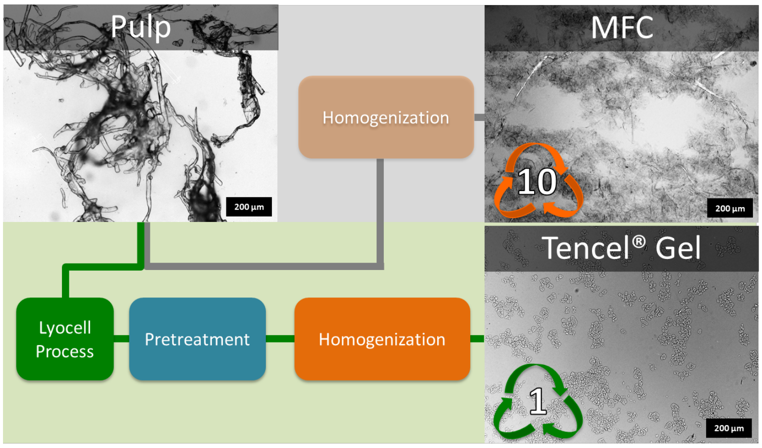

Figure 1: Production process of Tencel® Gel in comparison to microfibrillated cellulose from pulp. Tencel® Gel can be produced with much higher energy efficiency and special features such as a unique particle-like morphology.

Cellulose gels have lately been propelled into the focus of scientific and industrial research, and great potential in the development of advanced materials is expected from this kind of renewables. One example is microfibrillated cellulose (MFC) which is obtained by breaking down the lignocellulosic structure of pulp into cellulose fibrils, its production is therefore rather energy-intensive. In contrast to MFC which is obtained from native plant cellulose (cellulose I allomorph), Tencel® Gel is produced with higher energy-efficiency from a shaped cellulose II precursor (regenerated, i.e. dissolved and re-precipitated, cellulose). This gel possesses a particle-like, homogenous morphology and is composed of individual microparticles with a size of few microns featuring rheological behaviour of a soft solid.

The morphology of the cellulose particles was found to be very sensitive todrying. Special freeze-drying techniques have to be utilized to preserve the 3D-structure in the dry state. The crystallinity of the final product is similar to the pulp used as starting material, which distinguishes Tencel® Gel from micro- and nanocrystalline cellulose.

All in all, the studied gels feature some unique properties with respect to rheology and morphology compared to other nanocellulosic products. Due to the special morphology and high homogeneity of Tencel® Gel, possible applications are envisioned in the food, cosmetic, coating, and pharmaceutical industry.

P3: Alterung von Lignocellulosen – molekulare Mechanismen und Analytik

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Yellowing of paper, a process combined of several reaction types under the participation of polysaccharide components, lignin fractions, and other organic and inorganic additives, is of great interest in the context of the preservation of historic documents based on paper and of paper aging in general. The two major contributions for discoloration of cellulosic materials are i) residual lignin and ii) degradation products generated from carbohydrates. The latter can originate from Maillard-type browning reactions of soluble sugars on the surface. The resulting chromophores - which literally means "carrier of color" from Ancient Greek give the material a yellow tint.

The aim of the project is the development of novel analytical approaches to detect degradation products from lignocelluloses. The focus for the first project phase was placed on degradation products from cellulose and hemicellulose out of this browning reaction in historic papers applying DESI-MS (Desorption Electro Spray Ionization coupled with mass spectrometry) and Paper spray-MS as non-abrasive analytical tools. The sampling was done along a browning gradient that was found in the sample material shown in Figure 1a. The cumulative signal intensities aim the semi-quantitative detection of key-chromophores as shown in Figure 1b.

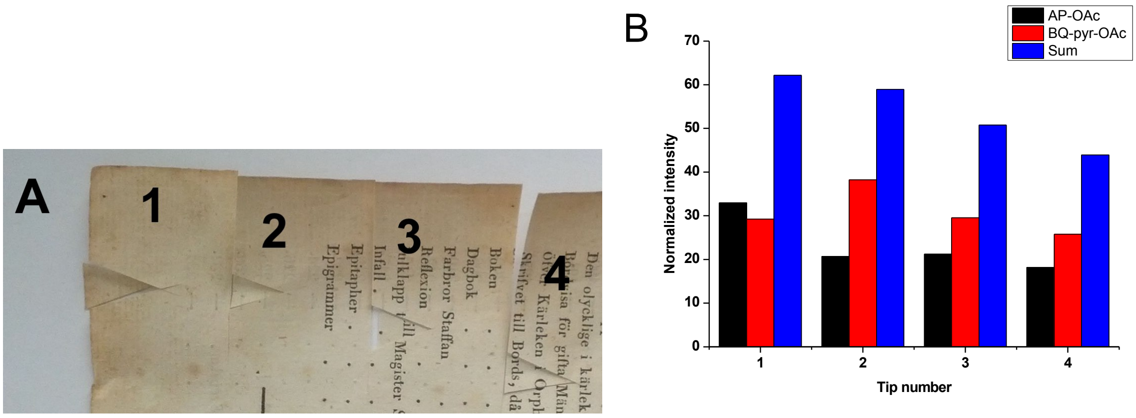

Fig. 1: Distribution of key chromophores along a browning gradient

At this point, so called key-chromophores could have been successfully detected on and from the paper surface in model samples as well as historic samples.

P4: Enzyme Refinery von Lignozellulose

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Ko-Betreuer:	Gibson Stephen NYANHONGO (TU Graz) Rupert WIMMER (BOKU)
Wirtschaftspartner:	ACIB GmbH – Austrian Centre of Industrial Biotechnology

In the production of pulp, lignin arises as a by-product in nearly the same amount than cellulose. This study therefore aims at assessing the potential of enzymes as effective biocatalysts for upgrading the by-product lignin and lignocellulose materials. Enzymes catalyze, in comparison to conventional processes, under mild conditions and selectively the conversion of small molecules up to complex polymers. Ultimately, in nature mainly fungal enzymes are responsible for the degradation of wood. Those enzymes can be used for refining valuable components out of lignocellulose or to impart to lignocellulose materials specified properties. In the past years, our working group and also others published several studies about the processing of lignocellulose with enzymes in international journals. These publications demonstrated that selective targeted enzymatic binding of functional molecules to lignocellulose creates materials with improved properties (e.g. antimicrobial, hydrophobic, etc.). Application of these enzymes also causes a crosslinking of fibers which, among others, economize the usage of binders in the production of fiberboards. Lately, besides the processing of lignocellulose with laccase, there was the finding that the properties of lignin on its own can be improved enzymatically to achieve, for example, a higher molecular weight. So far, the knowledge about specific coupling of functional groups to lignin with the help of enzymes has to be extended. Especially the strategy to improve lignin properties in an environmental friendly way could upgrade the applications of higher value lignins.

Therefore, this project aims at functionalizing the natural occurring heteropolymer lignin with the help of the enzyme laccase for various applications. First, lignin model substances were successfully coupled with laccase to the biopolymer chitosan, whereby also functional hydrogels were obtained. Chitosan is produced out of shrimps and other crustacean shells, so it is also a polymer that is a by-product in the food industry and has a wide variety for its usage. A hydrogel is a biomaterial that is able to absorb water and is used for example in wound treatment for biomedical applications. The ability of lignin model substances to form a hydrogel is a quite interesting technique that has not yet been reported. It is a green technology to create hydrogels without any crude oil based polymers or without any toxic cross-linkers like glutaraldehyde. Gelation time of the hydrogels, swelling properties, FTIR, coupling products has been charaterized. In addition, the release of methylene blue, which is used as an easy detectable model substance for drug release, has already been approved. One of the next steps, on which we are already working, is the purification of lignin from industry and also commercial available lignin to exchange the lignin model substances by the purified lignin fractions. Furthermore, a comparison study on functionalization of lignin model substances with chitosan by two different enzymes is already running. Due to these promising results we will further work on the functionalization of lignin model substances and we will exchange these model substances with purified lignin fractions in the next phase.