Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Daniel Lux
Student number	6037097

Studio		
Name / Theme	Building Technology Graduation Studio	
Main mentor	Dr. Michela Turrin	Design Informatics
Second mentor	Dr. Rebecca Hartwell	Structural Design
Argumentation of choice of the studio	The graduation topic presented by Michela Turrin before the start of the 6th quarter stood out due to its unique approach to developing a novel, wood-like material. Early in my master's program, during a visit to the LAMA Lab, I learned of a research initiative within the AE+T Department that utilizes lignin—a biopolymer so abundant in nature that it is found in every plant and functions as an adhesive in material production. The combination of lignin with cellulose in the creation of a new construction material offers the potential for properties such as biodegradability and full circularity, particularly when the materials are sourced from waste streams. Within architecture I have always been eager to address the challenges of the construction industries' impact on the global climate. Namely the production of energy intensive and non-renewable construction materials, especially cement, is fortifying this issue. The Building Technology Track at TU Delft has taught me many new skills including the implementation of computational methods in development of our projects, in Grasshopper and Python. The combination of this graduation topic, the making of a new sustainable construction material with computationally informed decisions, was compelling for me to dedicate myself to the project.	

Graduation project	
Title of the graduation project	Wood without Trees - Developing a computationally optimized and cellulose-based construction materials through the controlled repolymerization of lignin.
Goal	

Location:	Delft, Netherlands
The posed problem,	The construction industry is one of the largest contributors to global CO_2 emissions. Heavy reliance on energy-intensive materials like steel, concrete, and bricks are driving factors for that footprint (UNEP, 2024). The urgent need for more sustainable practices has fuelled the search for bio-based, renewable materials to reduce environmental impact. This research proposes using cellulose and lignin - two of the most abundant natural polymers on the planet - to develop a fully bio-based construction material with properties comparable to wood, without relying on traditional forestry practices – addressing the urgent need of the reduction of emissions in the construction sector This research project has been the topic of 3 preceding master theses in 2018, and 2022. The latest which resulted in the publication of a academic paper in 2023 and another one in 2024 have demonstrated different mixture types mainly for a cold extrusion process and small attempts for a hot press method. While the development of the mixture suited for a cold paste extrusion was focused on in both the 2023 and 2024 papers with promising results, the mixture that is used for manufacturing at high temperatures had unsuccessful results. The polymerisation of the lignin within this mixture was not mentioned. Lignin, however, is starting to gain much more acknowledgement in the previous years for its natural adhesive properties if processed with the right conditions. This characteristic implies that a mixture that harnesses the improved mechanical strengths can be devoid of any additional binder or adhesive – making the mixture simpler in its composition. When looking at adhesives used in traditional wood-based boards like MDF, plywood or laminated beams we often encounter formaldehyde containing resins (UF) or melamine resins (MF) or PMDI glue, all of which are of concern in terms of sustainability and recyclability of these wood products (Dunky, 2003). Circling back to lignin, it’s inherent "strength" to be a natural adhesive due to its superior bonding properties (Yang et al., 2023) is not effectively used, but shows big potential. Papers like Qin et al., 2023 however, demonstrate the structural capabilities when Lignin and Cellulose are cross-linked, and the lignin acts as a polyphenolic binder resulting in excellent flexural stability. Giving up on an additional binder opens the possibility of endlessly loosening and repolymerizing the lignin, enabling circular material use. Another field of concern that was found in the existing research is the process of the development of a new mixture, particularly

	the way of applying a mixture deemed to be suitable enough for application to a geometric case study. The traditional trial-and-error approaches of figuring out mixture concentrations, testing mechanical properties requires rigorous sampling and repetition. Lastly, when the material has gone through multiple improvement or experimental steps, and the timeframe of a research project comes to an end the application to a geometry is not able to receive enough attention. In the case of the two master theses from 2022, the outcomes included geometrically feasible designs and acceptable material behaviour. However, due to the lack of in-depth analysis of these case studies, the results remained limited to conceptual models rather than being validated as functional structural solutions. One of the key challenges in developing the cellulose-lignin mixtures lies in the managing of complex interactions between material properties, additives and production methods. By leveraging computational tools, it becomes possible to systematically explore a wide range of material compositions and their corresponding performance metrics. Such a tool can enable controlled variability, where first and foremost the mechanical material properties are optimized by adjusting parameters in a predictable way. Especially, the early integration of computational methods can also facilitate real-time feedback loops, allowing for the refinement of both the material mix and the production process during early development stages. This is followed by the exploration of design applications which can also benefit from this level of control over the three categories, composition, production and geometry. By incorporating computational frameworks into the material development workflow, the process can become more efficient, flexible and scalable, ultimately addressing the need for more holistic and sustainable workflows in the entirety of the chain of a material, from development to end-of-life.
research questions and	The focus of this research is to build upon the advancements made in the "Wood without Trees" research topic. Specifically, the aim is to develop a new material mixture suitable for a hot-pressing procedure that could ultimately be adapted for a hot extrusion process. While the insights and findings from previous theses within this topic are acknowledged and leveraged, they are treated as equally valuable as any other external publication reviewed during the literature study. This ensures that the current research remains distinct, original, and independently developed, integrating the existing body of knowledge without being constrained by it. With the implementation of a computational method to have a controlled variability within the experiments the results from

	these experiments should be directly contributing to the design of a functional structural member. Summarizing this context the following main research question arose: • How can an optimized mixture and a suitable hot-press production method be developed that uses by-product-lignin and -cellulose, to utilize lignin's natural binding properties through polymerization? Further Sub-research questions address the underlying fields of interest to be explored or problems to be investigated: • How can the early integration of computational software help with a more efficient and flexible material design? • What is the state of art in utilizing repolymerization of lignin in construction materials, as a natural adhesive in wood-like materials? • What are the limits of relying on solely cellulose and lignin as the main mixture's ingredients? • What additives are needed to improve the material quality in both appearance and mechanical performance? • How can the batch-based production and limited sample size of hot press processes be addressed? • How can the hot-pressing procedure be used to develop a hot extrusion process? • How can controlled variability in the material composition be achieved using a computational design tool? • What are the design implications that are specific to the production process and material composition?
design assignment in which these result.	The design assignment of this project and research proposal can be broken down into these two distinct focus fields: 1. Focus on the repolymerization of Lignin within a cellulose mixture. Harnessing lignin's natural adhesive qualities through hot-pressing 2. Influence of computational and analytical software on the material development and design process, through optimization, simulating and predicting of material behaviour Through the combination of these two fields the project aims to perform material tests that can ultimately be applied to the design of a structural member like a floor joist.

	The material tests are a way to explore and get a feel of the material properties and apply the methods found in the literature review phase. From this process it is to be expected that the review of more literature is required to continuously inform this process based on the current experiment results. This phase will not yet explore design variations but rather produce samples based on the geometric requirement of structural performance tests. Meanwhile the computational method must be developed. During the literature review phase the framework of this method is already predefined and the main goals are described. As the material development comes along, the design of this computational method will also be adjusted to accommodate the behaviour of the material. Once the material and fabrication method have had their initial testing and a material profile based on mixture ratios and mechanical properties can be created the computational tool is used to perform the first optimizations. The geometry input of a designed structural member and its environment will create certain constraints on the material mixture and structural design. The computational tool formulates the ratios of all mixture contents, the assembly pattern of the individually hot-pressed components and a structural analysis of the input geometry. Based on this virtual model of the design structural member. The accuracy of the model is tested by producing the prototype pieces and validating the structural behaviour through strength tests. The outcome of this design will then be the demonstration of a simulated member design and the validation of the new hot press production method and material mix through physical models.

Process

Method description

Following the described problem statements and research question, this research will divide into the steps below:

1. Theoretical Research Framework
2. **Literature Review** on Material Design and Computational Methods
3. **Material Experimentation** and **Tool Development**
4. Mechanical Testing and Creating of Material Profile
5. Data Integration into Computational Tool
6. Material Simulation
7. Validation of Simulation
8. Prototype Design

The highlighted parts of this workflow make up the core research aspects, and so will be further described:

Literature Review

The project begins with a literature review on the chemical information of cellulose and lignin, novel procedures of repolymerizing lignin, additive manufacturing techniques of cellulose-based materials at large, comparable wood-like materials and computational tools for modelling on the material scale and designing of experiments for multifactor testing. The information will be taken from sources like research papers, publications and conference papers, from different academic search platforms like Scopus and Google Scholar.

The literature that is reviewed is largely selected on the publication date, usually not earlier than 2022, as the valorisation of lignin in other ways than energy production is a very recent interest in the construction environment. Additionally, the sources selected are also limited to the fields Material Science, Environmental Science, and construction.

The literature review will first focus on explaining the chemical and biological fundamental information on lignocellulosic compounds.

Furthermore, looking at the availability of these materials will be part of literature research. Lignin as a raw material is available from multiple chemical extraction treatments. These treatments will be described and compared, based on functionality of the lignin and availability.

The state of the art of the (re)polymerization of lignin within wood-based and non-wood based lignocellulosic materials will also be reviewed. Besides wood derived cellulose, cellulose is also often available in the shape of natural fibrous cellulose or non-wood fibres. The investigation of these material sources will be relevant as it could provide superior flexural strength and be part of the review process. The last reviewed part in this segment are possible cellulose matrices that can be used in the hot-pressing process. This segment will be concluded and discussed based on the information researched.

This segment is followed by the investigation of comparative computational approaches used for modelling, designing and manufactural construction materials. Underlying frameworks within these approaches will be summarised and compared. So will be the utilized software for material modelling and predicting, to give exemplary cases that can inform the computational method of this research.

Material Development and Experiments

As a result, from the reviewed literature production methods that are in line with the project objectives are selected and combined to a new process. Each step will be based on a specific piece of literature that provides evidence of its functionality. This results in a workflow for the production where multiple sources are pieced together to come up with a new solution of a production methods that is specific to this design task.

Before the materials are tested for their mechanical properties the materials will be assessed on different criteria before and after the production. The literature review will also focus on the used methods of analysing the performance and behaviour of

the created materials, in order to make a informed decision about what procedures should be selected for this research.
The design of the mechanical testing is following standards from European norms and international standards. This includes the shape of test specimens for wood based or composite materials and conventionally tested strength properties for these material types. Another factor to determine the material properties that should be tested are the input values of the chosen modelling software. In Karamab3D inside Grasshopper the material module requires a set of properties of an isotropic material, namely Young's modulus, tensile strength, shear and compression strength.

The facilities used for the production, testing and general work are:

- Toi's LAMA Lab at the Faculty of Architecture; sample preparation and general research
- Composites Lab – DASML at the Faculty of Aerospace Engineering; Hot-pressing
- Bio Lab – DASML at the Faculty of Aerospace Engineering; Mixing and Pretreatment
- Microlab of CITG – 3MD at the Faculty of Civil Engineering & Geosciences; Facility for mechanical testing#
- Ecovillage; Hot-pressing

but have yet to be confirmed.

Computational Framework

Within the research through design approach at TU Delft, design exploration and material research are intertwined to create an iterative process of knowledge production and discovery. By developing and applying a design and optimisation tool during the material experimentation phase, immediate feedback loops are created that shape both the direction and depth of the research. This interaction not only refines the design outcomes but also deepens the understanding of the material's properties and potential applications.
The computational method will make use of multiple software for analysing, simulating and designing that have to be integrated into one another.
While the research objectives define what criteria the material should adhere to like the sustainability, the design objectives govern the process of how the materials is developed. At the start the process the design of experiments creates the first list of parameters that can influence the performance of the final product. However, before these parameters can be taken into account in the optimization, the parameters are tested based on the resulting materials strengths. Once the data of the initial material tests can produce a reliable material profile, these values can be fed into both structural modelling- and material modelling software.
Meanwhile, the design of a structural member gives the basic dimensioning, environmental constraints, and strength requirements to derive a preliminary structural shape. At this stage, the computational methods must interact. With the help of a multifactorial optimization tool, an optimal combination of all parameters is found – and if necessary, the tool makes adjustments to the parameters in the respective step. The way the parameters are adjusted is based on the requirements that are given by the structural member design. For example, if a beam is to be designed that has to carry a certain load, the tool tries to adjust multiple parameters

to satisfy the load requirements, and possible sizing constraints. Finally, the prototypes as the output of the optimization step are analysed and tested to validate or calibrate the tool.
In the research phase of this report computational methods of material design and program solutions are investigated to build up a suitable computational repertoire.

Literature and general practical references

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Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

In summary the proposed graduation topic focuses on the innovation of a new construction material. It merges multiple disciplines like structural and computational design, and also material science with the goal of creating an architectural component that can be a competitive alternative to the conventional catalogue of building materials and components.
Therefore, this research aligns seamlessly with the Building Technology track that encompasses a broad spectrum of architectural and engineering skills. The proposal demonstrates the design of an innovative and sustainable building component and provides ways past the initial development stage by providing a framework that can make use of the experimental results directly in the built environment.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

Social

While the possible application of this material is still to be determined, it is already possible to say that the material can benefit the construction industry and environment at large. The construction industry is in desperate need of sustainable, viable and quickly deployed building materials that can replace what we build with every day. The use of virgin materials should not possible in the near future according to the European plans for a circular economy, this also means considering the end-of-life scenario. This material can be a step in this direction with the use of only biobased waste materials as the feedstock.

At the example of traditional wood based particle boards which often use harmful chemicals for the binding of wood, this material can stand out by first relying only on materials from existing waste streams and then making use of such chemicals. Also in the finished building this will be beneficial as those chemicals are not at risk anymore of evaporating and affecting the indoor environment.

Professional
Within the master programme at the faculty of architecture this research holds relevance by being an attempt to provide a solution that will be publicly available to the whole of the students at TU Delft. Future graduates at this faculty, primarily, can either expand the work on the material design or focus on creative ways to implement such a new material in whole building designs.

Scientific
The graduation work also plays a key role for the scientific context. It challenges the traditional way of conducting experiments on new materials as usual with a trial-and-error method. The inclusion of a computational method that aims to inform the experiments directly and make implications on the mixture of the material, is something rarely seen in scientific literature, especially for the development of construction materials.