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	**CHRISTOPHER BIERACH**
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Telephone	
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Studio		
Name / Theme	Building Technology Graduation Studio / Computational Design	
Main mentor	Serdar Asut	Design Informatics
Second mentor	Ulrich Knaack	Façade Design
Consultant	Michela Turrin	Design Informatics
Partners	WUR, Saxion	
Argumentation of choice of the studio	I have always been fascinated by the geometrical freedom that 3D printing technology and computational design can offer to architecture. My past exploration on 3D printing architecture with clay has encouraged me to explore other materials, specifically sustainable ones such as wood. As a new state of the art technology and material, I wish to explore the potential of what can be achieved with wood waste and additive manufacturing to further help the housing crisis with a sustainable and innovative one. The choice of this studio will allow me to further master robotic fabrication and digital design to become better prepared for my future career.	

Graduation project	
Title of the graduation project	**Wood Without Trees** 3D printing a window frame with pure lignin and cellulose
Goal	
Location:	Delft, Netherlands

The posed problem,	**Overall Research Problem** Before getting into the topic of my graduation project, the context of additive manufacturing and biomaterials must be questioned and understood. As Cedric Price mentioned in 1966: “Technology is the answer, but what was the question?”. **Standard vs Customized** What is the use of advanced fabrication processes within the field of architecture? Does complexity come at a cost? Mollie Claypool explains that we went from mechanical matrices such as molds, casts, dies, or stamps to mass customization with either a subtractive or additive technology where cost is not an issue anymore [Claypool et al., 2019]. A great example is the design and construction of the glory façade for the Sagrada Familia. Mark Burry who is the Senior Architect to the Sagrada Famílìa Basilica Foundation since 1979, was able to complete the façade from surviving fragments of drawings by using parametric software to make ‘fast and accurate changes’ [Craswell, 2018]. Digital design and 3D parametric modeling software’s have been able to unravel the complex geometries of Gaudi’s work to be understood, archived, and allow construction to continue at a significantly accelerated pace [Burry, 2011]. Also, the sequential roof from Fabio Gramazio and Matthias Kohler at ETH, Zurich has shown how to assemble a freeform wooden roof in a layering process where every piece is irregular and would cost the same as a regular one. They have proven that the correlation between form and cost has changed today thanks to parametric tools. Finally, the Institute for Advanced Architecture of Catalonia has researched since 2001 that 3D printing permits us to customize our built environment, build faster, cheaper, and sustainably [IAAC, 2019]. As we are now aware that 3D printing offers a certain degree of freedom to design at a low cost, we must ask ourselves how 3D printing technology can be sustainable

	and circular? Can we 3D print with biomaterials such as cellulose and Lignin? **Sustainability & Circularity** With a rising population that is expected to reach 10 billion people by 2050 (United Nations 2015), global warming, and resource depletion, the built environment has the responsibility to act quickly as it is a major contributor towards global man-made greenhouse gas emissions (Pablo Van der Lugt, 2020). One of the many different ways to achieve zero net-carbon emissions at a global scale by 2050, is to use low-carbon materials such as wood. Naturals (hardwood, softwood, bamboo) are estimated to be one of the last supplies available in the coming up century (Pablo Van der Lutgt, 2020). Wood can be managed and used abundantly by replanting its trees. We could argue that wood deserves the grade “sustainable” more than other materials (Markus Hudert, Sven Pfeiffer, 2019). However, we can also add value to the way wood is harvested by utilizing its waste. In Europe itself, we disregard 25 million tonnes of wood annually (Storaenso, 2020). More specifically, forestry and agricultural waste in the Netherlands include relevant quantities of lignin and cellulose. Waste and bio-based materials have the great potential to be used and reused in the building industry. A great example is the exploded view beyond building, exposed at the Dutch Design week in 2021 [Leboucq, 2021]. Within all organic materials, Cellulose and lignin are one the most abundant organic polymers on earth [Chiujdea et al., 2020]. These biocomposites can be renewable alternatives to petrochemical-based products [Opedal et al., 2019]. Today, we have the possibility to use alternative products that are environmentally friendly materials and avoid using polluting ones such as insulating foam. Designers of the built environment can think of replacing mundane elements that are massively used with sustainable ones.

	A great tool to exploit the potential of waste materials into an artifact is 3D printing technology. Cellulose and Lignin itself have been 3D printed either in combination with bioplastics or more interestingly, pure [Liebrand, 2018]. The application of 3D printing biomass components is a hot topic today and is widely used [Zhang et al., 2020]. 3D printing with pure lignin and cellulose was made possible thanks to the research made by Thomas Liebrand in 2018 at TU Delft. As the material recipe is only using feedstocks, there is the possibility to produce wood without having to cut trees and reuse its waste to be further re-printed. In a circular approach, the recipe of Thomas can be recycled to easily replace components that become deficient. Thus, it would be interesting to see if his material recipe can be 3D printed to design elements for the building industry. Therefore, after the research done by Thomas Liebrand, this graduation project aims at continuing his research by combining pure lignin and cellulose via 3D printing as a feedstock to develop an element for the building construction market. at a larger scale, my graduation project aims to transform and vision an architecture of customization and curvatures at a low cost, produced sustainably and efficiently. More specifically, I will take a window frame as a case study to see if it can be 3D printed if it has the potential to be optimized for higher performances, and can be certified to enter the construction market. **Main Problem Statement** We must ask ourselves, why 3D print window frames? How and what will the design of the window frame be driven by? **Design Application** Openings in architecture have shown throughout history that their geometry is required to be measurable and understood by constructors in order to be properly built. Openings can bring many possibilities that can get away from the standard, traditional openings and expand its geometrical capabilities by using additive manufacturing.

	A great example is the research conducted by IAAC. Their students were able to 3D print with clay a range of openings to be printed without any support in a constant paste to accelerate the printing process [Chiou et al., 2020]. Another great example is the reconstruction of Notre-Dame-De Paris. After the catastrophic fire that destroyed the cathedral in 2019, the French president stated that the reconstruction of the cathedral will only take five years. However, as the renovations require specialized craftsmanship such as stone cutters or woodworkers, one Chinese company called Omni-CNC showed the potential of stone and wood carving with CNC machinery and waterjet cutting to speed up the process while being precise [omnicnc, 2019]. Therefore, CNC milling technology would allow to easily build complex window frames for gothic cathedrals. Another great possibility is to 3D print window frames for 3D printing houses. After interviewing Marijn Bruurs from Witteveen+Bos, he has elaborated his interest in my graduation topic. He explained that the interface between the window frames and 3D printed concrete buildings are still traditional with straight openings such as the 3D printing homes in Eindhoven built-in 2019. The complexity of a window frame can be utilized to offer a larger spectrum to design custom habitats. Another example is the Tecla house design by Mario Cucinella Architects and the WASP team in Massa Lombarda in 2021. They have proven that 3D printing a double dome with clay was possible thanks to customized highly efficient frames which were engineered and produced by Capofferi [WASP, 2021]. Therefore, 3D Printing a window frame can offer another typology of its own and possibly allow to restore any defective pieces for churches, push forward the capabilities to 3D print habitats and optimize its performances. My research will conduct a bottom-up approach, meaning from a nanoscale of cellulose & lignin-based material to reassemble its structure to form a window frame with additive manufacturing. Thus, the design of the

	window frame is already limited by the use of additive manufacturing and its material recipe. After conducting some tests and experiments, their results will help and guide the design of a window frame by understanding the limitations and advantages of 3D printing with wood.
research questions and	As explained previously, Thomas Liebrand who is an alumni student from TU Delft was able to extrude the recipe of cellulose and lignin without any additional plastics in 2018. From there, my partner Alexsander Coelho and I will take over the research to see the potential and limitations of Thomas's recipe to produce a 3D printed element to later enter the construction market. In the "Method Description", the individual and group tasks will be explained. As I will be researching on a window frame and Alexsander on a structural node, we will both conduct different individual tests to avoid repetitive tasks and achieve a design by the end of the master thesis. **Thus, the main research question:** **What are the potentials and limitations of 3D printing with cellulose and lignin to design and produce a window frame?** Different methods will be applied over the entire process of this research paper. The list of methods and phases explained in the "Methods description" will answer these **sub questions**. **Contextual framework (background)** - Why are we looking into AM and wood waste? - How can it be used sustainably & circularly? - What is the state-of-the-art technology with wood waste? **Design Evaluation** - What are the constraints that need to be considered? (process fabrication, scale of print, access to machinery in University, material mixture) - Which printing process between FDM or LDM is better for 3D printing with cellulose and lignin?

	- Which tests are necessary to evaluate a window frame? - How can we improve the material recipe made from Thomas Liebrand? **Design Integration** - Can we 3D print a window frame? - Can we replace and/or enhance the performance of a window frame with additive manufacturing? - Which limitations will influence the shape of the window frame?
design assignment in which these results.	Once the tests and evaluations are conducted, the boundary conditions of the recipe when printed will allow to frame the final shape of the design. Therefore, after P3, the printed shape will be established by the limitations of our findings within a 6 months' timeframe. The design objective of this research would be to 3D print window frames which can serve multiple building types from standard to custom-made.

Method description

As the design is a fundamental part of the research, creating new insights, knowledge, and product on robotic printing with biomaterials and a discourse that is practical and theoretical written to be accessible and validated by experts, my research strategy is: **Research by Design**.

Phase 1: Literature Reading, Review & Interviews (theory) will find and identify the answers to the sub-questions in the '**contextual background '**

The paper that I will be conducting, gathers literature papers, interviews, and visits to obtain enough information on 3D printing with wood (**Material, Fabrication, Application**). Each category is investigated to conduct a research & design plan to further establish scientific experiments. The literature sources were organized by establishing keywords in response to the research question and sub-questions. First in relation to the material: "wood", "lignin", "cellulose", "wood fiber" and secondly to the printing technology: "3D printing", Additive manufacturing", "wood filament". Finally, the Universities which are experts in robotic fabrication and digital design were also taken into account in the research: "Stuttgart ICD", "IAAC", "UCL", "TU Delft", "ETH". The literature sources were consulted in reviewed journals and in the TU Delft repository. The further exploration of these keywords was then used in Scopus for relevant and accurate articles, books, and academic researches. Among all findings, only relevant papers with a large number of equivalent keywords were selected. Also, the year of publication and amount of people who cited the publication was taken into account. As an efficient working station, the organization of my findings was first organized with an application called “liquid text” to easily find and review them. Then they were organized according to three topics: Material, fabrication, application, and further re-organized after proofreading each paper.

Phase 2: Literature Survey (writing) will explain and answer the sub-questions in the ‘**contextual background’**

Once the literature reading, literature review, and interviews are gathered, the literature survey can be written by answering my research question and sub-questions. A descriptive research is identified (why, how, what) to finalize my report for P2.

Phase 3: Design and experiments (practice) will explain and answer the sub-questions in the ‘**Design Evaluation”**

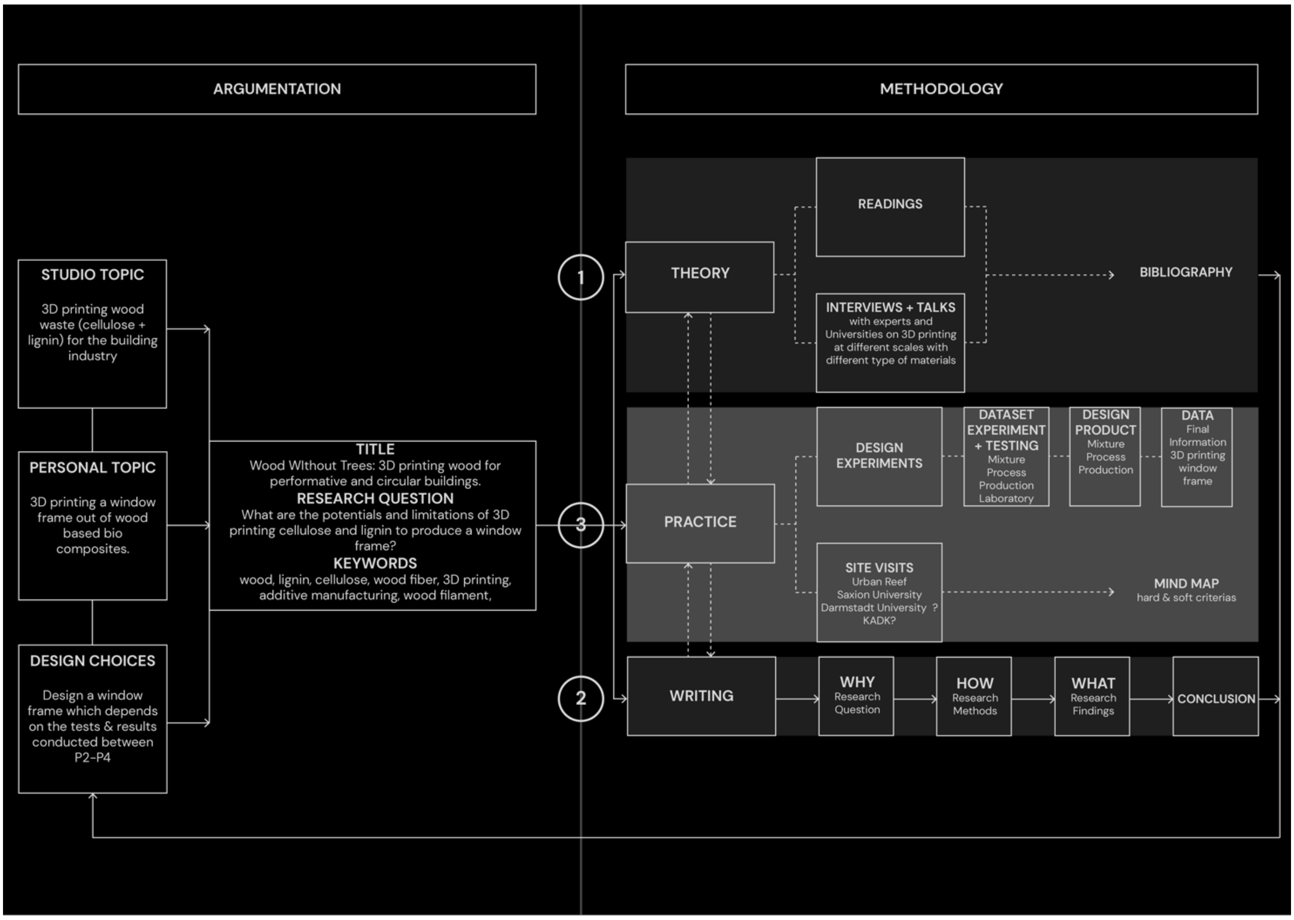
After P2, as explained in the research question: my partner Alexsander Coelho and I will be working together on multiple **experimental, exploratory designs**. In order to quickly find the limitations and potentials of our thesis, we will both conduct different experiments to validate the design of our final product. As Alexsander will be researching on a structural node and I will be researching on a window frame, our tests will have a different focus. We will decompose the complexity of this research into specific features to be analyzed. Alexsander will be researching the structural properties of Thomas’s recipe and I will be looking into the water absorption and resistance. Although these tasks are individual, we will both work within the boundary conditions of the behavior of the material, quality of the print, and geometrical influences.

As a Subtractive approach, we will first explore how we can improve the recipe done by Thomas Liebrand by testing, evaluating and validating the material mixture for an FDM or LDM process at home. Once the material mixture and printing process are valid with an educated guess, more experiments will be conducted at the LAMA lab at the University and tested in the 3ME laboratory with Fred Veer (to be confirmed) to gather a dataset of the mechanical properties of our 3D printed samples. The specimens will be 8X1X1 CM in batches of 3.

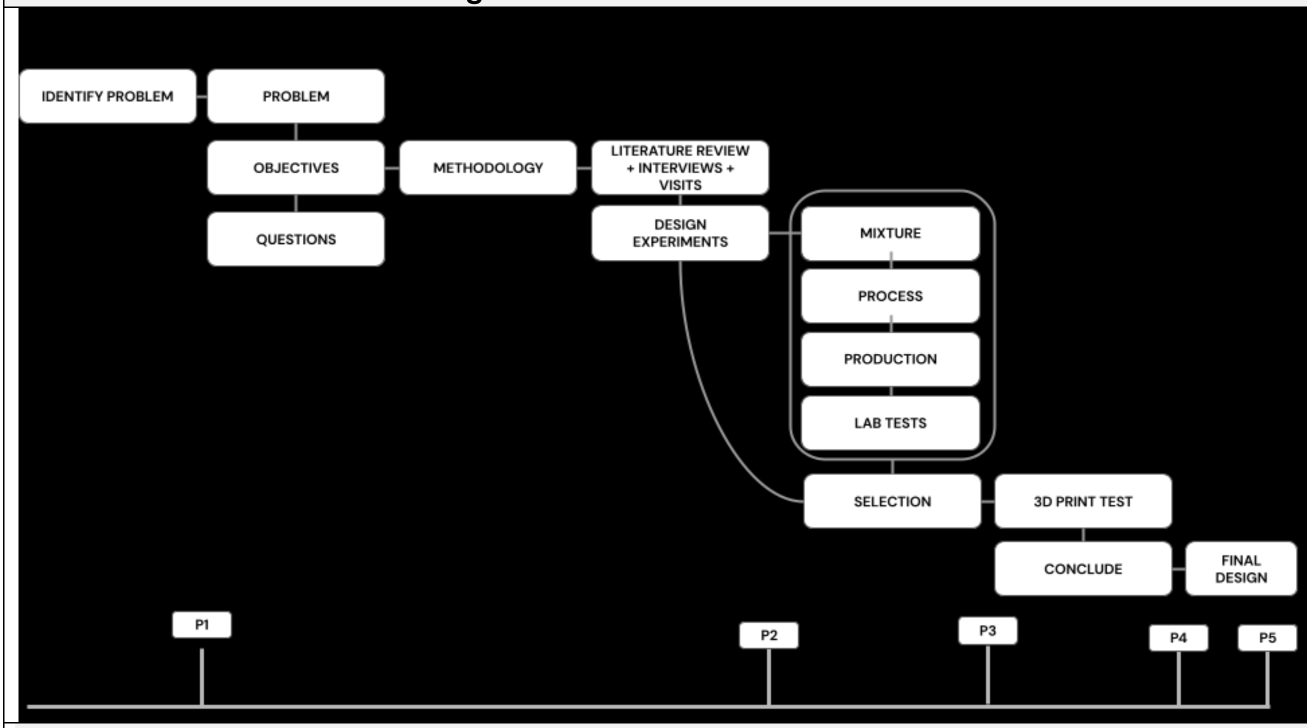
Phase 4: Prototype & Production (practice) will explain and answer the sub-questions in the ‘**Design Integration”**

After quickly validating our findings, we will be able to understand the limitations and potentials of 3D printing our material recipe to guide the design of the window frame and structural node. The final prototype is established individually.

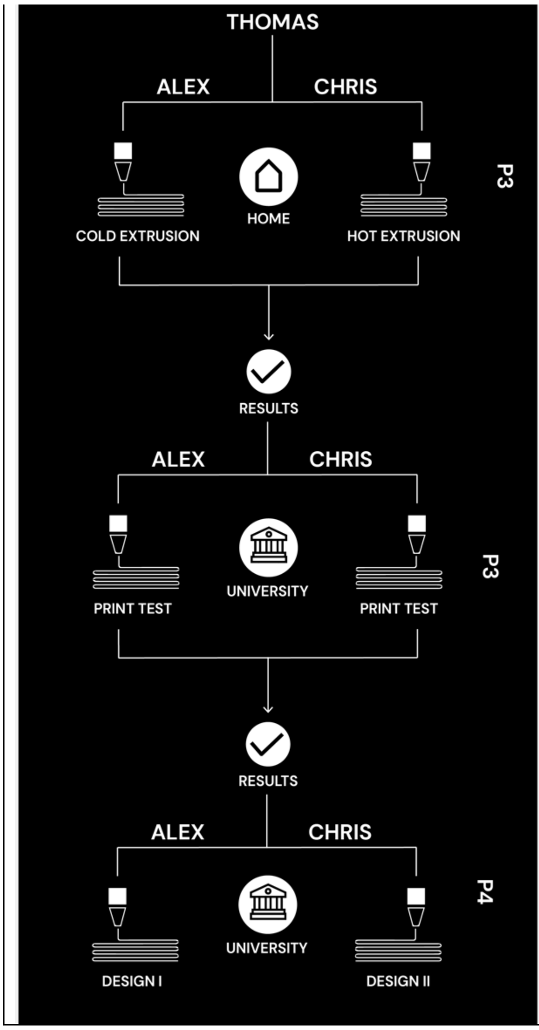
All these **Phases** englobe the methodology of **co-design** or interdisciplinary as Achim Menges describes [Bhattacherjee, 2019]. It is the ability to use digital technologies in order to rethink the materiality of buildings, the construction systems, fabrication processes, and design methods at the same time and in feedback with each other.



Research Framework Planning



Overall Workflow & Division of Tasks



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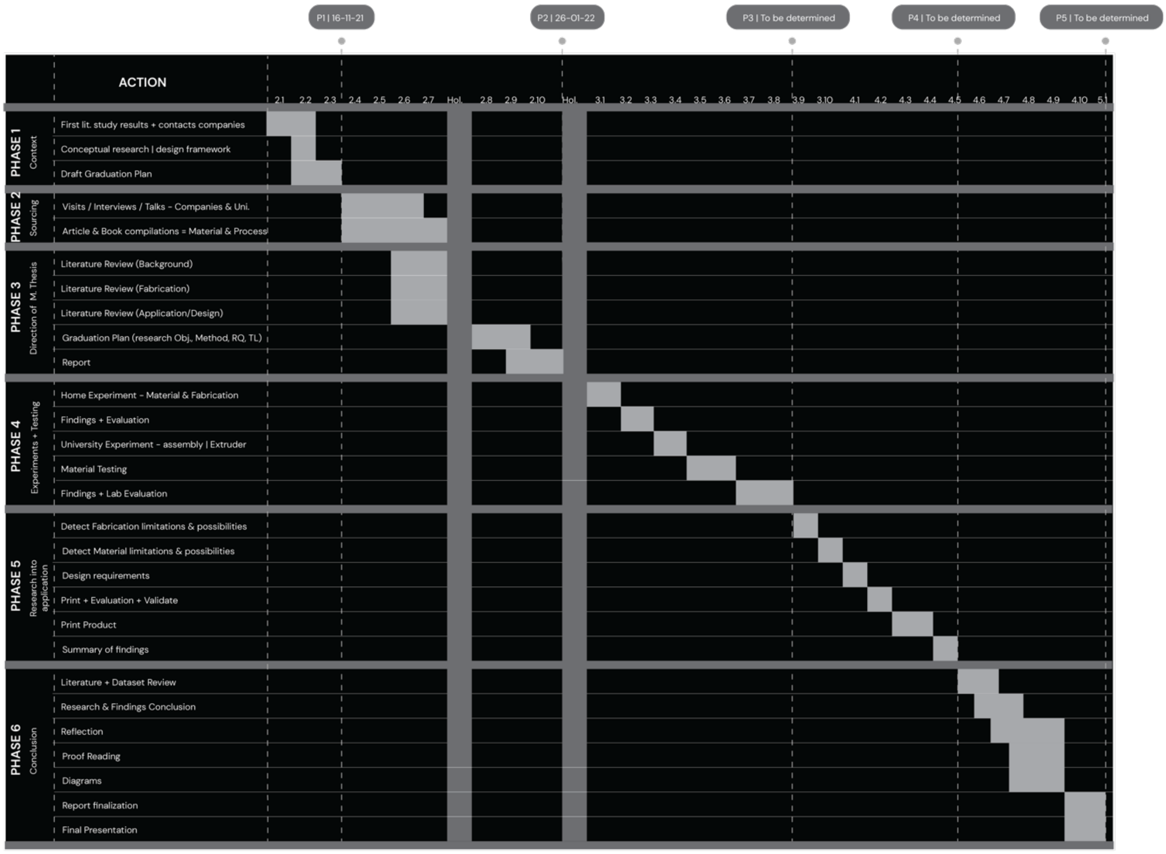
Reflection

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)?

With my strong interest in digital fabrication, while using raw materials to find new ways of sustainable, affordable, and durable construction methods, I wish to inject new design solutions to answer the current needs and challenges of our environment. In a time of environmental distress, architects have a responsibility to act with innovative ideas and solutions to be handed to our next generations for a better future. For this reason, I believe that my graduation topic on 3D printing wood waste marries the relationship between my graduation topic, master track, and master program.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework. Scientific Relevance The objective of this research is to understand the feasibility of whether this material recipe can enter the construction market. Through the development of different tests and experiments of a window frame and structural node, a dataset of our findings will be given to allow future researchers to explore in-depth the potential of 3D printing with the wood waste within the building industry. If the material paste is determined valid, the production of its recipe can change positively our built environment. Social Relevance As explained in the posed problem, all sectors have to work towards net-zero carbon emissions. From replacing or enhancing existing elements in the building industry to 3D printing homes with wood, we would come closer to becoming a green economy with the freedom to customize our built environment.
Timeline
• P2-P3: postpone choice of design depending on the results (limits of the material and print). • P3-P4: prototype the final product • P4-P5: Conclusions • Consideration: Check the equipment required for tests, equipment's availability at the University (lama lab) and specialized experts such as Fred Veer to access and test the material in a laboratory. The material (cellulose and lignin) is already offered by the University of Wageningen.



P1 | 16-11-21
P2 | 26-01-22
P3 | To be determined
P4 | To be determined
P5 | To be determined
ACTION
2.1 2.2 2.3 2.4 2.5 2.6 2.7 Hol. 2.8 2.9 2.10 Hol. 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 3.10 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10 5.1
PHASE 1
Context
First lit. study results + contacts companies
Conceptual research | design framework
Draft Graduation Plan
PHASE 2
Sourcing
Visits / Interviews / Talks - Companies & Uni.
Article & Book compilations = Material & Process
PHASE 3
Direction of M. Thesis
Literature Review (Background)
Literature Review (Fabrication)
Literature Review (Application/Design)
Graduation Plan (research Obj., Method, RQ, TL)
Report
PHASE 4
Experiments + Testing
Home Experiment - Material & Fabrication
Findings + Evaluation
University Experiment - assembly | Extruder
Material Testing
Findings + Lab Evaluation
PHASE 5
Research into application
Detect Fabrication limitations & possibilities
Detect Material limitations & possibilities
Design requirements
Print + Evaluation + Validate
Print Product
Summary of findings
PHASE 6
Conclusion
Literature + Dataset Review
Research & Findings Conclusion
Reflection
Proof Reading
Diagrams
Report finalization
Final Presentation