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	**Daan Weerdesteijn**
Student number	5699061

Studio		
Name / Theme	Discrete Timber	
Main mentor	Stijn Brancart	Structural Design (SD)
Second mentor	Hans Hoogenboom	Design Informatics (DI)
Argumentation of choice of the studio	As a designer, my interests lie mainly in the area of structures and optimization. I therefore took the corresponding courses during the master's program and also worked a lot on mechanics and construction during my bachelor. Within structural design, I often lean towards the material wood. Timber structures have always fascinated me and during my bachelor, I wrote my thesis on the use of timber as a construction material in high-rise buildings. So when I saw the topics about wood passing by, I was immediately excited. After some hesitation, I was greatly inspired by previous work at the SDU on reversible timber discrete systems as this gives a good balance between design, structural analysis and computational optimization, so I was eager to continue this research. This subject suits my ambitions as a structural designer to design efficient, sustainable structures that can take sustainable architecture to a new level. With this, I hope one day to be able to help the construction industry achieve climate goals.	

Graduation project	
Title of the graduation project	Stock discretized structural timber elements. A structural evaluation of computational optimized generative large timber load-bearing elements discretized by available stockpiles.
Goal	
Location:	Delft, The Netherlands
The posed problem,	Timber is becoming a more predominant building material to help reduce emissions in the construction sector. Building with timber helps in cutting carbon due to its positive ecological footprint. However to become fully circular and reduce emission even further it is important to also look at the embodied carbon of a building and in this case timber. Sadly, despite its potential to contribute greatly to a more sustainable industry, the circular loop of timber is still mainly focused on recycling/ down-cycling instead

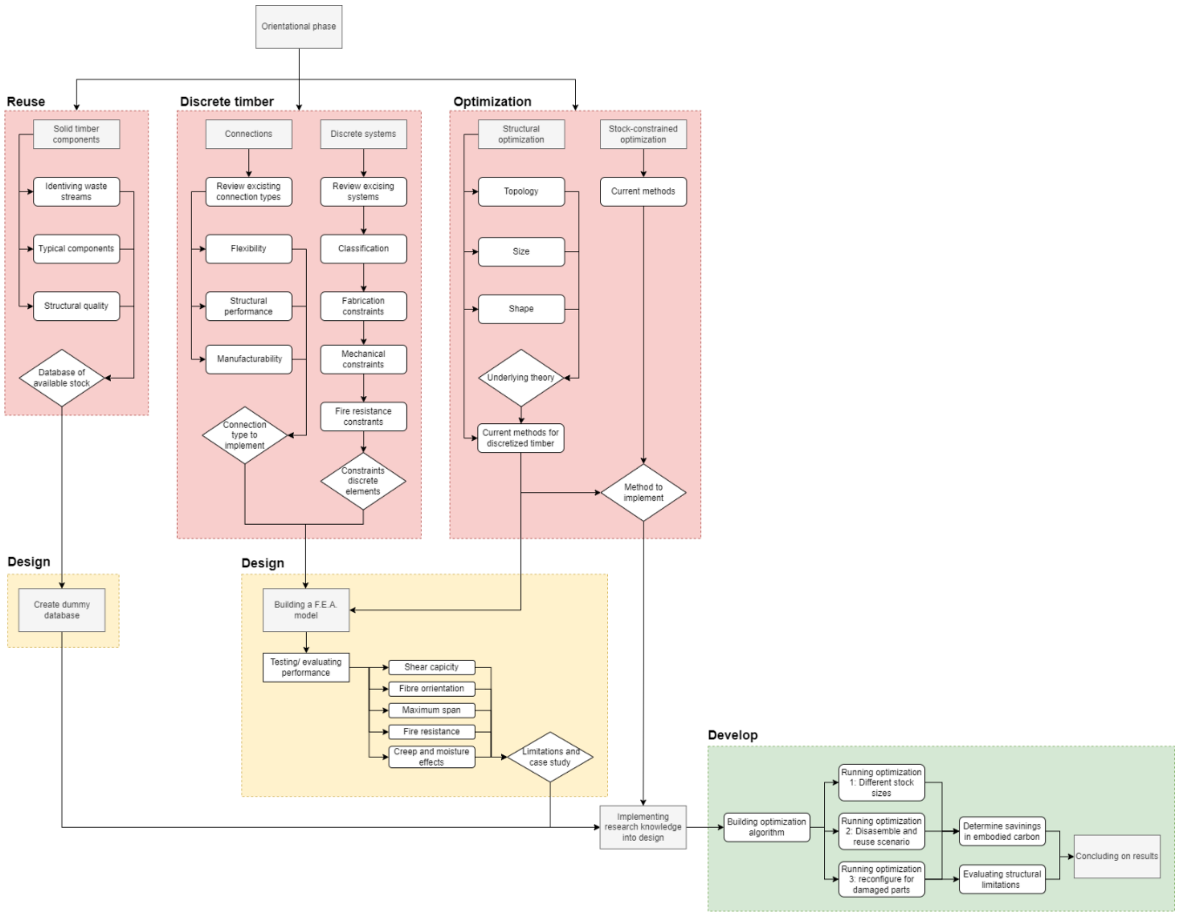
	of reusing resulting in a high embodied carbon. A lot of waste wood is shredded and used as fuel for bio-energy or for the production of engineered timber boards while these solid pieces have great potential for direct reuse. Timber is not a finite material but the forests are no infinite source either. It takes a long time to grow to harvest a tree so it is not considered environmental responsible to throw out used timber. In the Netherlands alone around 1740 kiloton waste wood is collected each year. 23% consists of solid non-glued or treated reusable timber. Translating roughly to 400kton of reusable wood that is now being discarded. Direct reuse of timber is often not considered or difficult for a number of reasons. Left over pieces often have different lengths and cross-sections, what makes it hard to directly reuse the pieces in a new design. Furthermore, the structural capacity of these scrap pieces is often uncertain and sorting and organizing a stockpile of timber is costly an without demand. The reuse of components therefore requires a shift in the current design method. Instead of designing for manufacturing there needs to be designed with what already is manufactured. Here discrete timber systems can start playing an important role in the construction sector. Besides the potential positive contribution to a more sustainable end-of-life cycle of timber, a discrete system also can help in achieving a material efficient yet flexible structural system. Topology optimization is employed to reduce self-weight and material usage. A technique which optimizes an element by removing parts where forces are negligible or small (Holmberg et al., 2013). This results in light weight constructions with low embodied carbon. A sustainable way of designing, however by optimizing on one scenario the element has no excess capacity left to accommodate future changes in function or loads. Discrete systems have the possibility to be designed in a way that damaged parts can be removed or new parts can be added. The structural element can therefore profit from both future flexibility while being optimized to the current scenario. Discrete timber can help in giving waste wood a new life so that a fully circular economy and net zero carbon emissions can be reached by 2050.
research questions and	Based on the above stated problem concerning the embodied carbon of timber and still unknown limitations of discrete structural elements a research question is formulated as: • How can an efficient, agile and transformable discrete structural system be created while being constrained by using salvaged timber components in order to reduce construction waste?

	The following question are the sub-questions that will help to answer the main research question and are formulated as: • How can the discrete system accommodate future adaptations and requirements? • What are the structural limitations and recommended dimensions for such a system? • How can a workflow be created so that the system can be implemented effectively in practise? • What is the environmental impact in comparison to a traditional system?
design assignment in which these result.	This research aims to get a better understanding in the structural behaviour of discrete timber systems. By scanning timber pieces a database can be created which can be linked to a design. Such a database removes one of the obstacles which now withhold design with salvaged timber pieces. With this data base a computational tool will be developed which generates a structure from waste wood. This will be a proof of concept for construction sector and hopefully will spark new idea's for implementing this new design strategy. The proof of concept also makes this way of design more accessible for designers. Hereby this study paves the way in making the life cycle of timber more circular, and therefore also helps reducing the carbon emissions emitted from the construction sector. The design assignment is formulated as: • To design a generative reconfigurable structural member out of available waste wood which can support a more efficient, agile and transformable form of architecture without the limiting spatial flexibility and adaptation.

Process

Method description

The study is divided into three phases. First a literature review in which general information will be gathered on three topics: Reuse, discrete timber and optimization. The results of this review will define the boundaries and constraints for the next phase, the design phase. In this phase the acquired knowledge will be combined to design the parts and joints of the system and create a computational FEA model that can indicate structural performance. In the development phase the computational model will be extended with more detail to start the matching process and project a stock on the element. Than different scenarios can be tested, evaluated and the impact calculated. With these results a recommendation can be made on the feasibility of a reclaimed structural discrete timber system in practice. A global overview with research topics can be seen in the scheme below.



In the "reuse" domain current literature will be consulted to provide a clear overview of the waste wood problem in The Netherlands. What kind of waste streams can be identified for possible direct reuse purposes and what dimensions and structural properties can these components compose of? The results of this literature study will output a database of available stock. In the "optimization" domain a general study to different optimization methods and available algorithms will conclude the most suitable workflow and programs for the matching problem. The last domain of the literature review "discrete timber" will concern the design of the structural element. In this part already exciting discrete structures will be compared and evaluated so that gaps in knowledge can be identified or exciting solutions can be implemented. Different aspects will be evaluated like fire resistance, mechanical properties, fabrication and dimensional limitations. But, also the ideology of discrete design will be highlighted.

The next phase "design" will use the results of the literature review as guiding principal in the design process. First the geometry of the parts and the joints is designed by the research through design concept. Than the first analyses will be and a simple working structural model that can generate an optimized geometry is sought after. With this model the first evaluations of the structural systems can be made and maximum spans and other limitations can be investigated. Furthermore, the influence of the fibre directions inside the system can be evaluated. With new information the design can be revised and the final detailed model can be created. In the last phase "development" a matching algorithm will be developed to assign available stock to the optimised geometry. Difference in structural performance will be analysed in different scenarios. Three scenarios will be created in this phase for comparison purposes in embodied carbon and structural performance. One scenario will simulate a case study like a portal frame with different types of stock. Another scenario will simulate a reconfiguration if the function would change. The last scenario will simulate what has to happen if a damaged part has to be replaced. These results will conclude the research and answer the main research question.

Literature and general practical references

The review of the waste wood market in the Netherlands will be derived from (Bruggen & Zwaag, 2017) and previous theses from Eijk (2021) and Mantje (2023).

For the discrete timber review information about the properties will mainly be derived from (Munck et al., 2011). This is a design guide form timber constructions based on the Eurocodes but encompasses also a wide variety of theory on wood as a material. Sanches (2020) is mainly used to get a grip on the design ideology of discrete systems. Xiao et al. (2020) is consulted for discretization methods. For discrete systems the previous work form the SDU are the leading sources explicitly (Kunic, Naboni, et al., 2021) and (Kunic & Naboni, 2023a) are very useful. For the connection technology the thesis of Paula (2023) and the research of (S. G. Hansen et al., 2021) and (J. L. Hansen et al., 2023) are consulted.

Tam & Mueller (2015), Li & Chen (2010) and Kumar (2016) are used to compare optimization methods. For the review on matching problems for optimization information is derived from (Tomczak et al., 2023), (Parigi, 2021), (Huang et al., 2021), (Brütting et al., 2021) and the thesis of Heine (2023). Information on formulation of algorithms and general optimization problems are derived from (Kochenderfer & Wheeler, 2019).

A detailed list of all references can be found in the reference list of the P2 report. The quoted sources above mentioned are listed below.

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Munck, E. D., de, Ravenhorst, G. J. P., & Jorssen, A. J. M. (2011). *HTO Dictaat Houtconstructies*. Centrum Hout Almere.

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Tam, K. M., & Mueller, C. (2015). Stress line generation for structurally performative architectural design. *Other repository*. https://dspace.mit.edu/handle/1721.1/125063

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Reflection

The building technology track is focused on teaching students to become sustainable designers. Especially an designer that can bridge the gap between the architect and the engineers. As a sustainable designer one has to be aware of the latest innovations and how to integrate this into an architectural design.

This thesis project embodies sustainability in the built environment by finding a new purpose for waste wood and turning it into a structural system. A structural system that embodies architectural engineering and cutting edge technology. This proof of concept will show a new possible way of sustainable design, design with what is already available, for architects and can improve the architectural value and flexibility of load-bearing structures to the quote 'form follows force'. The thesis topic thus fits perfectly between the engineering and architectural field and tries to improve existing systems to reduce carbon emissions and material consumption.

By addressing the waste wood problem a more circular loop can be created with discrete timber systems, reducing material waste and carbon emissions. Therefore contributing to a sustainable alternative for constructions.