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	Raymen Borst
Student number	5079810

Studio		
Name / Theme	Hygromorphic Timber	
Main mentor	Stijn Brancart	Assistant professor of structural design at the department of Architectural Engineering & Technology
Second mentor	Gilbert Koskamp	Researcher, Engineer and Architect for façade & product design at the department of Architectural Engineering & Technology
Argumentation of choice of the studio	The argumentation for choosing the Hygromorphic timber graduation topic is a fascination for timber structural elements. This interest started in the bachelor and has always been there since. Making models and working with timber is something I wanted to combine with my graduation thesis, therefore the link with product design is made. Understanding the characteristics of timber and experimenting with it in a laboratory to ultimately create a new structural manufacturing method is my goal.	

Graduation project	
Title of the graduation project	Passive curving method for multi-layered structural timber elements.

Goal	
Location:	Delft, the Netherlands
The posed problem,	The construction sector significantly contributes to total global emissions, with an estimated impact of approximately 5.7 billion tons of CO_2, representing a range between 23% and 30% of the annual global emissions, as indicated by Huang et al. (2018) and Zhang et al. (2019). The 5.7 billion tons of CO_2 is linked to the life cycle energy and consist of two factors; The operational energy which is used for the occupation of the building and the embodied energy, used for construction, renovation and maintenance.

	As the global human populations continues to expand, there is a corresponding demand for increased build environment. In the absence of changes to the current construction methodology, the global carbon footprint of the building sector is set to escalate. In times of potential human induced global warming effects, this continues process of current building methods is ethically questionable. Architectural issue Complex building forms become more conventional in current times. From external steel diagrid structures to internal 3d printed columns, the architectural design is evolving in complexity (Willmann et al., 2016). This evolution happens rapidly, and the material adaptation needs to develop just as fast. Architecture is progressing towards complex and modern geometries; however, the conventional building materials and construction methods fail to make a positively contribution to this transformation. Material issue To address the rising carbon footprint in the built environment, the choice to persist with materials that emit carbon rather than adopting carbon-neutral alternatives raises questions. Human engineered materials like steel and concrete contribute significantly to high concentrations of CO_2, NO_2, and other greenhouse gases. Transitioning from these unsustainable emitting materials to less environmentally impactful options, such as timber, presents a pathway for meaningful change. Timber is an organic material which absorbs carbon dioxide in order to grow. In other words, the material has a negative carbon footprint. According to the Arbor Day Foundation, a mature tree can absorb approximately 21 kilograms of CO_2 per year. This would suggest that due to the global warming crisis, timber would be the most used construction material. Nevertheless, due to long-standing fire safety concerns, the utilization of timber in the construction sector decreased, particular when reliable and safe alternatives like concrete and steel were widely available (Smith en Snow, 2008). While recent legislations have enhanced fire safety measures for timber, a substantial surge in timber usage has not been realised. This reluctance may stem from the timbers industry's challenges in meeting the growing demand for complex curved architectural designs, resulting in its continued insignificance when compared to steel and concrete (Grönquist et al., 2019) Currently, there are two conventional methods for bending timber. Cold bending involves the use of clamps, glue, and a mold, while warm bending requires the timber to be steamed to increase its flexibility. Subsequently, the timber can be shaped into the desired geometry. Both options are unsustainable in their own way, using glue or using energy to make steam. Although, the production and

design of complex curved timber elements can be realised, the method to do so is far from sustainable.

Circularity issue

Conventional curved beams are usually actively bend by steaming timber or using large amounts of adhesives to keep the timber in place (Bhooshan et al., 2023). Consequently, the reuse, re-purpose and other 'R'-strategies for these 'conventional' curved timber elements are not feasible.
The concept of 'R'-strategies is notorious in the departure from circularity in sustainable product design, highlighting challenges within the building sector concerning the sustainable life cycle of products. This concept endeavours to reduce the demand for products, repair damaged components, and recover energy at the end of a product's lifespan. New research in the field of hygromorphic characteristics in timber may shift this current unsustainable building & forming method into a better daylight.

Hygromorphic materials are known to absorb water. Timber is such a material, and will expend or shrink when moisture enters or leaves the material (Okuda en Sekida, 2001). Several studies have demonstrated the feasibility of achieving passive bending in timber through moisture control. An illustrative example is the Urbach Tower, where the University of Stuttgart successfully managed the swelling and bending of timber panels, resulting in a remarkable structural landmark standing over 14 meters tall. While bi-layer panels have been effectively curved using this method, it is noteworthy that various structural topologies employed in the construction sector can undergo alteration through passive bending techniques. The potential applications extend beyond bi-layer panels, suggesting a broader scope for innovation and transformative possibilities in timber construction.

Structural elements such as columns and beams have not received extensive research attention in the context of hygromorphic bending. To make a substantial impact on the timber construction sector, it is crucial to carefully select the appropriate element for research and development. Identifying which timber element can be effectively replaced by sustainable, curved hygromorphic elements has the potential to revolutionize construction practices, thereby positively influencing the building industry. Moreover, existing studies have predominantly focused on the bending of bi-layer elements, neglecting the aspect of multi-layered elements or straightening these elements to enhance their usability and flexibility. Actively incorporating both bending and straightening processes

	for timber elements can positively impact their lifespan and contribute to the effectiveness of 'R'-strategies. This thesis investigates the feasibility of bending and straightening a single timber element using hygromorphic effects to enhance the versatility of the element. Through an examination of 'R'-strategies, various timber structural elements, curving methods, and the utilization of curved elements, a deeper comprehension of the issue can be achieved.
research questions and	The primary research question for this thesis encompasses the objectives of comprehending the sustainability challenges in the implementation, fabrication, and forming of timber, identifying diverse timber topologies suitable for hygromorphic processing, and exploring the feasibility of integrating hygromorphic timber in contemporary contexts. *"How can hygromorphic curved structural timber elements contribute to a more sustainable architectural design option?"* The sub-research questions support the thesis research by elaborating different sub elements of the main thesis: 1. *What specific challenges contribute to the unsustainability within the timber industry sector?* 2. *How can curved timber elements be implemented in the build environment?* 3. *How do structural curved topologies contribute to sustainable architectural designs?* 4. *How will hygromorphic characteristics curve structural timber elements?*
design assignment in which these result.	The primary focus of this thesis will centre on the passive curvature of structural beams endowed with hygromorphic properties. Various alternatives, including solid timber beams, LVL-beams, GLT-beams, and others, will be thoroughly examined and considered. The secondary emphasis of this thesis involves altering the sustainable characteristics of timber, with the aim of minimizing the consumption of drying energy, adhesive usage, and waste management, aligning with the principles of 'R'-strategies. Following the research-by-design principle, this thesis will most likely incorporate a case study. While a specific case study has not been identified yet, it is crucial that the environmental conditions of its implementation differ from those of its production climate.

Process

Method description

There are multiple phases during this graduation thesis. First of all the theoretical phase where gathering information through papers, articles, news sources is essential to get an understanding of the problem and material. There is a logical order, from problem to history, topology, detailing, workflow, preparation, etc. All these sources contain viable information necessary to answer the (sub)research questions.

After the P2, the next phases starts. Here connections with structural timber element Manufacturers and the laboratory are made. This phase has already started as talks with Barbara from heritage already happened. Also manufacturers are contacted. When timber samples are acquired, the test in the laboratory can take place. Furthermore, a digital model with rhino and grasshopper could be made, to predict the curvature of the timber elements.

The second-last phase consist of implementing the findings from the second phase in a case-study and finalizing the product design part.

The last phase consist of concluding and summarizing the findings of the overall graduation thesis research and evaluating the case-study's positive impact on the construction sector. Further research may be needed, due to the large scope of the project.

Literature and general practical references

Abbott, A., & Whale, L. R. J. (1987). An overview of the use of glued laminated timber (GLULAM) in the UK. Construction and Building Materials, 1(2), 104–110. https://doi.org/10.1016/0950-0618(87)90007-9

Aziz, S., Brechenmacher, E., Alexander, B., Loutfi, J., & Gengnagel, C. (2023). Cap Ceilings revisited: A fabrication future for a Material-Efficient Historic Ceiling system. In Sustainable development goals series (pp. 393–408). https://doi.org/10.1007/978-3-031-36554-6_25

Bader, T. K., & Ormarsson, S. (2023). Modeling the mechanical behavior of wood materials and timber structures. In Springer handbooks (pp. 507–568). https://doi.org/10.1007/978-3-030-81315-4_10

Bertaud, F., & Holmbom, B. (2004). Chemical composition of earlywood and latewood in Norway spruce heartwood, sapwood and transition zone wood. Wood Science and Technology, 38(4). https://doi.org/10.1007/s00226-004-0241-9

Bhooshan, V., Nahmad, A., Singer, P. C., Chen, T. L., Mei, L., Louth, H. D., & Bhooshan, S. (2023). Spatial curved laminated timber structures. In Lecture notes in mechanical engineering (pp. 859–885). https://doi.org/10.1007/978-3-031-36922-3_43

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., & Thiel, A. (2016). Cross Laminated Timber (CLT): Overview and development. European Journal of Wood and Wood Products, 74(3), 331–351. Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., & Thiel, A. (2016). Cross Laminated Timber (CLT): Overview and development. European Journal of Wood and Wood Products, 74(3), 331–351. https://doi.org/10.1007/s00107-015-0999-5

Grönquist, P., Wood, D., Hassani, M. M., Wittel, F. K., Menges, A., & Rüggeberg, M. (2019). Analysis of hygroscopic self-shaping wood at large scale for curved mass timber structures. Science Advances, 5(9). https://doi.org/10.1126/sciadv.aax1311

Hill, C., [Aalto University - Wood Science]. (2021, 14 januari). Wood drying (7) cells and swelling [Video]. Youtube. Geraadpleegd op 11 januari 2024, van https://www.youtube.com/watch?v=bmmMXBd2054&list=LL&index=1&ab_channel=AaltoUniversity-WoodScience

Holstov, A., Bridgens, B., & Farmer, G. T. (2015). Hygromorphic materials for sustainable responsive architecture. Construction and Building Materials, 98, 570–582. https://doi.org/10.1016/j.conbuildmat.2015.08.136

Hradil, P., Talja, A., Wahlström, M., & Pikkuvirta, J. (2014). Re-use of structural elements; environmentally efficient recovery of building components. ResearchGate. https://doi.org/10.13140/2.1.1771.9363

Huang, L., Krigsvoll, G., Johansen, F., Liu, Y., & Zhang, X. (2018). Carbon emission of global construction sector. Renewable & Sustainable Energy Reviews, 81, 1906–1916. https://doi.org/10.1016/j.rser.2017.06.001

Ioannou, O. (2023). The R Strategies. In Circularity for Educators. https://circularityforeducators.tudelft.nl/article/the-r-strategies/

Issa, C. A., & Kmeid, Z. (2005). Advanced wood Engineering: Glulam Beams. Construction and Building Materials, 19(2), 99–106. https://doi.org/10.1016/j.conbuildmat.2004.05.013

Langrish, T., & Walker, J. C. F. (2006). Drying of timber. In Springer eBooks (pp. 251–295). https://doi.org/10.1007/1-4020-4393-7_8

Kothari, C. (2004). Research methodology: Methods and techniques.

Moody, R.C., Hernandez, R., Liu, J.Y., 1999. Glued structural members. In: Wood Handbook – Wood as an Engineering Material, General Technical Report, FPL-GTR-113. United States Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, pp. 11-1–11-24.

Okuda, K., & Sekida, S. (2001). Organization of Cellulose-Synthesizing terminal complexes. In Progress in Biotechnology (pp. 93–100). https://doi.org/10.1016/s0921-0423(01)80060-5

Ong, C. B. (2015). Glue-laminated timber (Glulam). In Elsevier eBooks (pp. 123–140). https://doi.org/10.1016/b978-1-78242-454-3.00007-x

PBL Netherlands Environmental Assessment Agency. (2018). Circular economy: what we want to know and can measure. In pbl (Nr. 3217). PBL Publishers. Geraadpleegd op 5 januari 2024, van https://www.pbl.nl/sites/default/files/downloads/pbl-2018-circular-economy-what-we-want-to-know-and-can-measure-3217.pdf

Perré, P., Rémond, R., Colin, J., Mougel, É., & Almeida, G. (2012). Energy consumption in the convective drying of timber analyzed by a multiscale computational model. Drying Technology, 30(11–12), 1136–1146. https://doi.org/10.1080/07373937.2012.705205

Pudasjärvi Log Campus | Lukkaroinen. (2023, 18 december). Lukkaroinen. https://lukkaroinen.com/projects/pudasjarvi-log-campus/

Sandberg, D., Eggert, O. T., Haider, A., Kamke, F. A., & Wagenführ, A. (2023). Forming, densification and molding. In Springer handbooks (pp. 943–989). https://doi.org/10.1007/978-3-030-81315-4_18

Seymour, L. M., Maragh, J., Sabatini, P., Di Tommaso, M., Weaver, J. C., & Mašić, A. (2023). Hot Mixing: Mechanistic insights into the durability of ancient Roman concrete. Science Advances, 9(1). https://doi.org/10.1126/sciadv.add1602

Smith, I. F. C., & Snow, M. A. (2008). Timber: an ancient construction material with a bright future. Forestry Chronicle, 84(4), 504–510. https://doi.org/10.5558/tfc84504-4

Strozzi, A., Bertocchi, E., & Mantovani, S. (2018). A paradox in curved beams. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 233(8), 2830–2833. https://doi.org/10.1177/0954406218797980

Teischinger, A., Maderebner, R., & Petutschnigg, A. (2023). Aspects of wood utilization and material selection. In Springer handbooks (pp. 1787–1833). https://doi.org/10.1007/978-3-030-81315-4_34

Thistleton, W. (2023, 26 september). Timber Typologies - Understanding options for timber construction. Timber Development UK. https://timberdevelopment.uk/resources/timber-typologies/

Thybring, E. E., Fredriksson, M., Zelinka, S. L., & Glass, S. V. (2022). Water in Wood: A review of current understanding and knowledge Gaps. Forests, 13(12), 2051. https://doi.org/10.3390/f13122051

Thybring, E. E., & Fredriksson, M. (2023). Wood and moisture. In Springer handbooks (pp. 355–397). https://doi.org/10.1007/978-3-030-81315-4_7

Tree facts at Arborday.org. (z.d.). https://www.arborday.org/trees/treefacts/

Ulleland, P. (2017). The Oseberg ship. Wikipedia. https://nl.m.wikipedia.org/wiki/Bestand:Osebergskipet_2016.jpg

van Bruggen, R., & van der Zwaag, N. (2017). Knelpuntenanalyse houtrecycling (Nr. R001-1250953RPB-hgm-V05-NL). Tauw. Geraadpleegd op 5 januari 2024, van https://www.eerstekamer.nl/overig/20180529/knelpuntenanalyse_houtrecycling/meta

Willmann, J., Gramazio, F., & Kohler, M. (2016). New paradigms of the automatic: Robotic timber construction in architecture. In Menges, A., Schwinn, T., & Krieg, O. D. (Eds.), Advancing Wood Architecture: a Computational Approach. (pp.13-27). Taylor & Francis Group.

Wood, D., Grönquist, P., Bechert, S., Aldinger, L., Riggenbach, D., Lehmann, K., Rüggeberg, M., Burgert, I., Knippers, J., & Menges, A. (2020). FROM MACHINE CONTROL TO MATERIAL PROGRAMMING: In UCL Press eBooks (pp. 50–57). https://doi.org/10.2307/j.ctv13xpsvw.11

Wright, R., Bond, B., & Chen, Z. (2013). Steam bending of wood; embellishments to an ancient technique. Bioresources, 8(4). https://doi.org/10.15376/biores.8.4.4793-4796

Zhang, L., Liu, B., Du, J., Liu, C., & Wang, S. (2019). CO2 emission linkage analysis in global construction sectors: alarming trends from 1995 to 2009 and possible repercussions. Journal of Cleaner Production, 221, 863–877. https://doi.org/10.1016/j.jclepro.2019.02.231

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)?**
   This thesis focusses on structural and material knowledge of timber elements in the build environment. For developing and designing a new manufacturing method of timber elements a know-how of product design is needed as well as comping with complex structural implementations. Furthermore, the use of the laboratory at the Architectural faculty shows great involvement in material science. Moreover, the probable use of digital 3D software's like Rhino7 and grasshopper also implements an computational design aspect.

2. **What is the relevance of your graduation work in the larger social, professional and scientific framework.**
   <u>Social relevance</u>

The main goal is to design a sustainable structural curved timber element. By doing so, these timber elements can compete against pollutant steel and concrete structural elements, and thus reducing overall emissions in the building/construction sector. Furthermore, this new product may result in less energy produced during manufacturing, less waste created and a more circular life-cycle motive. Resulting in a sustainable, circular and emission free global environment.

Scientific relevance

The use of hygromorphic characteristic to curve timber is not new. Many researcher developed and even constructed elements, for example the Urbach tower. However, there is a research gap in the development of multi-layered elements being able to curve. This thesis tries to understand the problems behind the multi-layered elements and develop new method in curving structural elements.