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	Sasipa Vichitkraivin
Student number	5765668

Studio		
Name / Theme	Structural Design / Architectural Timber	
Main mentor	Prof.dr. Mauro Overend	Structural Design
Second mentor	Dr. Charalampos Andriotis	Computational Intelligence
Argumentation of choice of the studio	This topic requires a deep understanding of the intricacies of timber structures and practical insights into the challenges and nuances of timber structural connections. Simultaneously, the project needs a wealth of knowledge in machine learning, computational models, and advanced computational techniques to analyze complex data patterns. Ultimately, it calls for the integration of computational methods with structural engineering to establish a cohesive connection between the two fields.	

Graduation project	
Title of the graduation project	Timber dry joints: Inspection and maintenance planning of timber structural connections
Goal	
Location:	The machine learning model developed as part of this master's thesis does not have a specific physical project location. Instead, the focus is on the development of a generalized model applicable to various contexts. However, for the purpose of evaluation and validation, the model may be applied to a specific case study.
The posed problem,	Timber, as a hygroscopic material, exhibits sensitivity to environmental factors such as light, temperature, and moisture. The increasing effects of climate change pose a significant challenge to the long-term performance and structural integrity of timber elements in construction, particularly in

	historical buildings. The evolving climatic conditions can lead to complex changes in the mechanical properties of timber, necessitating a proactive approach to inspection and maintenance planning. Traditional methods of assessing timber structural connections have proven insufficient in adapting to the dynamic nature of climate change impacts on this hydro-sensitive material. Current practices require time-consuming processes and often lack the precision needed to predict and address maintenance needs accurately. As a result, there is a pressing need to integrate advanced technologies, such as machine learning, to develop a nuanced understanding of the evolving condition of timber connections. This master's thesis addresses the intricate relationship between climate change, timber sensitivity, and the maintenance challenges in traditional construction. The central focus is on leveraging machine learning methodologies to create a predictive maintenance model tailored to the unique characteristics of timber. By harnessing the power of machine learning, this research aims to enhance the accuracy of inspection planning, allowing for timely interventions to preserve the structural integrity and longevity of timber connections in the face of climate-induced variations. The proposed model will not only contribute to the field of timber engineering but will also provide a scalable and adaptable solution for sustainable construction practices in the context of evolving climate patterns.
research questions and	As per the problem statement, the main research question is articulated. To address the main research question, several subordinate research questions are posed as outlined below. **Main Research Question:** How can machine learning models be effectively employed to predict inspection and maintenance planning for

	timber structural connections considering the impact of climate change on the mechanical properties of dry timber? **Sub-Research Questions:** - What are the key mechanical properties of dry timber connections that significantly influence structural integrity and degradation? - How can historical data on the condition of timber connections and simulated weathering process data be effectively collected and integrated to create a comprehensive dataset for machine learning? - What features and derived parameters should be considered in the feature engineering process to capture the unique characteristics of dry timber joints and their sensitivity to climate-induced changes? - Which machine learning (ML) models are most suitable for assessing timber strength and predicting the maintenance needs of timber connections? - How can these ML models be optimized to provide accurate and reliable predictions? - How can the model predictions be validated? - What measures can be taken to ensure the interpretability of the machine learning models for practical application in maintenance planning?
design assignment in which these results	Designing machine learning models that can be effectively applied to predict inspection and maintenance planning for timber structural connections while considering the impact of climate change on the mechanical properties of dry timber.

1. **Identification of Relevant Mechanical Properties:**
   Conduct an extensive literature review and consult with timber engineering experts to identify the mechanical properties most crucial for evaluating the structural integrity and degradation of timber connections in Japanese joinery.

2. **Data collection and Integration:**
   Systematically collect data on the condition of timber connections using both Non-destructive Testing/Evaluation (NDT/NDE) and historical records.

3. **Feature Engineering for Timber Joints:**
   Develop features that encapsulate the unique characteristics of timber joints, leveraging insights from Non-destructive Testing/Evaluation results.

4. **Model Selection and Optimization:**
   Evaluate machine learning models suitable for predicting maintenance needs based on NDT/NDE and historical data (potentially reinforcement learning).

5. **Validation and Interpretability:**
   Apply the machine learning model, enriched with NDT/NDE data, to a case study representative of traditional timber connection to validate its performance and interpretability.

Process

Method description

1. **Identification of Relevant Mechanical Properties:**
   Analyze existing research and practical experiences. Consider insights from Non-destructive Testing/Evaluation techniques to identify measurable properties for inclusion in the model.

2. **Data collection and Integration:**
   Collaborate with NDT/NDE specialists to acquire detailed data from inspections of historical timber members or utilize the data from existing papers. Integrate this information with historical records and simulated weathering process data for a comprehensive dataset.

3. **Feature Engineering for Timber Joints:**
   Utilize NDT/NDE findings to inform the development of features that capture specific aspects of joinery craftsmanship and timber conditions. Incorporate climate-related features to model the impact of weathering on timber properties.

4. **Model Selection and Optimization:**
   Train and test different models, considering reinforcement learning methods for dynamic decision-making. Optimize models using insights from both historical and NDT/NDE data to enhance accuracy and adaptability.

5. **Validation and Interpretability:**

Collaborate with practitioners and NDT/NDE specialists to validate predictions. Ensure interpretability by providing clear explanations of how the model integrates NDT/NDE insights into its decision-making process.

Literature and general practical references

van Nimwegen, S. E., & Latteur, P. (2023). A state-of-the-art review of carpentry connections: From traditional designs to emerging trends in wood-wood structural joints. *Journal of Building Engineering, 78*, 107089. https://doi.org/https://doi.org/10.1016/j.jobe.2023.107089

Poletti, E., Vasconcelos, G., Branco, J., & Isopescu, B. (2019). Effects of extreme environmental exposure conditions on the mechanical behaviour of traditional carpentry joints. *Construction and Building Materials, 213*, 61-78. https://doi.org/10.1016/j.conbuildmat.2019.04.030

Knoppert, S. (2023). *Incorporating climate change in I&M planning for engineering structures - A Deep Reinforcement Learning Framework* Delft University of *Technology*]. http://resolver.tudelft.nl/uuid:95df05a4-cbbe-4d52-8787-7e46071a8765

Cavalli, A., & Togni, M. (2015). Monitoring of historical timber structures: state of the art and prospective. *Journal of Civil Structural Health Monitoring, 5*(2), 107-113. https://doi.org/10.1007/s13349-014-0081-8

Feio, A. O., Lourenço, P. B., & Machado, J. S. (2014). Testing and modeling of a traditional timber mortise and tenon joint. *Materials and Structures*, *47*(1), 213-225. https://doi.org/10.1617/s11527-013-0056-y

Frühwald, E., Serrano, E., Toratti, T., Emilsson, A., & Thelandersson, S. (2007). Design of safe timber structures-How can we learn from structural failures in concrete, steel and timber?

Frühwald Hansson, E. (2011). Analysis of structural failures in timber structures: Typical causes for failure and failure modes. *Engineering Structures, 33*(11), 2978-2982. https://doi.org/https://doi.org/10.1016/j.engstruct.2011.02.045

King, W. S., Yen, J. Y. R., & Yen, Y. N. A. (1996). Joint characteristics of traditional Chinese wooden frames. *Engineering Structures, 18*(8), 635-644. https://doi.org/https://doi.org/10.1016/0141-0296(96)00203-9

Kunecký, J., Hasníková, H., Kloiber, M., Milch, J., Sebera, V., & Tippner, J. (2018). Structural assessment of a lapped scarf joint applied to historical timber constructions in central Europe. *International Journal of Architectural Heritage, 12*(4), 666-682. https://doi.org/10.1080/15583058.2018.1442524

Verbist, M., Nunes, L., Jones, D., & Branco, J. M. (2019). 11 - Service life design of timber structures. In B. Ghiassi & P. B. Lourenço (Eds.), *Long-term Performance and Durability of Masonry Structures* (pp. 311-336). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-08-102110-1.00011-X

Xin, Z., Ke, D., Zhang, H., Yu, Y., & Liu, F. (2022). Non-destructive evaluating the density and mechanical properties of ancient timber members based on machine learning approach. *Construction and Building Materials, 341*, 127855. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.127855

Nasir, V., Fathi, H., Fallah, A., Kazemirad, S., Sassani, F., & Antov, P. (2021). Prediction of Mechanical Properties of Artificially Weathered Wood by Color Change and Machine Learning. *Materials, 14*(21), 6314. https://www.mdpi.com/1996-1944/14/21/6314

Csébfalvi, A., & Len, A. (2020). THE CLIMATE IMPACT ON TIMBER STRUCTURES. *Iran University of Science & Technology, 11*, 143-154.

García-Iruela, A., Fernández, F. G., Esteban, L. G., de Palacios, P., Simón, C., & Arriaga, F. (2016). Comparison of modelling using regression techniques and an artificial neural network for obtaining the static modulus of elasticity of Pinus radiata D. Don. timber by ultrasound. *Composites Part B: Engineering, 96,* 112-118. https://doi.org/https://doi.org/10.1016/j.compositesb.2016.04.036

Harada, M., Hayashi, Y., Hayashi, T., Karube, M., & Ohgama, T. (2005). Effect of moisture content of members on mechanical properties of timber joints. *Journal of Wood Science, 51*(3), 282-285. https://doi.org/10.1007/s10086-004-0656-9

Gedeon, G. (1999). *Wood handbook--Wood as an engineering material.*

Choidis, P., Kraniotis, D., Lehtonen, I., & Hellum, B. (2021). A Modelling Approach for the Assessment of Climate Change Impact on the Fungal Colonization of Historic Timber Structures. *Forests, 12*(7), 819. https://www.mdpi.com/1999-4907/12/7/819

Li, Y., Cao, S., & Xue, J. (2016). Analysis on mechanical behavior of dovetail mortise-tenon joints with looseness in traditional timber buildings. *60,* 903-921. https://doi.org/10.12989/sem.2016.60.5.903

Ranjith, S., Setunge, S., Gravina, R., & Venkatesan, S. (2013). Deterioration Prediction of Timber Bridge Elements Using the Markov Chain. *Journal of Performance of Constructed Facilities*, *27*(3), 319-325. https://doi.org/doi:10.1061/(ASCE)CF.1943-5509.0000311

Nasir, V., Fathi, H., & Kazemirad, S. (2021). Combined machine learning–wave propagation approach for monitoring timber mechanical properties under UV aging. *Structural Health Monitoring*, *20*(4), 2035-2053. https://doi.org/10.1177/1475921721995987

Dietsch, P., Gamper, A., Merk, M., & Winter, S. (2015). Monitoring building climate and timber moisture gradient in large-span timber structures. *Journal of Civil Structural Health Monitoring*, *5*(2), 153-165. https://doi.org/10.1007/s13349-014-0083-6

Zheng, X., Lam, F., Li, Z., & He, M. (2023). Long-term performance assessment of post-tensioned timber connections under different climates. *Construction and Building Materials*, *368*, 130360. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2023.130360

Lanata, F. (2015). Monitoring the long-term behaviour of timber structures. *Journal of Civil Structural Health Monitoring*, *5*(2), 167-182. https://doi.org/10.1007/s13349-014-0095-2

Li, Z., Tao, D., Li, M., Shu, Z., Jing, S., He, M., & Qi, P. (2019). Prediction of Damage Accumulation Effect of Wood Structural Members under Long-Term Service: A Machine Learning Approach. *Materials*, *12*(8), 1243. https://www.mdpi.com/1996-1944/12/8/1243

van Blokland, J., Nasir, V., Cool, J., Avramidis, S., & Adamopoulos, S. (2021). Machine learning-based prediction of surface checks and bending properties in weathered thermally modified timber. *Construction and Building Materials*, *307*, 124996. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2021.124996

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)?

   The graduation topic focuses on implementing machine learning for predictive maintenance planning in timber structural connections. The project aligns with the studio topic of sustainable structure design by addressing the long-term performance and maintenance of timber connections. Sustainable structure design involves not only the initial construction but also the ongoing maintenance to ensure the durability and resilience of the structure. By leveraging machine learning for predictive maintenance, the project contributes to the sustainability goals of minimizing resource use and extending the lifespan of structures.

   The graduation topic is directly aligned with the BT track as it delves into the technological application of machine learning to enhance the maintenance planning of timber connections. It integrates advanced technologies into the field of building technology, emphasizing innovation and efficiency in maintenance practices.

   The graduation topic contributes to the building sciences aspect by addressing the scientific and technological dimensions of timber construction. Moreover, it aligns with the interdisciplinary nature of the program, combining architectural principles with technological advancements to address real-world challenges in building maintenance.

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

   This project contributes to the sustainability and resilience of built environments, ensuring the safety and longevity of structures. It also addresses societal concerns about the environmental impact of construction materials by promoting the responsible use and maintenance of timber.

   In terms of professional relevance, the topic offers a practical and data-driven approach to maintenance planning, enhancing the efficiency of professionals in the field of timber engineering and construction. This aligns with industry trends by integrating advanced technologies into traditional construction practices.

In the scientific framework, an advancement of the scientific understanding of the impact of climate change on timber connections and the application of machine learning in predictive maintenance is addressed. The project also provides a basis for further research and development in the intersection of building technology, machine learning, and sustainable construction practices.