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	**Minke Venus**
Student number	4998502

Studio		
Name / Theme	Building Technology	
Main mentor	Prof. James O'Callaghan	Architectural Glass Structural Design & Mechanics Glass & Transparency Research Group
Second mentor	Dr. Gabriele Mirra	Digital Technologies
Argumentation of choice of the studio	I hope to improve my skills in structural design together with digital methods for structural analysis/optimization (Karamba, plugin for Grasshopper) and verification (FEA analysis), to become a designer whose ideas are also structurally feasible.	

Graduation project	
Title of the graduation project	**Structural glass design for flexibility** **A reconfigurable glass plate structure for changing spatial needs**
Goal	
Location:	The case-study location is the Viminacium Archaeological park in Serbia.
The posed problem,	There is an urgent need for sustainable building practices as the construction sector contributes significantly to global greenhouse gas emissions. Glass structures, traditionally valued for transparency, are increasingly used as primary structural materials due to technological advancements. However, these structures often have no reuse scenarios, which, especially in the case of a temporary structure, results in significant underutilisation of materials and energy, further increasing their environmental impact.

research questions and	Main question: *What structural elements and connections enable the design of a structurally feasible, reconfigurable float glass structure that can be assembled and disassembled by a small team, allowing it to respond to changing spatial needs?* Subquestions: 1. How do module geometry and connection types influence the reconfigurability of the structure? 2. How can a small team assemble, disassemble, and reconfigure the structure with minimal reliance on heavy machinery? *3. How can the structure be designed for efficient transportation of its components?* *4. What key factors must be considered when designing with float glass as the primary structural material during the preliminary and final design phases?*
design assignment in which these result.	

The design of a reconfigurable glass plate structure, easily assembled and disassembled by a small team with minimal reliance on heavy machinery, and efficiently transportable for use at different locations.

Process

Method description

Literature and Design

In the initial phase of the research, doing literature research to answer my sub-questions will occur simultaneously with the concept design process. By conducting literature and translating the acquired insights into design concepts - also informed by additional requirements and sub-objectives - a preliminary concept will be developed. Furthermore, relevant information from the literature, such as structural numerical values for glass design, will serve as input for the subsequent analysis and verification phase.

Analysis and Verification

The digital design and analysis process comprises parametric design using Grasshopper for Rhino, structural analysis with Karamba for Grasshopper, and structural verification in ANSYS, an FEA analysis software.

Final Design

The process ends with a final design consisting of standardized glass modules and connections. With these modules, a structure with a small span can be constructed. These modules can later be disassembled, transported, and reassembled into a different configuration with a larger span. To demonstrate the feasibility of the principle, the design will be applied to a case study that covers two locations on a big archaeological park in Serbia.

Literature and general practical references

Practical experience will likely include testing various module sizes and weights, as well as evaluating connection principles through 3D-printed prototypes during the concept design phase. Additionally, a laboratory test will be conducted to assess the performance and reliability of the connection system.

The literature I have gathered and utilized thus far encompasses several key areas. It includes foundational theory that inspired me for this research proposal, research on adaptable structures, and insights into connection design for foldable (glass) plate structures. Furthermore, it incorporates case study analyses and theoretical frameworks that directly support my research questions, such as identifying critical factors in structural glass design:

Barou, L., Oikonomopoulou, F., Bristogianni, T., Veer, F., & Nijsse, R. (2018). Structural glass: A new remedial tool for the consolidation of historic structures. *Heron, 63*(1–2), 159-197.

Brancart, S., Paduart, A., Vergauwen, A., Vandervaeren, C., De Laet, L., & De Temmerman, N. (2017). Transformable structures: Materialising design for change. *International Journal of Design & Nature and Ecodynamics, 12*(3), 357-366.

Brütting, J., Senatore, G., & Fivet, C. (2021). Design and fabrication of a reusable kit of parts for diverse structures. *Automation in Construction, 125,* 103614. https://doi.org/10.1016/j.autcon.2021.103614

Chun, J., & Shi, Z. (2024). Algorithmic analysis and application of structural tessellation in design and optimization. *MATEC Web of Conferences, 396,* 05008.
Cooper, D. R., & Gutowski, T. G. (2017). The environmental impacts of reuse: a review. *Journal of Industrial Ecology, 21*(1), 38-56.

Dalalbashi, A., Pinto, J., Reis, C., Pimenta, F., Ferreira, N. O., & Pereira, N. B. (2024). A proposal for an alternative structural modular solution. *Journal of Building Engineering, 85,* 108709.

Feldmann, M., Laurs, M., Belis, J., Buljan, N., Criaud, A., Dupont, E., ... & Sikynova, A. (2023). The new CEN/TS 19100: Design of glass structures. *Glass Structures & Engineering, 8*(3), 317-337.

Giese, F., Wolf, S., Hindelang, L., & Krauter, A. (2024). Glass in Architecture from the Pre-to the Post-industrial Era: Production, Use and Conservation. De Gruyter.

Hussein, H. E., Agkathidis, A., & Kronenburg, R. (n.d.). Towards a Free-form Transformable Structure.

Jørgensen, K. A. (2010). Customisation design: Levels of customisation. In *Mass Matching-Customization, Configuration & Creativity: Proceedings of the 5th International Conference on Mass Customization & Personalization MCPC 2009*. Aalto University School of Art and Design, Helsinki, Finland.

Jóźwik, A. (2022). Application of Glass Structures in Architectural Shaping of All-Glass Pavilions, Extensions, and Links. *Buildings, 12*(8), 1254. https://doi.org/10.3390/buildings12081254

Krousti, A., Snijder, A., & Turrin, M. (2018). Kinematics of folded glass plate structures: Study of a deployable roof system. In *Challenging Glass 6: International Conference on the Architectural and Structural Application of Glass* (pp. 53-70). Delft University of Technology.

Marinitsch, S., Schranz, C., & Teich, M. (2016). Folded plate structures made of glass laminates: A proposal for the structural assessment.

Matheou, M., Phocas, M. C., Christoforou, E. G., & Müller, A. (2023). New perspectives in architecture through transformable structures: A simulation study. *Frontiers in Built Environment, 9,* 1051337. https://doi.org/10.3389/fbuil.2023.1051337

Mazzoli, C., Prati, D., & Bonci, M. (2021). An eco-sustainable parametric design process of bio-based polymers temporary structures. *TEMA, 7*(2), 145-158.

Mesa, J., Maury, H., Arrieta, R., Bula, A., & Riba, C. (2015). Characterization of modular architecture principles towards reconfiguration: a first approach in its selection process. *The International Journal of Advanced Manufacturing Technology, 80,* 221-232.

Mitsimponas, D., & Symeonidou, I. (2024). Identifying Trends and Typologies of Modular Constructions in Architecture. *Nexus Network Journal, 26*(1), 49-69.

Newell, C., Hoag, A., & Oliyan, O. (2024, June). Light Forms: Modular Variation, Pattern, Structure. In *Challenging Glass Conference Proceedings* (Vol. 9).

Nikolić, E. (2018). Evaluation of the protection and presentation of historic buildings in the Viminacium Archaeological Park in relation to their spatial context. *Spatium,* 26-37.

Ottenhaus, L., Yan, Z., Brandner, R., Leardini, P., Fink, G., & Jockwer, R. (2023). Design for adaptability, disassembly and reuse – A review of reversible timber connection systems. *Construction and Building Materials, 400,* 132823. https://doi.org/10.1016/j.conbuildmat.2023.132823

Petrović, M., Ilić, I. D., Džombić, N. M., & Šekularac, N. D. (2021). Design of Protective Structures for Active Archeological Sites. In *12th International Conference on Structural Analysis of Historical Constructions (SAHC). SAHC.*

Phocas, M. C., & Matheou, M. (2021). Revisiting transformable structures in architecture. In *Proceedings of the 2nd International Conference on Architecture, Technology and Innovation* (pp. 24-09).

Pizzigoni, A. (2010, February). A high fiber reinforced concrete prototype for reciprocal structures of demountable building. In *Symposium of the International Association for Shell and Spatial Structures (50th. 2009. Valencia). Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures: Proceedings*. Editorial Universitat Politècnica de València.

Pour-Moghaddam, N. (2020). Glass Properties and Refinement Processes. *On the Fracture Behaviour and the Fracture Pattern Morphology of Tempered Soda-Lime Glass,* 7-15.

Rammig, L. (2022). The pursuit of transparency. In *Rethinking Building Skins* (pp. 89-115). Woodhead Publishing.

Rotilio, M., Di Giovanni, G., Cucchiella, F., De Berardinis, P., & Amici, C. (2022). Temporary building construction to make cities more sustainable: An innovative "Square Box" proposal. *Journal of Cleaner Production, 372,* 133657. https://doi.org/10.1016/j.jclepro.2022.133657

Siddiqi, A., de Weck, O., & Hoffman, J. *IAC-05-D3. 3.03 Sustainability in System Architectures through Reconfigurability: A Case Study of Planetary Surface Vehicles.*
Sposito, C., & Di Salvo, S. (2020). Innovative Applications and Experiments for the Protection of Archaeological Sites. *Project. Essays and Researches, 3,* 10-37.

Tapavički-Ilić, M., Nikolić, E., & Anđelković Grašar, J. (2022). Managing the Archaeological Park and Open-Air Museum Viminacium (Serbia). In *Handbook of Cultural Heritage Analysis* (pp. 2073-2107). Cham: Springer International Publishing.
Trometer, S., & Krupna, M. (2006). Development and design of glass folded plate structures. *Journal of the International Association for Shell and Spatial Structures, 47*(3), 253-260.

Tuncbilek, G. (2020). Experimentation in architecture: Pavilion design. *Athens Journal of Architecture, 6*(4), 397-413.

Zhu, Y., & Filipov, E. T. (2024). Large-scale modular and uniformly thick origami-inspired adaptable and load-carrying structures. *Nature Communications, 15*(1), 2353.

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 Master in Building Technology equips students with a mindset that integrates sustainable, technical, and architectural design into a cohesive approach. This MSc programme emphasizes the use of computational tools to guide and

enhance the design process. My graduation project, situated in the fields of structural and computational design, focuses on developing an innovative and sustainable structural design. Using different computational tools, the design is analyzed, design changes are made, and the design will be verified.

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

My graduation work will result in a sustainable design concept for glass structures by making them reusable and adaptable to spatial changes, contributing to a more sustainable building industry. This design outcome is directly applicable to sites that like to use transparent structures to encourage social and/or cultural gatherings. Examples are archaeological sites looking for temporary but aesthetically integrated canopy structures for their excavation sites.