Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

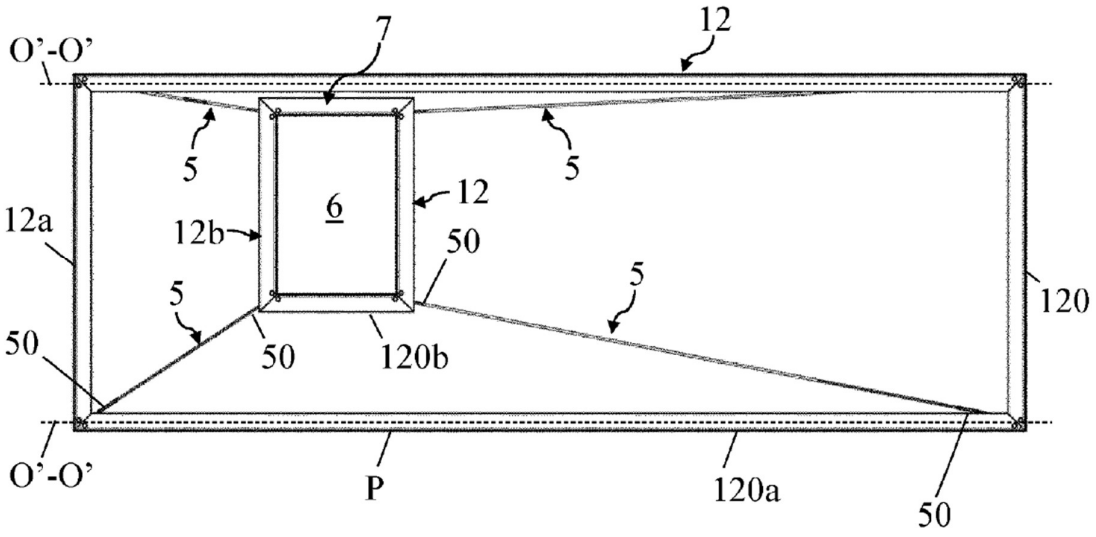
Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Sander Bentvelsen
Student number	4851579

Studio		
Name / Theme	Façade Design & Structural Design	
Main mentor	Alessandra Luna Navarro	Façade Design & Engineering
Second mentor	Mauro Overend	Structural Design & Mechanics
Argumentation of choice of the studio	- (Predetermined with the choice of topic)	

Graduation project	
Title of the graduation project	Tensile Façade design and prototyping
Goal	
Location:	Delft
The posed problem,	With increasing sustainability and performance criteria and an ever-lasting desire to minimize cost; Existing facade systems are reaching their limits. There is a need for innovative solutions that could address the gaps current facade systems face.
research questions and	How can the principle of a tensile based system be utilized to create a more effective facade solution?
design assignment in which these result.	Prototype and compare the new tensile based system to existing industry solutions.



Category	Sub-question	Method of answering
Market questions: *What is the systems market potential?*	What opportunities exist across current prefabricated facade systems for improved performance through new structural configurations?	*Literature* *Interviews* *Market research*
	How does the proposed system compare with existing prefabricated facades and where could it compete with industry solutions?	*Literature* *Market research* *Modelling*
	What is the potential of a tensile based system from industry perspectives?	*Interviews* *Market research*
	What forms of intellectual property protection are there and how can they be best utilised?	*Literature*
Structural questions integrated: *How does the system structurally work and how can it be optimised?*	How does pretensioning of the cables influence the out of plane resistance, bending and buckling of the system?	*Interview with Octatube* *Literature of similar systems* *Modelling* *Prototype tests*
	What are the immediate and long-term pretension losses of the system caused by factors such as embedment, relaxation, elastic interaction, joint compression, creep, vibration & material degradation, and what are the effects on the systems out of plane resistance, bending & buckling behaviour?	*Literature* *Modelling* *Prototype tests*
	What potential methods are there to transfer out of plane loads (e.g. wind) from cladding to the substructure and how do they influence the out of plane resistance, bending & buckling behaviour of the system?	*Interviews* *Industry research* *Modelling*
	How does the system perform as a load bearing façade?	*Interviews* *Modelling*

Structural questions related to the tensile members:	How does the pretensioning sequence influence the structural response of the system?	*Modelling* *Prototype tests*
	What is the structural response due to pretension deviations and how can this be accounted for?	*Literature* *Modelling*
	How does the placement of the inner frame opening influence the out of plane resistance of the system?	*Modelling* *Prototype tests*
Structural questions related to the compressive members:	How does precompression influence the bending and buckling behaviour of the system?	*Literature* *Modelling*
	How do material imperfections and/or out of plane loads influence bending and buckling behaviour of the system?	*Literature* *Modelling*
	How do combining varying composite profiles influence bending and buckling behaviour of the system?	*Literature* *Modelling*
	How do additional spacer placement and gap width influence bending and buckling behaviour of the system?	*Literature* *Modelling*
	How does the precise placement of cable attachment points influence bending and buckling behaviour of the system, i.e. what is the influence of eccentricity, and could it potentially be utilised to bend the frames in a controlled manner?	*Literature* *Modelling*
Facade Design / Manufacturing Questions: *How can such a system be manufactured and how does it perform in other aspects?*	What methods are there to effectively and accurately pretension/manufacture such a system?	*Literature* *Interviews* *Market research* *Prototype tests*
	How do all the structural variations influence the detailing of the facade system and thereby affect a wide range of performance criteria, e.g. **cost, circularity, adaptability, logistics, thermal, acoustic, fire** etc.?	*Literature* *Interviews* *Market research* *Modelling*
	What potential applications are feasible for the proposed tensile facade system? E.g. design freedom, transparency, size, finishes.	*Literature* *Market research* *Modelling*

Process

Method description

The main methods for answering the questions and sub-questions are the following:

- Literature research
- Industry / Market research
- Modelling
- Prototype
- Interviews

In literature I can find a theoretical basis for some of the structural effects that take place in this system and learn more about the methods there are for tackling such a non-linear structural problem. Furthermore, literature provides a good basis for evaluating performance criteria of other façade systems. There are a lot of papers that review industry solutions from a non-biased position on for instance economic and circular performance.

Secondly, I am reviewing industry design guides and manufacturing documents on existing façade solutions. These give me a better overview of what the market has to offer and review design criteria/regulations the products must reach. Also looking at novel façade solutions that reviewing literature might not have reached or caught up to yet.

The modelling effort is threefold. First there are hand calculations and Excel sheets. They are preliminary calculations to give first insights into the structural response of such a tensile system and used for defining the prototype materials. Second there are parametric models. Using Rhino Grasshopper and the plugins Karamba and Kangaroo. With them I can test a large variety of design configurations and give an insight into the passive stabilities of the system, or how it might buckle or fail and under what loads. Third there is Ansys, a finite element modeling software. With this model I can make the most accurate predictions of certain scenarios and specifically model the buckling behavior of the compressive elements subjected to wind loads. As I won't be able to test this on a full-scale prototype.

Then there is the prototype, the main body of the research. Using the models described before it should be possible to get a picture of how the system behaves under certain pretensions and loads, however this is not certain. Hand calculations can only handle the effects of single or a few members or a symmetrical system, the Karamba model doesn't properly handle second order effects and Ansys FEA is highly cumbersome and still a model. It is therefore prudent to create a test setup in which to verify the models and empirically find out what the performance is of such a system. With the prototype I aim to, first: find out what the exact out of plane resistance is under varying configurations and preloads, second: verify the possible instabilities of the system, third: understand the effects of pretension sequencing, and forth and finally: test other pretension configurations including a continuous cable and pully setup. With this data I should be able to give accurate predictions on what the full-scale façade element might look like and what its performance would be.

Finally, there are the interviews. As a large proportion of the knowledge on façade systems is industry knowledge partially unwritten about. Additionally, experts in the field might have perspectives on how this system could be applied or what specific bottlenecks might be when designing such a system. These varying perspectives will be especially valuable when finalizing the design and detailing of the façade system. Furthermore, I am specifically interested in the ways manufacturers hand out guarantees for facades. As of now there is an implication that this system might not be able to minimize deflections enough for traditional finishes. However, there might be a potential for this system to allow for larger deflections than normal. Since there are no rules for maximum deflections in Europe (apart from glazing) manufactures are now the ones handing out guidelines and limits. Figuring out ways to allow for greater deflections will make this system more efficient.

Literature and general practical references

So far, my Endnote Library looks like this:

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Timoshenko, S., & Gere, J. M. (1961). *Theory of elastic stability* (2nd , Dover ed.). Dover Publications. http://www.freading.com/ebooks/details/r:download/ZnJlYWQ6OTc4MDQ4NjEzNDgwMjpl

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Zhang, Z., Shi, G., Wang, S., & Zhou, L. (2022). Investigation on buckling behavior of T-shaped box-T section columns under axial load. *Engineering Structures*, *254*, 113904. https://doi.org/https://doi.org/10.1016/j.engstruct.2022.113904

Zhao, Y., Chen, G., Song, S., Huang, M., Zhang, T., Li, P., & Xiong, G. (2024). Research on Wind Resistance Optimization Method for Cable-Stiffened, Single-Layer Spherical Reticulated Shell Based on QPSO Algorithm. *Buildings*, *14*(8).

Some of these sources are books on structural engineering, that I might not reference in the thesis, but help me improve my understanding of some of the problems. I also use other online resources like recorded lectures or videos of reputable sources to develop my understanding of structural engineering. (e.g. https://www.youtube.com/@TheEfficientEngineer, https://www.youtube.com/@AnsysLearning).

Furthermore, as stated in the method description I use the Grasshopper plugins Karamba (https://karamba3d.com/) and Kangaroo (http://kangaroo3d.com/), the FEA software Ansys mechanical (https://www.ansys.com/products/structures/ansys-mechanical) and the Granta EduPack material database (https://www.ansys.com/products/materials/granta-edupack). These packages or plugins are all supported and licensed by TU Delft. Any other software packages or plugins will be discussed with my mentors if need be.

In terms of practical expertise, there is an external advisor Jacopo Montali from Algorixon. His company also holds the patent in the design concept, and he provides a large amount of knowledge already gained on the system.

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)?

There is a strong correlation between the BT courses and the body of research of my thesis. I am using a lot of the knowledge gained in courses like SAMS and electives such as Façade Design. Furthermore, there is a lot more knowledge within the Department of AE+T with the professors that are assisting me so far. As this project strikes a great balance between Façade Design & Engineering and Structural Design & Mechanics.

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

There is a high relevance for the professional field. Testing and evaluating a new system that might outperform others on the market.
Scientifically it is also relevant as there currently is no other similar system like it properly tested. Out of plane resistance realised with in plane pretensioned cables is only done in cable stayed facades spanning larger areas with external load bearing structures. Within a panelised and modular context there is a gap in knowledge.

Socially there could be an impact if the system performs well enough. If it turns out the system could be more affordable or efficient, it might create scenarios where a certain design can be realized that otherwise would have to be compromised.
Also, there is a body of research on the acceptable deformation limits under the graduation topic 'Are users a barrier to leaner façades & structure?'. There could be a possible conclusion to this research where if we do start to accept higher deformations, this system could potentially be much more efficient. However, this is currently still outside the scope of my thesis.