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	Nick Heijne
Student number	5432944

Studio		
Name / Theme	Sustainable Structures studio	
Main mentor	Mauro Overend	Structural design
Second mentor	Hans Hoogenboom	Design informatics
Argumentation of choice of the studio	Structural steel members count for a large proportion of the construction industry's embodied energy and emitted emissions. Although the manufacturing of structural steel elements has a negative impact on the environment their lifespan tends to be long. Therefore it is interesting to look at the reuse potential of steel members for structural design. It is interesting to work on such a big topic and try to make a positive impact on the environment. Solving this in a smart and innovative way with the use of computational design is what motivated me to choose this studio.	

Graduation project	
Title of the graduation project	Computational optimization of gridshell structures designed with reused steel members.
Goal	
Location:	The location of the case study for this research is located at the Carel van Bylandtlaan in the Hague where the campus of Shell is situated. Here the company Octatube already constructed a gridshell above one of the courtyards this office building has.
The posed problem,	The building industry is responsible for a large amount of CO_2 emissions. With an estimated 11.7 GT in 2020, the building industry emitted 36% of the worldwide CO_2 emissions (Bertin et al., 2022). This results in the need to efficiently use the current material supply. Within the principles of the circular economy, materials are kept in use by creating closed loops. Strategies for this are repairing, reusing and recycling of members (Brütting et al., 2019). Where recycling of steel components is common practice, reusing steel components is less known. Reusing structural steel components can reduce overall emissions because it excludes the highly impactful manufacturing phase (Yeung et al., 2016).

	Structural steel is suitable for reuse because members are often connected by reversible connection principles. The steel industry also has a high level of standardization and prior to reuse the structural integrity can be easier guaranteed through testing in comparison to concrete (Fivet & Brütting, 2020). Currently, there are some bottlenecks regarding the reuse of building components and therefore structural steel members. One of those problems is the lack of supply and demand (Gorgolewski, 2019), this results in scraps whereby the sizes (length and cross-section) greatly differ. To make the design of structures out of reclaimed materials even more complex is the fact that a reuse rate of 100% doesn't necessarily mean an optimal environmental performance (Brütting et al., 2020). From 1925 to 1975 shell structures were a popular structural topology made out of concrete or masonry. In this time material was more expensive than labor (Chilton & Chuang, 2017). Development in digital design, digital fabrication and the demand for the reduction of material usage shell structures are again an upcoming structural topology. In particular, the gridshell, existing out of members and nodes instead of a surface (Dyvik et al., 2021). The reuse of components in new structures implies a shift in the design paradigm. Instead of manufacturing for design there needs to be designed from what is manufactured (Gorgolewski, 2008). To facilitate and ease the reuse in structural design the concept of stock-constrained optimization is introduced. Stock-constrained design is the configuration of a structure from a set of finite amount of members. A lot of research in this area is conducted by Jan Brütting. The work is mostly focused on trusses and the designs remain fairly conceptual. The load cases that are used are not always realistic. Node-design and cladding-design is something that is not taken into account. Lastly, they mention that more research with an existing stock would contribute in validating their presented principles (Brütting et al., 2020). Additionally, the constraints that are used in this research work do not directly relate to the design of gridshell structures. It is also mentioned in Brütting et al. (2019) that simultaneous optimization of topology, geometry and stock assignment could potentially lead to more optimal results. In Warmuth et al. (2021) a computational tool integrated in the visual programming software Grasshopper is introduced. Here stock is assigned by either the Best-Fit method or the MILP method. What this current tool is lacking is the freedom to change the reuse scenario.
research questions and	**Main question:** How can computational optimization contribute to improving the eco-impact of gridshell structures consisting of a finite stock of reclaimed steel members? **Sub-questions:**

<table>
<tr><td></td><td>Related to current knowledge and literature study:

1. How can we classify gridshell structures and what are current constraints?
1.1 What is the influence of the classifications on node and glass design?
1.2 What are the manufacturing constraints in gridshell design?
1.3 What are the mechanical constraints in gridshell design?
2. How can structural steel members be reused in new structures?
2.1 How to guarantee the structural integrity of reused steel members?
2.2 How do we calculate the eco-impact of reused structural members?
3. What are existing computational optimization methods used in stock-constrained design?
4. What are existing computational optimization methods used in gridshell design?

Based on/related to the design:

5. What are the constraints that are taken into account in the C30 gridshell from Octatube?
6. What Grasshopper integrated black-box algorithm can solve the structural problem most efficient?
7. What type of gridshell performs best in terms of GHG emissions?</td></tr>
<tr><td>design assignment in which these result.</td><td>This research will result in a computational optimization tool/method for designing gridshell structures out of a predefined stock with the objective of reducing the eco-impact of the overall structure.

To validate the feasibility of the outcome of the optimization tool/method final detailing of the gridshell structure will be proposed.</td></tr>
<tr><td colspan="2">[This should be formulated in such a way that the graduation project can answer these questions.
The definition of the problem has to be significant to a clearly defined area of research and design.]</td></tr>
<tr><td colspan="2">Process</td></tr>
<tr><td colspan="2">Method description
The first phase of the research is focused on existing literature. This research is subdivided into the general topics: reuse, optimization and gridshells. Within these different topics multiple subtopics are divined. Then again these subtopics are divided into even smaller topics. The smaller topics will help answering the questions related to the broader topic. Each topic or subtopic is related to a research sub-question (see diagram).</td></tr>
</table>

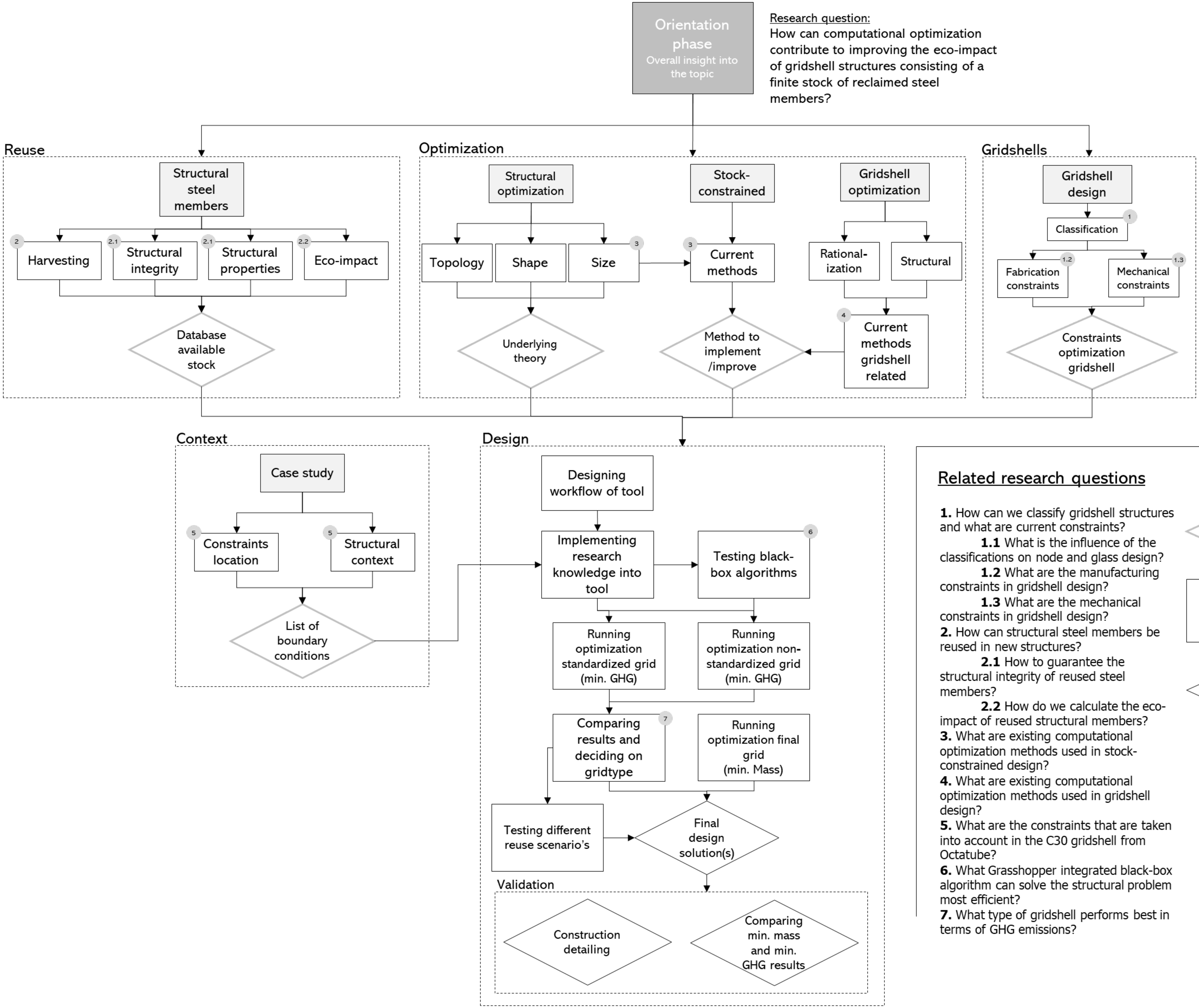
Resultant of the literature research is the knowledge that can be used for the final design of an optimization tool/method. Examples of these resultants are as follows. Within the topic "Reuse" the resultant will be a definition of a database with available stock including necessary member properties. For the topic "Optimization" the resultant will be knowledge of existing methods and the underlying theory. This can be used as the basis for the design of the optimization tool/method. Within the topic "Gridshells" the resultant will be a set of constraints to be implemented into the tool/method.

Parallel to the literature research phase, research will be conducted into the context of the project C30 from Octatube. This project will be used as a starting point for the optimization tool/method and will help present a realistic case. Research into the context of this project include constraints presented by the location (overall dimensions, maximum height) and the structural context (load cases, supports etc.). Currently, there is good contact with the engineering office Octatube, it is expected that this general information can be provided by them. This part of the research will result in a list of boundary conditions and constraints related to the site.

The design phase includes the design of the optimization tool/method as well as the validation of the design. First, the tool/method itself will be designed. The design of the tool/method uses all the knowledge from previous research and will be designed in Rhino3D Grasshopper from McNeel with the possibility of integrating Python. Within the topology optimization methods for gridshells there is a clear distinction between a rationalized standardized grid and a non-standard grid. After designing the tool/method the difference in performance will be tested and there will be decided which of the two topologies will be further tested and validated. After finding the best-performing topology the greenhouse gas-optimized structure will be compared to a structure that is made out of only new members with the objective of minimizing mass. Additionally, different reuse scenario's could be tested. Testing of different scenario's can give an insight into when reuse is feasible. To validate the constructability of the optimized gridshell, a proposal of detailing is presented.

On the next page, the research diagram is presented illustrating the steps as mentioned in the text above. On the page after the research diagram, an overall time planning is illustrated.

[A description of the methods and techniques of research and design, which are going to be utilized.]



Related research questions

1. How can we classify gridshell structures and what are current constraints?
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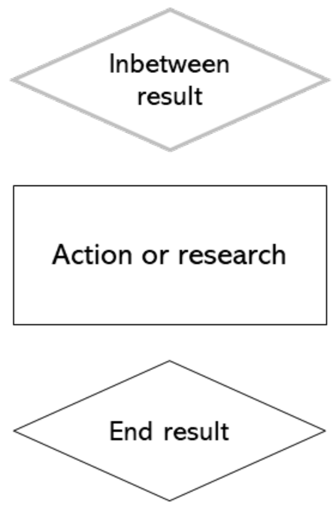
Legend



	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
	Start	14/Nov	21/Nov	28/Nov	05/Dec	12/Dec	19/Dec	26/Dec	02/Jan	09/Jan	16/Jan	23/Jan	30/Jan	06/Feb	13/Feb	20/Feb	27/Feb	06/Mar	13/Mar	20/Mar	27/Mar	03/Apr	10/Apr	17/Apr	24/Apr	01/May	08/May	15/May	22/May	29/May	05/Jun	12/Jun	19/Jun	26/Jun	03/Jul
	Stage	P1										P2									P3								P4					P5	
P2 phase	Influence on glass																																		
	Constraints location																																		
	Structural context																																		
	Gridpattern & topology																																		
	Influence on nodes					report writing																													
	Structural integrity																																		
	Structural properties																																		
	Harvesting						report writing																												
	Eco-impact reuse																																		
	Gridshell opt. meth.										report writing																								
	Gridshell constraints																																		
	Stock-constrained meth.																																		
	Report																																		
	Graduation plan																																		
	Outline of the design-task																																		
P3 phase	Optimization tool																																		
	Research by design results conceptual																																		
	Draft reflection																																		
	Conceptual thesis report																																		
P4 phase	Comparison new versus old																																		
	Final reflection																																		
	Research by design results final																																		
	Draft final thesis report																																		
P5 phase	Reflection																																		
	Final thesis writing																																		
	Final presentation																																		
											Graduation plan deadline→		←P2 presentation																						

Literature and general practical preference

Reuse of structural members

In terms of reuse and related bottlenecks, the research output from Gorgolewski (2019) is interesting. Also, the research from Brütting, Senatore, et al. (2019) will be used. The more practical reports that will be used regarding the certification and testing proceedings are (den Hollander, n.d.) and (Girao Coelho et al., 2020).

(Structural) optimization

Interesting literature on the overall methodology of structural optimization can be found in (Li, 2018). For optimization approaches focused on gridshell structural performance the research conducted by (Gythiel & Schevenels, 2022), (Grande et al., 2020) and (Feng et al., 2016) is interesting. In terms of grid rationalization approaches the research conducted by (Z. Li et al., 2022) and (Q. Wang et al., 2019) is interesting. For the underlying theory of optimization (algorithms) the sources (Burczyński et al., 2020), (Kochenderfer & Wheeler, 2019) and (Snyman & Wilke, 2018) will be used.

Stock-constrained optimization

Within the topic of stock-constrained optimization, the methods presented in (Brütting et al., 2021), (Brütting et al., 2018) and (Warmuth et al., 2021) will be used. For the underlying theory of the methods referred to in the above-mentioned research (Albers et al., 2021) and online sources related to combinatorial optimization can be consulted.
In the design of the method/tool parts of the software developed by Warmuth et al., (2021) can be implemented.

Gridshell related

For an overview of current gridshell research (Dyvik et al., 2021) will be used. For general knowledge of gridshells the books (Schober, 2015) and (Adriaenssens et al., 2014) will be consulted. For additional knowledge from the industry, this research is conducted in close contact with the company Octatube.

See the appendix for the full list of sources.

[The literature (theories or research data) and general practical experience/precedent you intend to consult.]

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 research "Computational optimization of gridshell structures designed with reused steel members" combines knowledge in design informatics and structural engineering. Therefore it is related to the chairs structural design and design informatics, thus related to the master track Building Technology. By including the circular economy strategy of reuse, this topic also aligns with the vision of sustainability of the overall master track and TU Delft.

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

On the social aspect, this research is relevant because it stimulates one of the strategies related to the circular economy. A circular approach in the built environment will decrease the need for virgin material and therefore decrease overall emissions. This will eventually help in tackling the climate crisis that we are facing now.

On the scientific aspect, this research is relevant because it contributes to already consisting research in stock-constrained design. This research will benefit the translation of scientific theoretical knowledge towards real-world practice. It will also provide knowledge into a structural topology that hasn't been intensively researched yet within the domains of stock-constrained design.

On the professional aspect, this research is relevant because the reuse of members in gridshell topologies will be more approachable and therefore easier. With the development of a tool/method that could be used by designers and engineers a good indication can be made of what the ecological benefits of reusing versus producing new members will be.

Appendix - Full reference list

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