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	Jirri van den Bos
Student number	4801792

Studio		
Name / Theme	AR3B025 Building Technology Graduation Studio	
Main mentor	Serdar Asut	Design Informatics
Second mentor	Marcel Bilow	Façade & Product Design
Argumentation of choice of the studio	My growing interest in the practical, technical and digital side of building development is the leading characteristic of my development through Architectural Education. The natural next step in this process is a Graduation in BT.	

Graduation project	
Title of the graduation project	(Re)assembly towards a future of automatic reuse and reconfiguration
Goal	
Location:	Serpentine Pavilion at Kensington Park, London, UK
The posed problem,	Realizing freeform building geometry requires complex and time-consuming processes in computational shape rationalization, fabrication of custom nodes & beams and in-situ construction. Custom building elements are not suitable for reuse and are preferably recycled in a relatively high energy-consuming melting process.
research questions and	How can a design to production workflow be developed towards automatic assembly and circularity of nodes & beams in different freeform building façades? Sub-questions: How can optimal rationalizations of freeform building façades be determined and computationally implemented in a user accessible manner? How can façade design variation be generated and used to further define the boundary conditions of reusable nodes & beams in freeform building façades? What is the state of the art in robotic construction and how can it be used to further define the boundary conditions of reusable nodes & beams in freeform building façades?

	How can a reusable node & beam system for freeform building façades be designed? How can the designed nodes & beams be used in a computationally informed robotic construction process to develop an ever changing pavilion?
design assignment in which these result.	While this research is focused on developing the technology of a design to production workflow through an extensive literature review on mesh rationalization, robotic construction and facade systems, many integral steps in this process require different design assignments. Some are part of the technical implementation: A facade system has to be designed iteratively to increase efficacy and efficiency and a computational workflow has to be designed to optimally communicate complex information to the user. A design to production workflow also naturally needs different designs to test whether initial objectives have been achieved. To provide this testing canvas this research proposes an ever changing pavilion to be displayed at Serpentine Gallery in London. This rearranging architectural art installation will cycle through different design layouts, validating the workflow and providing a tangible example of the systems potential. A scale model of this design will be realized to do practical testing in the LAMA lab.

Process

Method description

To structure the process a symbiotic supporting relationship between literature research, technical development and iterative design is desirable. Throughout the entire process the ratio between these aspects is liable to change, but none should ever fall completely to the background. Each can positively reinforce the process of others. Development is only possible with a broad literature understanding and conversely focussed literature review is only possible when developmental limitations are understood. Similarly, any design assignment should be approached from clear boundaries understood through development and literature. This framework aims to support an integral research and design approach directed at developing a design to production framework towards automatic assembly and circularity of nodes & beams in different freeform building façades.

Before any design assignments can be considered preliminary research and integration has to be done to establish boundary conditions. Starting with rationalization decisions in the development of freeform architecture as these are of paramount importance to the feasibility of all consequent steps in realisation. Rationalization can be defined as any interpreted adaptation of the initial shape to refine constructability. An example of rationalization is the process of panelising an input shape into developable elements. Increasingly complex steps can be considered to further increase simplicity and feasibility of realisation. In order to present these different considerations in an understandable manner a user-accessible computational tool will be developed. This will form the computational backbone to all further development, research and design.

By generating and testing many different design configurations in the computational model, design parameters like rotation axes, angle ranges and node similarity can be established. Consequently, these parameters can be used to firstly make an informed decision on the design direction and can secondly be used as a list of requirements. This will then result in the design assignment to create a system to reuse beams & nodes. Feasible methods seem to be reusing nodes with high similarity or by developing a node that can be variably configured. Which approach is preferable will result from quantitative analysis.

Since optimization of starting conditions has been a main consideration in the computational workflow it should have a similar position in the physical fabrication and assembly processes. Taking limits of automatic fabrication methods into account when designing parts is referred to as Design for Manufacture. How well this is implemented is often the deciding factor in the feasibility of a design and as such should be central to the design process. While robotic automation has undeniably skyrocketed productivity in factories, implementation of this technology outside a controlled environment has only recently seen development. Although still in its infancy, robotic automation of the construction sector promises to provide on-site automation to increase productivity. The state of the art in robotic construction will be reviewed and findings will be used to both inform the design process of node reusability and to recommend technical development towards a well-integrated robotic construction solution.

Robotics and construction are currently two far removed sectors of technology. Any development in robotic construction requires deep collaboration between robotic development and constructional implementation. As this research is written within the scope of building technology the focus will naturally lie on implementation, not robotic development. While discussed robotic options may be seen as more optimal solutions to the proposed problem, the eventual implementation will be limited to the available hardware, in this case a UR5 in the LAMA Lab. This industrial robot arm will use a scale model of the facade system to reassemble a pavilion between different configurations as the practical culmination of every aspect in this research.

Literature and general practical preference

The aim of this research is to develop a novel design to production workflow for freeform building façades with a focus on automatic processes and circularity of elements. By using contemporary literature on freeform rationalization techniques a computational model is developed. A quantitative analysis of this model is to be combined with the state of the art in robotic construction to establish design requirements for a reusable node & beam system. Subsequently, this system will be iteratively designed and used as the building block for an ever changing pavilion.

This research will be conducted under the following research question: "How can a design to production workflow be developed towards automatic assembly and circularity of nodes & beams in different freeform building façades?" The scope of this research is purposely limited to nodes & beams. Façade panels will be discussed as an important part of rationalization theories. The added complexity of also considering the automation and circularity of façade panels could not be afforded within this master thesis. Next to this the scope of the practical implementation is limited to the available technology at the Faculty of Architecture and the Built Environment at the TU Delft. While this limit should not have a large impact on the design process as all existing technologies will be considered, the final produced design might have to be adapted to be compatible with available hardware.

The structure of this research is defined by a collection of sub-questions that further specify each step along the process. In this section the sub-questions will be introduced and, where applicable, the literature search methodology will be described and a selection of the associated literature will be presented.

First, "How can optimal rationalizations of freeform building façades be determined and computationally implemented in a user accessible manner?". To answer this question an extensive literature review into rationalization theorems has to be done. A research survey titled "Architectural Geometry" by Pottman et al. (2015) is a good place to start. Since this topic has a significant overlap with Discrete Differential Geometry a general understanding and explanation of this topic is required. "A Glimpse into Discrete Differential Geometry" by Crane & Wardetzky (2017) clearly explains these mathematical intricacies. A more specific literature search has also been started via Scopus and by analysis of specific journals. This has currently resulted in 16 references. To develop a user accessible interface a research by design approach will be used.

Second, "How can façade design variation be generated and used to further define the boundary conditions of reusable nodes & beams in freeform building façades?". Most of the literature related to this sub-question has been used in the previous section to develop the computational method applied here. This subsection will contain technical development to create a shape generator which is used to collect quantitative data to inform design boundaries. Some preliminary research will be done into shape generation and statistical principles will be applied to data analysis.

Third, "What is the state of the art in robotic construction and how can it be used to further define the boundary conditions of reusable nodes & beams in freeform building façades?". This subsection will again be characterised by an extensive literature review into the state of the art in robotic construction. A research survey titled "On Site Autonomous Construction Robots: Unsupervised Buildings" by Melenbrink et al. (2020) is a very useful general reference. An exhaustive literature review using Scopus yielded 226 sources of which 27 were deemed relevant to this research. A selection of secondary sources has been prepared but those are not yet analysed.

Fourth, "How can a reusable node & beam system for freeform building façades be designed?". A lot of previously gathered literature and data will be used in this subsection to inform the iterative research through design process of a node & beam system. Literature will be used to establish the state of the art in the construction of freeform façades.

Fifth, "How can the designed nodes & beams be used in a computationally informed robotic construction process to develop an ever changing pavilion?" Literary knowledge collected on robotic construction will be used in this subsection to inform the design of an everchanging pavilion. A proposal for an integral robotic construction system will be made based on the collected literature and the practical implementation of the scale model in the lab will be described.

Throughout the entire research the quality of sources will be scrutinised to ensure a high academic quality of this thesis. Abundant contemporary sources will be consulted, compared and discussed to ensure the academic relevance and novelty of the provided research.

Reflection

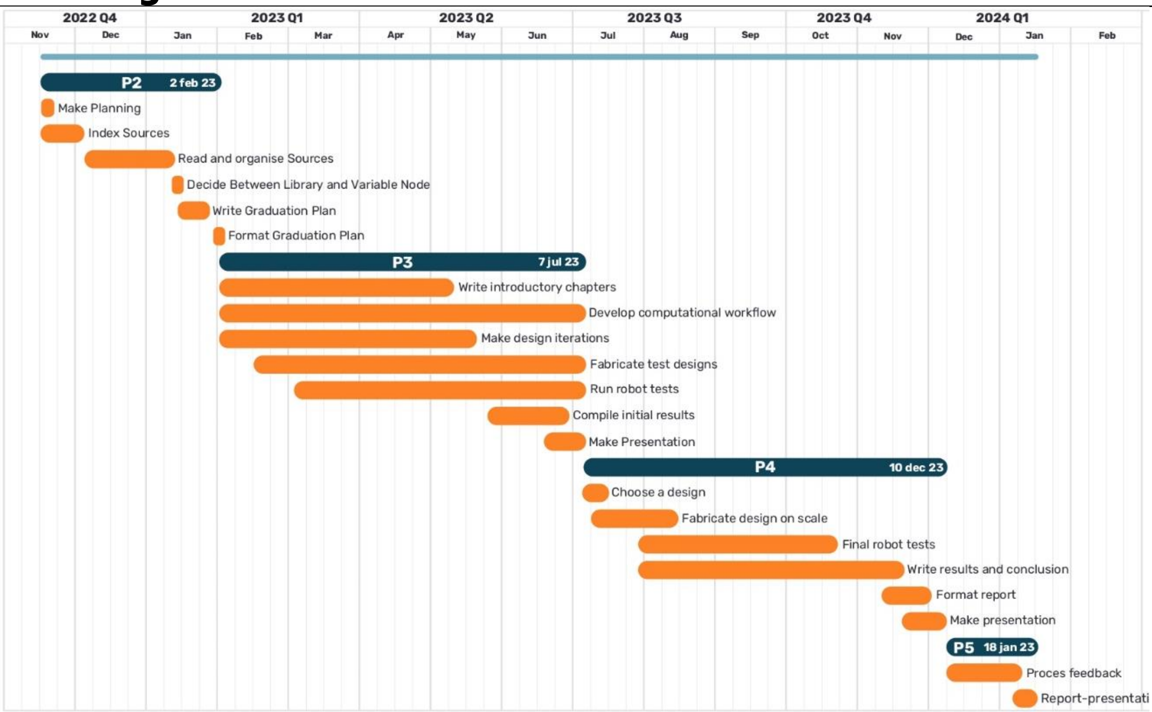
1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

The goal statement of Building Technology is the following: "The emphasis of Building Technology is on the design of innovative and sustainable building components and their integration into the built environment." (Track: Building Technology, 2023). Research into a reusable freeform façade system in order to motivate circularity and productivity in construction perfectly fits the description of developing innovative and sustainable building components. Working to increase feasibility with every step along the design and development process will constantly improve the likelihood of integration into the built environment. Arguably the most valuable skill taught at BT is iterative design to create progressively simpler solutions to complex problems, personally I'd like to further develop this skill.

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

The complexity and time-consumption of realizing freeform architecture inherently raises the cost, ensuring the minority stake of this architecture in all construction. Due to this high cost and minority stake, custom solutions are often viewed as sufficient. Consequently, research and implementation of a unified system has been slow. In contrast, the further development of computational tools has skyrocketed and with it the occurrence of freeform architecture is bound to increase. This research hopes to respond to this trend in the built environment and provide a solution that will increase circularity and productivity in this specific subsection of the construction sector.

Planning



As shown in the above Gannt chart, my planning is extended to Q1 of 2024. This will result in a graduation process that is exactly twice as long. This is due to my position as student assistant for the Handzone project for which I work 0.5FTE. While the graduation does take twice as long, the time spent will be the same as I only have the other 0.5FTE left. This has been discussed by the exam committee and they have expressed their approval.

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Note: All sources have been read, indexed and notes have been taken for future use.

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