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	**H.N.Rusting**
Student number	9717445

Studio		
Name / Theme	Building Technology Graduation Studio	
Main mentor	Dr.-Ing. M. Bilow	Chair of Building Product Innovation
Second mentor	ir. P. de Ruiter	Chair of Design Informatics
Delegate Board of Examiners	ir. G. Coumans	Architecture Form and Modelling Studies
Argumentation of choice of the studio	The construction industry in the Netherlands is under a lot of pressure to deliver a large number of sustainable buildings (Tavares et al., 2019) to meet the demand in the coming years. To do this, it is necessary to apply innovative building techniques and more sustainable building materials. Both the Chair of Building Product Innovation and the Chair of Design Informatics are indispensable to achieve this goal.	

Graduation project	
Title of the graduation project	**Automating Wood for free form architecture**
Goal	
Location:	Depot Boijmans van Beuningen, Rotterdam, The Netherlands
The posed problem,	The problem addressed in this research is twofold, although wood is being considered a good alternative for less sustainable building materials (Dangel, 2016) it is not yet widely used in free form architecture and secondly the level of automation and industrialization of the construction industry is low compared to other sectors. Wood in free form architecture Wood is and always has been widely used in buildings but became less common with the rise of new building materials like concrete and steel during the industrial revolution. These

	materials helped to enable the design and construction of larger and higher buildings. Around 1885 this led to the first modern skyscrapers in the United States of America (USA). These buildings cannot be considered free form because they do not fit the definition as formulated by (Veltkamp, 2007) as building shapes that are double curved, which do not feature repetition of elements and of which the shape is not structurally optimized. For the introduction of free form architecture other advancements in technology were needed. Through developments in computer aided design (CAD) and computer aided manufacturing (CAM) techniques in the second half of the 20th century it became much easier to design and fabricate complex free form shapes in architecture (Kolarevic, 2004). These free-form buildings mostly rely on concrete, steel, glass and aluminum for their structure and facades. In the design and construction of family housing timber remains widely used because of its availability, design flexibility and the short construction times. In Germany the choice for timber as a construction material is obstructed by classical prejudices such as low value stability, the poor overall quality of timber frame houses, respectively, their high combustibility and extensive maintenance, and their relatively high price (Gold and Rubik, 2009). The interest in wood as a sustainable alternative building material (Dangel, 2016) for high-rise buildings nevertheless has increased with the growing awareness that the threats of climate change and the scarcity of non-renewable resources are real and need to be dealt with. Using wood instead of steel and concrete for tall, super-tall and even mega-tall buildings is being researched (Li et al., 2019, Foster et al., 2017) and the first timber high rise buildings have been built. The use of wood in free-form architecture however is rare even though it could contribute to a more sustainable built environment and construction industry. Because of this the first part of problem statement is about using wood (or wood products) as a building material for free-form architecture. Level of automation and industrialization of the construction industry In the traditional construction industry, the level of automation and industrialization is low compared to other industries (McKinsey Global Institute, 2017). There are exceptions. For example, in timber frame construction. Companies operating in this area mostly limit themselves to

	the design and fabrication of orthogonal buildings and incorporate multiple facade functions into their building components. For example, insulation. The fabrication processes they use have a relatively high degree of automation and industrialization compared to the more traditional on site construction methods. Contemporary architecture however does not limit itself to orthogonal shapes. A lot of academic research is being done by, for example, Eidgenössische Technische Hochschule (ETH) Zurich's Chair of Architecture and Digital Fabrication and the University of Stuttgart's Institute for Computational Design and Construction into the industrial fabrication of free form timber architecture. This is where the research gap becomes clear. There is a demand for free form timber architecture but the knowledge to fabricate multifunctional free form wooden facade panels in an industrial way is limited.
research questions and	Main research question *How can curved timber multi-functional facade panels be fabricated using an industrial fabrication process?* The sub research questions can be divided in two categories: 1. The curved wooden facade panel Sub Research Questions (SRQ) SRQ 1a: *What are the requirements for a wooden facade?* SRQ 1b: *What are the techniques for creating curved surfaces?* SRQ 1c: *What is the conventional way to build a curved wooden facade?* 2. The automated fabrication process. SRQ 2a: *What is the state of the art regarding the industrial fabrication of wooden building components?*

	SRQ 2b: *What is the influence of curved surfaces on the industrial fabrication process?* SRQ 2c: *What is the state of the art of the fabrication of curved surfaces?*
Design assignment in which these result.	*Design a curved timber facade panel and an automated production process to fabricate it.*

Process

Method description

The research for this thesis has been divided into four phases. These are not perfectly sequential as can been seen in the process scheme below.

Phase 1. Literature research and plan analysis case study

This phase focuses on understanding the two main research topics. Wooden curved facades and automated production processes of wooden building elements. A plan analysis of the Depot Boijmans van Beuningen (Depot) in Rotterdam designed by MVRDV will also be executed to be able to validate the research and the design assignment. This case study will be on going, roughly, between P1 and p4.

Phase 2. Design phase wooden facade

In this phase a wooden facade will be designed for free form buildings using the Depot as validation. The design should be able to be fabricated in an automated industrial process. This process will be designed in phase 3.

Phase 3. Design phase fabrication process

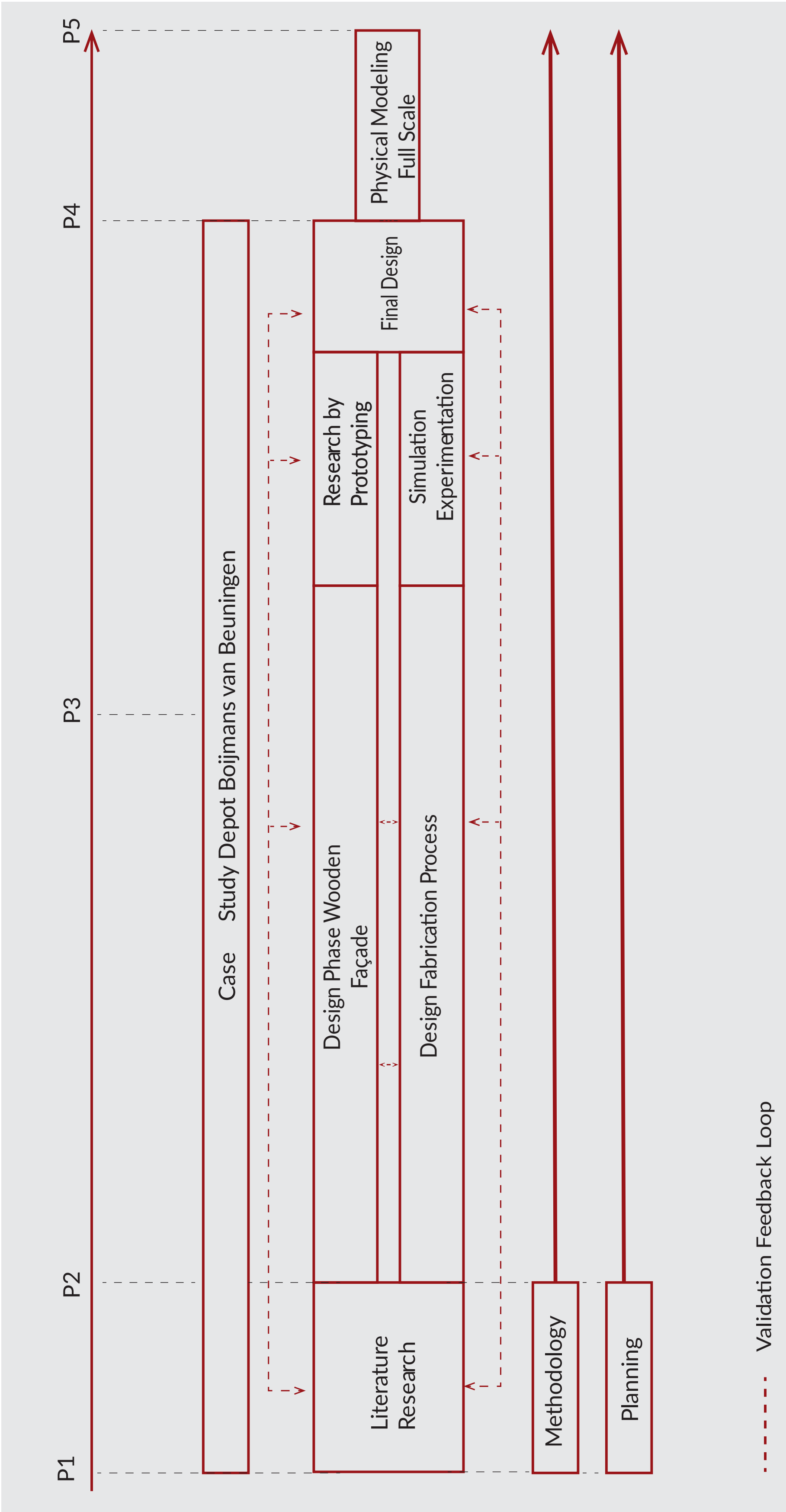
In this phase the facade design produced in phase 2 will be used as input. One of the goals of this research is being able to fabricate wooden building components for free form buildings in an automated industrial process.

Phase 4. Modelling and simulation

The facade panel design produced in phase 2 will be modelled on a small scale and if possible, on full scale. This depends on the design. The production process will be researched by simulation in a virtual environment or by experimentation.

Phase 5. Final design

The findings gathered during the design phase and the validation cycles as shown in the process scheme will be incorporated in the final design. This design will be presented during P4. Feedback received during P4 will be evaluated and if feasible in the given timeframe applied before P5.



Process chart

Literature and general practical preference

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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 programme Architecture, Urbanism and Building Sciences (MSc AUBS) combines knowledge and skills of architectural design, innovative technology, and engineering to create a more sustainable built environment. The master track Building Technology aspires to reach the same goal by integrating sustainable building components into the built environment.
   The subject of my thesis is to design a more sustainable free form facade by applying sustainable materials (built environment) as well as a more sustainable fabrication method (construction industry). This will help to make both the built environment as the construction industry more sustainable.
   Transitioning from on-site construction to off site fabrication and on-site assembly of building components.
   By using renewable materials like wood, the embodied energy and greenhouse gas (GHG) emissions (Tavares et al., 2019) are lower than by using more traditional building materials like steel, concrete, aluminium, and glass. Thus, contributing to a more sustainable built environment. This meets both the goals of the master track building technology and MSc AUBS.

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

   Social relevance

   The construction industry must face several challenges in the years ahead. These can be divided into two main categories (1) increasing productivity to meet the demand (McKinsey Global Institute, 2017). and (2) becoming more sustainable to help limit the effects of climate change (Spence & Mulligan, 1995).

   Because the conventional construction sector is fragmented (McKinsey Global Institute, 2017) the levels of automation and industrial construction are relatively low compared to other sectors (Buš et al., n.d.). This leads to lower productivity and higher variable costs per unit. One of the tactics to meet the challenges can be found in the off-site fabrication of timber building components (McKinsey Global Institute, 2017). This is effective because timber, when produced in a sustainable way, is a very sustainable construction material (Dangel, 2016). Automated, off-site, industrial production of building components can also contribute to a more sustainable built environment by reducing waste, energy consumption, and the production of Global Greenhouse Gas (GHG) (Tavares et al., 2019, Wasim et al., 2020). Examples are plentiful but they mostly deal with conventional timber frame construction.

However, if we look at contemporary architecture there is a demand for curved façades. The goal of this research however is not to promote the design of curved façades per se but to expand the design freedom of architects by introducing a more sustainable and efficient way to fabricate curved timber building components.

Professional relevance

The above-mentioned arguments regarding the social relevance are also true on the professional level. Society demands a more sustainable and productive construction industry. Which has to be made possible by all disciplines in the sector working together. From the architect, responsible for the design, to the contractor who is responsible for the realisation of the building. For us, as building technology engineers, the responsibility is in making the future built environment, envisioned by architects, urbanists and clients, technically possible without compromising the needs of future generations.

Scientific relevance

Scientific relevance is, in my opinion, the presence of a research gap. Does the research of this thesis add anything to the knowledge already available on the subject? In this research that is the case.

The knowledge available about free form wooden architecture is limited as is the knowledge on the industrial fabrication of building parts of curved wooden buildings.