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	Jun Wen Loo
Student number	5205662

Studio		
Name / Theme	Building Technology / Sustainable Design Graduation	
Main mentor	Dr. Serdar Asut	Design Informatics
Second mentor	Ir. Joris Smits	Structural Design
Argumentation of choice of the studio	I chose to work with professors in Design Informatics and Bridge Design as I believe that the design & construction workflow of infrastructures can be empowered with the integration of robotics and bio-based materials, specifically timber.	

Graduation project	
Title of the graduation project	Sustainable Timber Bridge Design with Design-to-Build Workflow involving Robotics
Goal	
Location:	Buiksloterham, Amsterdam, NL
The posed problem,	The problem addressed in this thesis stemmed from 2 main areas; firstly the lack of urban connectivity in Buiksloterham and secondly the need for an exploration towards an effective automated workflow of digital design to a production process involving robotics for the ease and precision of construction. With the rapid urban development in the northern bank of the IJ in Amsterdam, its transition from an industrial town to a mix-use development underscores the growing need for better urban connectivity. Buiksloterham, is amongst the many neighbourhood on the northern bank of the IJ undergoing massive developments. The Amsterdam Gemeente (Municipality of Amsterdam) has identified in Bruggen Buiksloterham (Gemeente Amsterdam, 2021) the need for seven separate bridges to be designed and constructed in accordance to the circular vision as laid out in Groenevisie 2020-2050 (Gemeente Amsterdam, 2020) as well as Circular Buiksloterham (Metabolic et al., 2014). Planned to be built in phases, a tender (Gemeente Amsterdam, 2021) has been

	recently issued on 7th December 2021 for the design and construction of the first of seven bridges, connecting Asterweg and Grasweg across Tolhuiskanaal. This highlights the importance of this bridge hence justifying its choice in this thesis project. This site is also chosen because of the alignment of the municipality's aim for circular construction and materials with the thesis's exploration of timber bridge structures. With a main span of 38m and use as a pedestrian and cyclist bridge, this sets manageable site and functional requirements to design and test a novel timber structure built with robotic construction processes. The second problem stems from the lost of information and efficiency between digital fabrication and its subsequent assembly which is typically manual. The conversion of digital assembly information into analogue plans for the worker to interpret and assemble requires a translation of highly precise information into less precise manual instructions. Furthermore, with the growing complexity and inter-dependencies in computational design of structures and buildings, it is no longer sufficient to represent it in static plans (Helm et al., 2017). Since the inception of digital technology into timber fabrication processes in 1980s, it has transformed hand-tools to multi-axis machines, enabled further by parametric models, to produce highly varied components without lost in efficiency (Buri & Weinand, 2013). Despite the high degree of automation in fabrication, the assembly of these structures are still largely manual (Helm et al., 2017), limited by the scale of the components, machines involved and transportation required. Should the digital information of fabrication and assembly be directly transmitted to the robots and implemented, this would allow for a seamless workflow (Bachmann, 2009) without the intermediary manual process where digital information and assemblage efficiency could be lost. Thus the focus on minimizing the gap between digital fabrication and assembly workflow is key to this thesis project.
research questions and	The main research question is formulated as: - How can we develop an architectural design with a design-to-build workflow by integration of robotics in the construction of a timber bridge in Buiksloterham, Amsterdam? With sub-questions grouped according to the various themes:

	Site Design & Analysis 1) What are the site conditions and requirements of connecting Buiksloterham and how to design for it? *Structural Design* 1) What are the conventional typologies of timber bridge structures? 2) What are the novel timber structures involving digital design, fabrication and assembly which has been explored? 3) What are the requirements and constrains of robotic fabrication processes? *Workflow Design* 1) How to develop a design-to-build workflow for the proposed bridge design and how to integrate robotics into the process?
design assignment in which these result.	This research will culminate in a timber bridge design proposal connecting Asterweg and Grasweg in Buiksloterham, Amsterdam and a design-to-build workflow outlining how the construction processes can be integrated with the use of robotics. The construction workflow will be automated through the use of robotic arm to establish the constructability and potential opportunities and challenges of this proposal. This will allow for a comprehensive design proposal fulfilling the requirements of the site and constructed with state-of-the-art robotic construction processes in achieving a novel timber bridge.

Process

Method description

This research has four main phases with overlaps during the transition from one to another. They are further specified as follows:

Phase 1: Research; Site Analysis and timber structures

This research phase has two main focuses, one in analyzing and understanding the site and its context and the other in establishing an understanding of the state-of-the-art timber structures built.

The first part on Site Analysis will involve the study of masterplans from Geemente Amsterdam and other architecture and urban planning studios in understanding the urban context of future developments. A site visit to Buiksloterham together with

studies into climatic and environmental conditions of the site will culminate in mappings and analysis which will inform the bridge design on the urban and architectural scale.

Running parallel to Site Analysis, a consolidation of conventional timber bridge structures as well as novel timber structures involving digital design, fabrication and assembly processes will be conducted. Key insights on factors such as water management, structural system and span, as well as connection details will be studied for selected case studies. These insights will form a foundation of knowledge required for designing a novel timber bridge structure which will meet the site requirements and be implemented by a robot-based timber construction.

Phase 2: Design Phase; Bridge Design

The Bridge Design phase will build on the research in Phase 1 and develop an urban and architectural design. The design will address the requirements set out by the document provided by Gemeente Amsterdam as well as responding to the mapping and analysis. This will culminate in an urban plan including programmatic arrangement, user profiling, mobility and accessibility together with an architectural proposal in the form of drawings, impressions, preliminary structural and forces evaluations. Relevant physical models of the design across various scales will also be produced to convey the architectural intentions.

Phase 3: Design-to-Build workflow & analysis

With the urban & architectural design of the bridge developed, a design-to-build workflow of typical construction techniques used in constructing this bridge will be studied and mapped. If pre-existing construction techniques for this bridge structure has not been industrially conducted, a new design-to-build workflow will be proposed. Within this workflow, procedures where robots can be integrated will be identified and a new workflow will be proposed and detailed. A section of this new workflow will be selected for prototyping in LAMA Lab using the UR5 Robots or the other robotic arms available. Timber members required for prototyping will also be purchase at this stage.

Phase 4: Robotic Construction & Prototyping

The final phase of the project is experiment based with a scaled or 1:1 robotic programing and execution. This phase aims to test and verify the suitability of implementing a robot-based construction within the scope of this design. It also aims to consolidate the challenges and opportunities of timber construction using robots, whilst building on to existing research in this field. Relevant areas to develop includes the end effector design, physical work site layout, machineries and manpower required. This phase will culminate with video and drawings of the new proposed workflow demonstrating the translation from digital design to fabrication as well as a prototype displaying the segment of the bridge used to demonstrate this workflow.

Literature and general practical preference

The literature referenced in this thesis includes scientific papers, books, programming scripts, weather data and municipality masterplans regarding the site (Buiksloterham, Amsterdam), timber structures as well as robotic fabrication and assembly methods.

References:

Bachmann, E. (2009). Optimierungspotenzial Vorfertigung. *Conference Top Programm Holz.*

Buri, H., & Weinand, Y. (2013). The tectonics of timber architecture in the digital age. *Building with Timber - Paths to the Future*, 56–62.

Gemeente Amsterdam. (2020). *Groenvisie*. Green Vision 2020-2050, A liveable city for people and animals.

Gemeente Amsterdam. (2021a). *Bruggen Buiksloterham 1*.

Gemeente Amsterdam. (2021b). *Selectieleidraad Inhoud*.

Helm, V., Knauss, M., Kohlhammer, T., Gramazio, F., & Kohler, M. (2017). Additive robotic fabrication of complex timber structures. In *Advancing Wood Architecture: A Computational Approach* (pp. 29–43).

Metabolic, Studioninedots, & DELVA Landscape Architects. (2014). *Transitioning Amsterdam to a Circular City*.

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)?

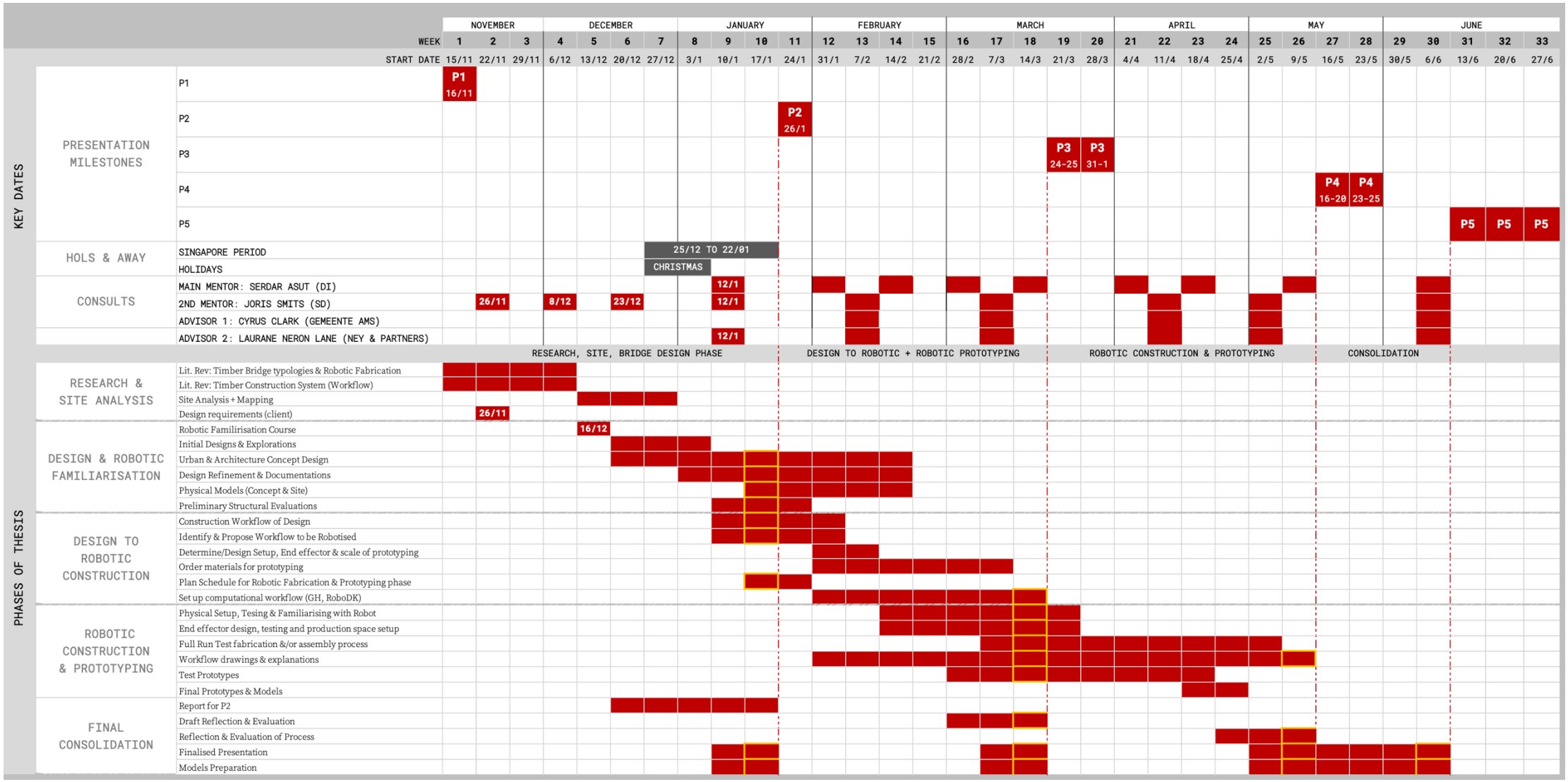
This thesis titled "Sustainable Timber Bridge Design with Design-to-Build Workflow involving Robotics" relates to 2 chairs within Building technology. Firstly Design Informatics is involved in generating the architectural form of a novel timber structure, preliminary evaluation of its structural performance as well as the formulation of the robot-based timber construction workflow. Secondly, Bridge Design, part of the chair of Structural Design & Mechanics is integrated to make socially informed urban and architectural design of infrastructure which reflects the site context and its social fabric as well as ensure a structurally sound design is created.

Both areas relate to the Building Technology Track as it aims to extend the knowledge in the field of robotic construction of novel timber structures. The use of bio-based material and digital design and fabrication techniques aim to make the built environment more sustainable and circular, which is key to achieving the ambitious UN Sustainability goals.

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

Bridge Design has a significance impact on the local communities from urban connectivity, activation of social spaces and creating a sense of identity for neighbouring communities. With the UN Sustainability goals, COP26 and the Netherlands' nation-wide sustainability goals, designing infrastructure with circular and bio-based material like timber has yet to mature. Hence this thesis aims to push the envelope of the possibilities of designing structures in timber.

With the increasing complexity and mutual dependencies of construction components with architectural design, the need for an integrated and seamless digital design and fabrication workflow is necessary. Hence the development of a design-to-build workflow using robots contributes to the increasing pool of knowledge from research labs and studios to actualise and further the integration between design and construction. Within this thesis, the application to a bridge structure seeks to connect state-of-the-art construction techniques to a case where functionality with live and dead loading conditions is required. This thereby demonstrates the real world application of robot-based timber construction to a bridge design.


NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
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
START DATE 15/11 22/11 29/11 6/12 13/12 20/12 27/12 3/1 10/1 17/1 24/1 31/1 7/2 14/2 21/2 28/2 7/3 14/3 21/3 28/3 4/4 11/4 18/4 25/4 2/5 9/5 16/5 23/5 30/5 6/6 13/6 20/6 27/6
KEY DATES
PRESENTATION MILESTONES
P1
P1 16/11
P2
P2 26/1
P3
P3 24-25
P3 31-1
P4
P4 16-20
P4 23-25
P5
P5 P5 P5
HOLS & AWAY
SINGAPORE PERIOD
25/12 TO 22/01
HOLIDAYS
CHRISTMAS
CONSULTS
MAIN MENTOR: SERDAR ASUT (DI)
12/1
2ND MENTOR: JORIS SMITS (SD)
26/11
8/12
23/12
12/1
ADVISOR 1: CYRUS CLARK (GEMEENTE AMS)
ADVISOR 2: LAURANE NERON LANE (NEY & PARTNERS)
12/1
RESEARCH, SITE, BRIDGE DESIGN PHASE
DESIGN TO ROBOTIC + ROBOTIC PROTOTYPING
ROBOTIC CONSTRUCTION & PROTOTYPING
CONSOLIDATION
PHASES OF THESIS
RESEARCH & SITE ANALYSIS
Lit. Rev: Timber Bridge typologies & Robotic Fabrication
Lit. Rev: Timber Construction System (Workflow)
Site Analysis + Mapping
Design requirements (client)
26/11
DESIGN & ROBOTIC FAMILIARISATION
Robotic Familirisation Course
16/12
Initial Designs & Explorations
Urban & Architecture Concept Design
Design Refinement & Documentations
Physical Models (Concept & Site)
Preliminary Structural Evaluations
DESIGN TO ROBOTIC CONSTRUCTION
Construction Workflow of Design
Identify & Propose Workflow to be Robotised
Determine/Design Setup, End effector & scale of prototyping
Order materials for prototyping
Plan Schedule for Robotic Fabrication & Prototyping phase
Set up computational workflow (GH, RoboDK)
ROBOTIC CONSTRUCTION & PROTOTYPING
Physical Setup, Tesing & Familiarising with Robot
End effector design, testing and production space setup
Full Run Test fabrication &/or assembly process
Workflow drawings & explanations
Test Prototypes
Final Prototypes & Models
FINAL CONSOLIDATION
Report for P2
Draft Reflection & Evaluation
Reflection & Evaluation of Process
Finalised Presentation
Models Preparation