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	Jasmine Sham Yu Wong
Student number	5628849

Studio		
Name / Theme	Building Technology Graduation Studio / Computational Design	
Main mentor	Dr. Serdar Asut	Design Informatics
Second mentor	Dr. Stijn Brancart	Structural Design
Argumentation of choice of the studio	The choice to focus my master's thesis on Design Informatics and Structural Design, is based on a personal interest to take the opportunity to learn and gain skills regarding innovative and sustainable technologies in the built environment with a particular interest in developing a sustainable building component with the integration of Additive Manufacturing by using bio-based materials, specifically bamboo.	

Graduation project	
Title of the graduation project	Additive Manufacturing with bamboo
Goal	
Location:	Delft, Netherlands
The posed problem,	The building industry accounts for 30% of global greenhouse gas emissions and utilizes a considerable amount of the raw materials produced worldwide (Craveiro et al., 2019). As the population is rapidly increasing, which impacts the need for affordable houses, the growing demand of non-renewable resources needs to be reduced. The aim to create more ecologically friendly and sustainable processes has boosted interest in the use of natural buildings and production materials. Several natural, re-emerging materials used in the past (e.g. bamboo, straw, reeds,

	and hemp) have been found useful again and deserving of research to fully understand their potential for different applications. By encouraging creative uses of natural resources, spurring eco-innovation, and advancing the circular economy, bamboo products have been proposed as having a major positive environmental impact and specific social and economic benefits. In many industrial applications, bamboo can be used instead of wood, helping to save and restore the world's forests. Bamboo has been used in construction and the built environment for centuries in many parts of the world, particularly in Asia. However, it is not as commonly used in the Western world and other developed countries. This is largely due to a lack of knowledge and understanding about the material's properties and how to properly use it in construction. The material typically comes in different diameters, and it is difficult to make a selection and apply it in the built environment, bamboo characteristics vary as its anatomy varies. Since it is a natural material and due to its anisotropy, it shows a wide variety of mechanical properties, therefore it has limited application in complex geometries. Having bamboo dust and fibers will allow to have freedom in shapes and additive manufacturing is one of the solutions to manage complex geometries and reducing the amount of materials to a minimum. Today, advanced technologies that are frequently utilized in manufacturing are exported for use in the building and architectural industries. Large challenges are being faced by the construction industry as digital technology sensor systems, intelligent machines, and smart

	materials are adopted. Construction-related additive manufacturing is a crucial enabling technology of this change, which has been called "Construction 4.0" (Craveiro et al., 2019). Even though Additive Manufacturing methods have been upgraded to adapt to construction requirements, there is still a need to design materials that can replace existing conventional materials on the market and that are compatible with the aforementioned processes. One of the goals of Construction 4.0 is to increase the use of sustainable construction methods, and using Additive Manufacturing as a platform for materials design enables the use of natural and recycled materials (Craveiro et al., 2019). Natural materials, particularly those derived from bamboo, are still not a common available feedstock for additive manufacturing. There are bamboo-composite filaments made of PLA and bamboo dust (Zhao et al., 2015) and chemically modified bamboo fibers mixed with ABS (Gama et al., 2021), but there is still no fully bio-based composite for additive manufacturing. Bamboo is a sustainable and environmentally friendly material that can be used in additive manufacturing. The fast-growing nature of bamboo means it can be harvested quickly, making it a more sustainable alternative to wood. Additionally, it is a renewable resource, easy to process and distribute, which could make it a cost-effective material for additive manufacturing. However, few explorations have been pursued towards using bamboo in additive manufacturing regarding the consistency, quality control during the printing process and the use of natural additives and binders to enhance material properties.

	More research is needed to better understand the properties and potential of bamboo as a material for additive manufacturing, as well as develop strategies for processing, designing, fabricating and post-processing objects made of bamboo. This research project focuses on filling these gaps.
research questions and	The main research question mentions the goals of looking into the material development, fabrication process and design intention: What is the workflow to develop a building component made of bamboo with additive manufacturing? **Research sub question** The following sub-questions were also elaborated to support the research and as by-products of the work to be developed in order to address the main question. Material - What is the state-of-the-art of additive manufacturing with bio-based materials? - What is the state-of-the-art of additive manufacturing with bamboo? - What does make bamboo relevant for additive manufacturing? Mixture - What are the possible bio-binders that can be used with bamboo to create a printable mixture? - How does the size of the fiber affect the mixture? Fabrication - How does the temperature of the extruder affect the outcome of the paste?

	- What are the geometric limitations when printing with bamboo? Mechanical Properties - What are the structural properties that you get by printing with bamboo? - How much do the structural properties change when the fibers are implemented in the mixture? Design - What are the design criteria in order to develop a building component with additive manufacturing?
design assignment in which these result.	The goal of this research is to build a bridge between bamboo and the construction sector by examining the possibility of novel feedstocks and innovative fabrication processes in order to address the mounting challenges brought on by complicated geometries and designs. The use of bamboo requires innovation and reopening to natural materials, which have been suggested as the basis for the economy of the future because they reflect the transformations brought about by creative thinking, progressive ideas and solutions, industrial evolution, and technological advancement (Borowski et al., 2022). Bamboo's unique combination of strength, growth rate, and sustainability make it an interesting and promising alternative for sustainable construction and manufacturing, especially in additive manufacturing. A bottom-up approach is used in the research, which means that a building component is created using additive manufacturing by reassembling a bamboo dust base and fibers. As a

	result, the use of additive manufacturing and its material composition already places restrictions on the design of the construction component. By understanding the constraints and benefits of additive manufacturing with bamboo, their findings will aid and direct the design of the building component once several tests and trials have been conducted. The tests and assessments can be carried out once the interview and literature review data have been compiled into tables. Additionally, when the recipe is printed, the boundary requirements will allow the design's final shape to be framed. The constraints and benefits of the acquired information will thus be used to determine the printed shape within a six-month period. As little study into the use of bamboo as a feedstock for additive manufacturing is conducted, the design objective of this research is to design an essential element for the building industry.

Process

Method description

As the design is a fundamental part of the research to create new insight, knowledge, and a printed product with a discourse that is practical and theoretical written to be accessible and validated by experts, the typology of this thesis is going to be **research by design**.
This research is based on project-based experimentation by using all currently available technologies regarding digital design and fabrication in architecture with the use of robotic printing.

The process of development of this research is divided into four phases:
Phase 1: Literature Review
Phase 2: Material Research
Phase 3: Design and Prototyping
Phase 4: Conclusions and reflections

The first phase consists of a thorough review of books, reports and websites relevant to the research question leading to a better understanding of the design problem and the definition of the design criteria needed for the next step. More specifically, books

on additive manufacturing and bamboo were consulted at the library of the Faculty of Architecture and Built Environment from TU Delft to build a foundation knowledge on the material and fabrication process. Scientific papers, articles and reports found through search engines such as Google Scholar, Scopus, Research Gate and Springer Link, were selected by establishing keywords in response to the research question and sub-questions.
The research began from a review of bamboo as a construction material, focusing on its properties and the circular use of the material in the built environment. An overview of the different process of additive manufacturing was searched, and also the use of bio-based materials in additive manufacturing.
The current state-of-the-art of additive manufacturing with bamboo was studied in order to understand what are the necessary developments that need to be fulfilled. At the end of the literature review, the conclusions led to the development of specific design criteria that need to be integrated into the design phase and some initial design concepts that could answer the research question.

Phase 2 will start once the literature reading, literature review, and interviews are gathered. Material research consists of material exploration, printability exploration and mechanical testing.
Material mixes will be developed, viscosity and homogeneity will be manually tested. Afterwards, their printability will also be manually tested with the help of a syringe at room temperature. All the results will be documented for analysis and grading, allowing for conclusions to be drawn and for the most promising ones to be selected for the mechanical testing.
With the materials defined, the results will be proceeded by print-testing samples with a simple design using the robotic arm and extruders available at LAMA, the Laboratory for Additive Manufacturing in Architecture. The samples will be tested to gather a dataset of the mechanical properties of the recipes, the aim will be to identify the potential for structural applications and to create a benchmark in terms of mechanical properties of bamboo-based materials for additive manufacturing.

The third phase will be the design and prototyping, a building component will be defined. This element will be fabricated using the material and process explored in the previous phases. Mixture composition and printing process will be refined in order to obtain relevant input from the prototyping phase to draw the final conclusions of the research.

The last and 4th phase will be the compilation of all the work executed and the final answer to the research question. The outcome of the report will be a material mix with the corresponding mechanical properties dataset, and an evaluation of its potential and challenges in the fabrication of a building component, setting a direction for further research work.

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)?

This thesis titled "Additive Manufacturing with Bamboo" relates to two chairs within Building Technology. Design Informatics and Structural Design are involved in developing a prototype and controlling the fabrication process of a product. The latter could as well be transformed into a building component of larger scale, through additive manufacturing, and computational design plays a fundamental role. Structural design is essential to have a better understanding of the entire process, from the characteristics of the material to the mechanical properties of the prototype made with additive manufacturing.

Both areas relate to the Building Technology Track as it aims to extend the knowledge in the field of additive manufacturing with bamboo. The use of a bio-based material and digital design and fabrication techniques aim to make the built environment more sustainable and circular.

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

Social relevance

The construction industry is a significant contributor to greenhouse gas emissions and environmental degradation. To reduce these, the industry must go through a number of changes to become less polluting and more effective with its use of materials and energy. To pave the way for zero-energy or even positive-energy buildings, structures need to be responsive to climate change and designed more intelligently. Additive manufacturing is seen as the future of the construction industry because it offers several advantages over traditional construction methods, such as precision, flexibility, cost savings, speed, and new opportunities. It also can be a sustainable solution for the construction industry as it allows to use sustainable materials such as bamboo in an efficient way.

The use of bamboo in the construction industry has several social and environmental benefits. One of the reasons is given by its potential to create jobs and economic opportunities in rural areas, where bamboo is often grown. Bamboo is a highly renewable resource, and its cultivation and processing can provide a source of income for farmers and rural communities.
In addition, bamboo is a sustainable material that can be grown and harvested with a low environmental impact. Using bamboo in construction can reduce the use of non-renewable resources such as concrete, steel, and lumber, and can lower the carbon footprint of building projects.
Additive manufacturing technology allows for the precise fabrication of complex shapes and geometries, which can enable the use of bamboo in a wider range of applications than traditional construction methods. It facilitates the precise use of the material, reducing waste and saving on costs.

Scientific relevance
This research will look into potential uses for a novel material that could be implemented in the building sector. A natural substitute that could take place of conventional ones.
The mechanical properties of a new material, as well as any potential improvements, will be examined in addition to its viability. These procedures will be scientifically based and could open the door to further research into more material and advancements in the field of material science. Future building materials will be made of natural materials, and new uses for them will be made possible through research into how to reproduce, modify and improve their properties.
The presentation of better and more efficient fabrication techniques will be accompanied by suggestions for clear replacement routes for conventional materials.