

# 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](mailto: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	Ece Sel
Student number	5703581

Studio	
Name / Theme	BT Graduation Studio]
Main mentor	Mauro Overend
Second mentor	Marcel Bilow
Argumentation of choice of the studio	BT   Structural Design & Mechan. BT   Facade & Product Design
	BT Graduation Studio, argument regarding the chosen topic: The construction industry stands out as a major contributor to high carbon emissions due to unsustainable material usage and energy used in the production. There is an urgent need to redefine how we approach design and construction to eliminate the global warming. Therefore is an important need to utilize environmentally friendly, bio-based materials for various applications. The utilization of natural fibers for constructing load-bearing structural components represents an innovative concept to overcome from this problem. Hence, the focus of the "Engineered Circular Biocomposites" theme selection is to address this critical issue.

Graduation project	
Title of the graduation project	Fla[x]lgae: Investigations of Flax fiber reinforced composites with algae-derived polymers for Bio-based Floor Systems
Goal	
Location:	The Netherlands
The posed problem, research questions and design assignment in which these result.	Explained below
	Explained below
	Explained below
<b>The Posed Problem</b>	
The construction industry is one of the major contributors to a high percentage of carbon emissions, primarily due to the usage and production of materials. This includes essential structural components such as concrete and steel, as well as small scale building materials (Barriers, insulation, acoustic materials...) which are used across diverse applications. These materials are mainly non-bio-based, cause unhealthy gases in production, and are limited sources.	

When construction industry is looked from a more detailed perspective, concerning the embodied energy of materials, the analysis from LETI Climate Emergency Design Guide shows that the superstructure claims the largest share at 30%, followed by the substructure at 27%. The guidelines recommend a reduction target of 40% for these emissions. Therefore, upon evaluating the structural volume of components, the floor slab holds the highest percentage at 65%, implying that the floor systems in buildings contribute significantly to carbon emissions (IEA, 2021; IEA 2020, LETI 2023.) Therefore, selection of a material in the construction industry plays a curial role in decreasing carbon emission, also decreasing this problem the global perspective. This will require a shift within approach to selection of materials and lowering the demand for conventional materials to promote low-carbon and bio-based materials (EA, 2021; ETC 2018).

Even though wood is a bio-based material and commonly used supply, it is also limited, and excessive usage might even lead to deforestation. Therefore, looking for further fiber non-wood bio-based approaches are needed to address this environmental impact. It is important to explore alternative, natural, and sustainable materials that are renewable, easily accessible, and do not result in extensive energy loss, but at the same time strong enough to bear loads. Despite the urgency of this matter, the existing literature provides limited insights into comprehensive natural solutions for mitigating the environmental footprint associated with fiber-based natural building materials for their primarily structural building applications as well as bio-based foams which are derived from renewable sources.

### Research Question

“How do the mechanical and structural properties of natural fiber-reinforced bio-composites, featuring a algae-based experimental core, compare to conventional floor systems?”

#### Sub-Research questions

##### 1. Regarding the general composite

- 1.1 To what extent will this floor system be used in the building industry?
- 1.2 What are the flexural, tensile, and compressive strengths of the composite material?
- 1.3 What are the mechanical properties of the component? (flammability, acoustical properties...)
- 1.4 How easy is it to construct/repair/replace the material? What are the connection details?
- 1.5 What is the assumed CO2 emission of the whole product compared to wooded hollow core and concrete hollow core system?

##### 2. Regarding the algae-based polymer

- 2.1 What are the possibilities of algae-derived resin as the matrix for the NFRC
- 2.2 What are the possibilities of using algae-derived epoxy as the core?
- 2.3 What are the effects of foaming agents with alginate/isocyanate on the density and strength of the bio-based core?
- 2.4 What is the overall performance of algae-derived polymers compared to non-biodegradable petroleum-based materials?

### Design assignment in which these result

The primary assignment is to *investigate, experiment, produce, and evaluate by lab testing* the mechanical and structural properties of natural flax fiber-reinforced bio-composites with an algae-based experimental core by resulting in a floor component 30cm x 30cm with different thicknesses at the end. However, through the structural lab analysis, different dimensions might be produced. Through comprehensive bio-based materials investigation, *several composite formulations*, and *structural testing*, the study aims to contribute valuable insights into the feasibility, performance, and environmental sustainability of this bio-based sandwich floor system that can replace conventional floor systems. By doing so, this research aims the understanding and adopt eco-friendly and local construction materials, which are also easy to build, within the built environment.

## Benchmarks

As the design assignment goals a benchmark two hollow core floor systems are considered: wooded and concrete. The comparison primarily focuses on product cycle and environmental criteria sourced from local references specific to the Netherlands. The resulting product is expected to perform better in the following Life Cycle Stages of a product, specifically in A3 (Manufacturing and Fabrication), A5 Construction and Installation Process; B1 (Use), B2 (Maintenance), B3 Repair, B4 Replacement; C1 (Deconstruction and Demolition); C3 (Waste Processing for reuse, recovery or recycling). (EN 15978, EN 15804 standards, United Nations Environment Programma, 2022).

## Building Industry Goals

### 1. Product: Reducing the embodied energy.

- Natural Material Embrace
- Recycled Content Incorporation
- Low-VOC (Volatile Organic Compounds) Materials
- Renewable Resource Utilization
- Carbon-Neutral Material Exploration

### 2. Maintenance: Decrease the need for maintenance for deconstruction, demolition, transportation.

- Easily Detachable Connections:
- Modular and Easily Maintainable Pieces
- Longevity and Efficiency

### 3. Transport: Decreasing the effort for transport

- Handling Efficiency
- Local Material Use:

### 4. Construction: Decreasing the effort for transport

- Ease of Construction
- Minimal Waste Production

### 5. End of life: Biodegradable material

- Following the R-Ladder as much as possible
- Planned end of life scenario

## Material Based Goals

### 1 Material supply

- Bio-based renewable and healthy choice materials
- Minimize material

### 2. Climate and environmental systems effect: Reduced Dependency on Additional Systems:

- Easily Detachable Connections:
- Modular and Easily Maintainable Pieces
- Longevity and Efficiency

### 3. Product Life Span

### 4. Strength-to-Weight Ratio

- Lightweight Design:
- High Strength Properties:

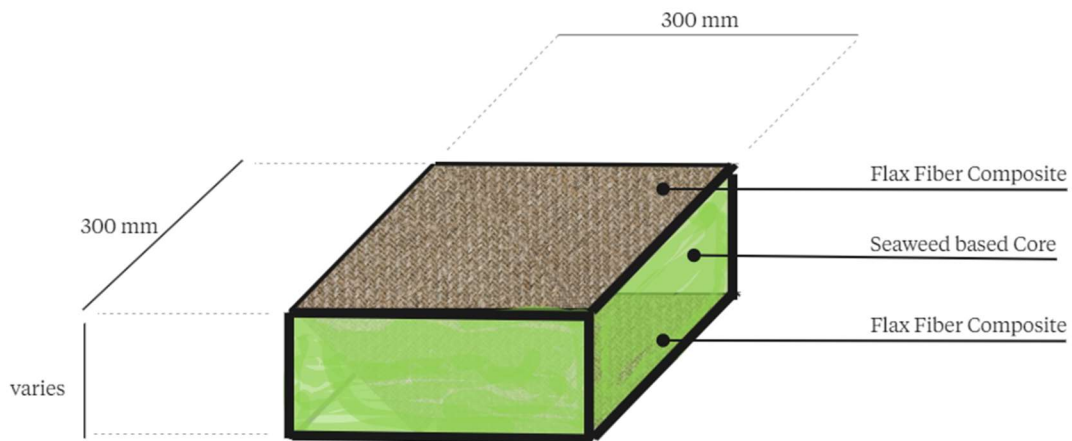
### 5. End-of-life Scenarios & Life-cycle assessment Scenarios

- Following the R-Ladder as much as possible
- Planned end of life scenario

## Process

### Method description

Throughout the research, **three main options** are planned to be investigated, mainly as backup options if the previous option does not work and not possesses good mechanical properties. In each option, while the fiber selection is the same as **flax continuous fibers** (with a change in the fiber structure orientation), **the experimental algae polymer formation** changes. Additionally, it is planned to evaluate the feasibility and merits of those options in the materials sense. Below, the overall process has been explained as producing the fiber-reinforced composite; and as the exploration of the bio-based core.



*Fig: Showing the proposed sandwich panel floor system as a basis for the materials and dimensions*

### Production of the Flax Fiber Composites

#### Materials:

1. Continuous flax fiber matrix (gathered from NPSP, composite company)
2. Algae-based epoxy resin (Gathered/experimented with Aerospace engineering TU Delft)
3. Vacuum infusion technique (NPSP)

#### Test (regarding different weaving for the matrix)

1. Plain weave
2. Twill reinforcement
3. Dobby reinforcement

#### Detailed technique explanation:

Mold Preparation: Creating the flax-fiber arrangements by the desired dimensions

Dry Fiber Placement: Arrange dry flax fibers in the mold.

Vacuum Bagging: Seal the mold with a vacuum bag to create an airtight environment.

Resin Infusion: Pour the pre-prepared resin into a feed line, use a vacuum pump to draw resin through fibers, ensuring a balanced saturation.

Curing: Allow the composite to cure, transforming the resin into a solid.

Demolding: Remove the vacuum bag, and demold the cured composite

Repeat the technique for the other weaved flax fibers.

## Production of the Bio-based Core

### 1. Challenging option: "The bread formation"

This option is regarding the exploration of bio-based partially renewable epoxy-resin, and it so called as "the bread" as it resembles the expanding of the bread. In this stage, the algae-derived renewable epoxy formation will be realized in collaboration with Aerospace Engineering at TU Delft.

After stage one, which is the vacuum infusion technique for flax fibers by combining them with a pre-prepared algae resin, the foam formation starts. For the algae-derived epoxy formation, epoxidized phloroglucinol (PHTE) will be extracted from **brown-algae** and used in the formation of the epoxy by replacing the traditional one. The process begins by assembling mold and pouring the pre-prepared algae-derived epoxy resin formulation. Subsequently, a bio-based epoxy is introduced into the mold. A foaming agent is added to facilitate controlled expansion, allowing the foam to reach the desired level. After approximately 30 minutes, the foam gets ready. The next step involves removing the edges of the mold. If the bond between flax-fibers and foam is not robust enough, additional adhesion may be required; otherwise, the composite is ready.

### 2. Feasible options: "The pop-corn method"

This process offers a simplified approach that can be conducted experimentally, even with a home oven in terms of the foam formation. The pop-corn name comes from the idea of raw materials to expand under certain circumstances, resembling the pop-corns. While this method shares the same starting point as the previous option, the formation of the foam takes a more straightforward route.

Following the preparation of algae-derived foam beads and PLA-derived foam beads, they undergo molding using a similar mold employed in the previous process. Subsequently, the molded beads are subjected to a heat/steam treatment in an oven. This step serves to expand the raw mixture into foam beads and facilitates their integration with the algae-derived resin, imparting strength and ensuring a cohesive bond.

### 3. Safe options: "The pop-corn method"

The option is rather easy and corporately safer option regarding the pre-mentioned two methods. Again, this method also shares the same starting point as the previous options but in this one the core is made through natural sources which are already used; wood foam or cardboard.

## Testing Stage

The standard specimen is intended for use during the testing stage. Consequently, structural testing will be carried out at the TU Delft faculties of Bouwkunde, Civil Engineering, and Aerospace Engineering, taking into account the required tests and the availability of test environments. For these testing phases, a different type of specimen is planned for production compared to the ones mentioned earlier as the lab testing machine might require it and to comply with the test regulations.

## Literature and general practical references

Literature research has been conducted according to the following topic. (general topics)

1. Construction Industry and Carbon Emission, sustainability, and Paris Agreement
2. Floor systems and their related carbon emission
3. Natural Fiber reinforced composites and their applications
4. Polymers and composites, how they are made of
5. Bio-based polymers and their methods
6. Natural fiber reinforced composite Manufacturing Techniques
7. Algae-based foams/insulations and the methodology to produce them

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## THESIS

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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 thesis choice aims to advance the current state-of-the-art design with non-wood fibers. Throughout the research, two chairs of Building Technology are involved: structural design and mechanics, and product design. While both chairs are closely related to material choice, the structural and mechanical chair aims to design a floor system capable of withstanding loads properly with great tensile and compressive strength proven by the further testing of the product. For the product design part, the focus is more on the product in terms of methodology/testing choice as well as the design of the floor system with efficient connections and proper tools. As the BT track delves into the details of designing innovative and sustainable building components and their integration into the built environment, the proposed research on "Investigations of Flax fiber reinforced composites with algae-derived polymers for Bio-based Floor Systems" is well-integrated with the study track's objectives.

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

### Social framework

The research is aiming to find a potential floor system made of non-toxic and renewable resources by providing equal or better mechanical properties, in turn in any of the product phase the carbon emission will be as less possible, leading healthier environments as well as local and long-term inexpensive solutions; which is also a step toward the decreasing the risk of global warming and increasing the goal of reaching net zero. Even though the first attempt could be expensive, by using local and renewable sources, the long-term approaches expected to be effectively affordable. While the initial focus is on the Netherlands, the selection of the fiber could be adapted for several countries.

Furthermore, the product aims to align with the UN Sustainable Development Goals (UN SDG Goals):

Goal 9: Build resilient infrastructure, promote inclusive and sustain. industrial. and foster innovation

Goal 12: Ensure sustainable consumption and production patterns

Goal 13: Take urgent action to combat climate change and its impacts

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustain. develop.

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

### Scientific framework

Regarding the scientific framework, the research is aimed to investigate potentials of flax-fiber natural composite as structural building applications which is not common in the literature. Additionally, a further experiment is made through experimental research regarding the resin formation and foam formation considering them being produced with natural and local resources replacing them to the petroleum-based application, which will lead to an understanding of bio-based and foam insulation more into the chemistry side, raising a detailed perspective on what leads products to be bio-based, renewable, biodegradable etc. This experimental framework is planned to be done in collaboration with Aerospace Engineering at TU Delft, specifically to investigate the possible various strength levels and stiffness of the algae-derived foam and its further possibilities for environmental conditions. Therefore, through this experiment it is expected to answer the gap in the state-of-the-art bio-based lightweight materials with an exceptionally low environmental impact that can be used in various structures and mostly for structural applications.

