# 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** | |
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| Name | Fieke Konijnenberg |
| Student number | 4362764 |

| **Studio** | | |
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| Name / Theme | Building Technology / Bio-based product design | |
| Main mentor | Olga Ioannou | Façade & Product Design |
| Second mentor | Wido Quist | Heritage & Technology |
| Argumentation of choice of the topic | This research intents to provide knowledge on bio-based material design, to aid in lowering emissions produced and energy used by the built environment. The built environment is currently responsible for 37% of global emissions. Although extensive measures are being implemented to reduce "operational carbon" (the emissions being produced by building use) reducing "embodied carbon" (the emissions being produced by building construction and material) receives significantly less attention (UNEP, 2023).<br><br>To reduce "embodied carbon", minimizing emissions from building materials is crucial. Using bio-based materials reduces the greenhouse gas emissions during the building's lifecycle on average by 45%, compared to fossil-based materials (Zuiderveen et al, 2023).<br><br>One of the oldest building materials is raw earth; bio-based, widely available, and low-waste (during construction, as well as lifespan, and End-Of-Life) (Dethier, 2020). A construction technology of raw earth that is being re-developed for modern use is rammed earth construction. This technique can also be traced back to the beginning of building construction (Birznieks, 2013).<br><br>Combining available historical information on this widely used bio-based material/construction technique with modern material knowledge allows for further sustainability improvement of the material (Zawistowski et al, 2020). The aim is to eliminate the need for additives in rammed earth that prevent the material from being fully bio-based and reusable, replacing the currently used binders like cement and lime (Basanna et al, 2020) with bio-based alternatives. | |

| **Graduation project** | |
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| Title of the graduation project | Bio-based Binders for Rammed Earth Construction:<br>Exploring historical and modern-day binders as implementation for the future. |
| **Goal** | |
| Location: | Northwestern Europe |
| The posed problem, | Despite rammed earth being a sustainable and widely available construction material, with historical traditions throughout Northwestern Europe (Jaquin et al, 2008) a lack of national and international building norms specified to rammed earth construction prevents designers and engineers from choosing the material for construction (Canivell et al, 2020) (Zawistowski et al, 2020).<br><br>The regulations Rammed Earth construction is often tested against are originally developed for other materials such as concrete, causing Rammed Earth construction not to fulfil the strength requirements (Walker et al, 2010). To overcome this issue, a binder (cement) is often added to the material mixture, transforming the rammed earth into a stabilised material (Cockram, 2018).<br><br>However, with the use of cement the environmental benefits of rammed earth construction decrease drastically (Taghiloha, 2013). The embodied energy of Rammed Earth construction increases linearly to the amount of cement in the mixture (Reddy & Jagadish, 2003). Furthermore, this use of cement prevents the Rammed Earth construction from being re-used after End-Of-Life, as pure rammed earth mixtures could be.<br><br>Research is needed to replace cement with bio-based binders. This would allow rammed earth construction to fulfil strength requirements and protect the structures against weather conditions (Eyeson, 2022). Additionally, these bio-based binders could potentially be obtained from existing waste-streams from the food or agricultural industries, allowing for a sustainable and circular building material. |
| research questions and | **Main question:**<br>• What bio-based binders can be used to improve the performance of Rammed Earth for construction in Northwestern Europe?<br><br>**Sub questions:**<br>• What knowledge can be transfered from historical raw earth construction techniques into modern-day rammed earth construction? |

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| | • What historical binders were used for construction?<br>• What modern-day bio-based binders are available for construction? |
| design assignment in which these result. | The research results can be split up in three parts:<br><br>*Overview historical raw earth architecture*<br>To start considering modern-day use of raw earth architecture, it is imperative to look retrospectively at the material. An overview of the historical use and techniques allows for a construction manual that has been tried and tested over time. This can bring modern raw earth architecture further by not having to reinvent the material, but rather rediscover it.<br><br>*Overview bio-based binders*<br>An overview of bio-based binders, both modern-day and historical, allows for benefits and drawbacks of each binder to easily be compared to each other. This comparison provides a tool to find the right binder for the desired properties of a (new) material.<br><br>*Rammed earth prototyping and testing*<br>The prototyping of rammed earth samples can be considered the true 'design assignment' of the research. The prototyping combines the two knowledge overviews to produce samples that compare bio-based binders in rammed earth construction. These samples are tested against mixture consistency, strength, and weathering performances. Testing will allow to determine the most suitable bio-based binder(s). Afterwards this can also be compared to currently used, non-bio-based, binders. |

# Process

## Method description

The research can be divided into four stages:

*Stage 1: Literature research*
In stage 1 literature research is conducted into the above mentioned two topics; historical raw earth architecture materials and construction techniques (with a special focus on rammed earth) and bio-based binders used in construction (both historical and modern-day). This literature research is to be conducted using various forms of publications. When the historical construction data cannot be retrieved, as traditional building techniques rely on oral tradition, a broader search scope outside of the construction sector is applied. With the found information regarding rammed earth and bio-based binders, conclusions can be drawn as to the hypothetical ideal construction method and material mixture.

*Stage 2: Prototyping*
In stage 2 prototypes are made, using the most promising binders and construction techniques from stage 1. While creating the various mixtures a first round of testing can be conducted by observing the consistency and texture. The optimal mixture performance is described with various rules of thumbs and practical visual tests. This allows for a first round of conclusions to be drawn. After mixing, the prototypes are made uniformly in size according to the tests that will be done, to allow for accurate comparison with test samples from other researchers.

*Stage 3: Testing*
In stage 3 the samples are tested against both strength and weathering requirements. These tests are based on existing rule of thumb tests in the compressed earth construction sector as well as standardised strength testing of materials. In this way, both visual cues of performance and quantitative values of performance can be attributed to the prototypes. Using the rules of thumbs allows for prototype comparison against standard rammed earth construction. Using the traditional strength testing of materials allows for prototype comparison against alternative materials, like stabilised rammed earth or concrete.

*Stage 4: Repeat sampling & testing*
After testing the first round of samples, conclusions can be drawn. These conclusions can be translated into adjustments to the rammed earth mixture. Therefore, after consideration of the first prototypes, this process has to be repeated, implementing the knowledge found in the first round of testing. The repeated process will only be done with the best performing samples. Besides the previously conducted tests on samples, larger samples will be made to be placed in a weathering circumstances, either outside or through simulation.

## Literature and general practical references


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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 research into bio-based binders for rammed earth construction relates to the AUBS master track of Building Technology by researching an energy and emission low construction material to be used in the construction sector. This would help reduce the overall pollution related to the built environment. Within the track of Building Technology, the research relates to the chairs of 'Façade & Product Design' and 'Heritage & Technology' by combining the development of a structural bio-based material and construction technique (the product design aspect of the research) with the historical knowledge already available for this material (the heritage aspect of the research). By looking into the historically available sources on the material and construction technique, the development of an improved material is aided. Without considering the past of the material, lots of available knowledge and trial-and-errors would be lost to time.

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

Although this research aims to improve the sustainable character of rammed earth construction, compliant with the current national and international building regulations, the conclusions can be drawn further. By researching raw earth construction techniques, an overview can be provided of the benefits and drawbacks of using raw earth. Besides the technical knowledge this provides, it also allows for a demonstration of the relevance of raw earth architecture for modern construction. As technology advanced, the view on traditional building techniques changed. Traditional raw earth architecture came to be considered as 'lesser than' newly developed materials such as concrete (Dethier, 2020). The compilation of the benefits and future potential of raw earth as a construction material could help reduce the stigma the material currently faces. Research into bio-based binders and their historical uses provides a framework to compare said binders on their specific properties, from which other product designers can draw lessons. Examples of this would be other raw earth construction techniques, such as cob or compressed earth blocks, but also innovative technologies such as bio-based 3D printing. These materials all heavily rely on the consistency of the material mixture, which is in large provided by the binder that is chosen.