Harmonizing heritage and sustainability : Exploring the potential of bio-based Materials in heritage preservation

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Introduction

| Concepts & Relations

Within this research, there will be looked at the various bio-based materials that could be considered for use in contemporary building processes, with a focus on heritage.
To this purpose, the following keywords have been compiled that define the research.

| Bio-based materials | Heritage preservation | Circularity | Sustainability | Material properties |

| Problem Field

In today's urban environment, we run into a number of problems that pose a bottle neck problem for building development (of housing) in the Netherlands. Today's construction industry constructs buildings in a traditional way, being a linear process, using conventional building materials such as concrete and steel (Gagg, 2014). These building materials are newly produced for the sector from mostly non-renewable raw materials (Ethical Unicorn, 2020). In addition, most of these building materials are not reused or not sufficiently reused after their lifetime in the specific building. These are some of the reasons why the construction sector is responsible as one of the largest carbon and nitrogen emitters and users of water in the world (Ethical Unicorn, 2020). Re-use initiatives and circular construction methods are attempts that seek to stem the tide of this straight line by re-using building materials after they have done service in existing buildings. Thus, fewer building materials are destroyed, but the production of new, non-renewable building materials can also decrease this way. This helps to make the construction sector more sustainable, but at the front end of the process, the same non-renewable building materials are still being used which have a negative impact on the emission volumes and thus the climate.
In addition, the Netherlands has a large number of structures with heritage values.
These buildings are valued for their appearance and style of bygone days. Also, the problem in the Netherlands is that urban outdoor space is reaching a ceiling for the expansion of cities (Nederland is druk en vol (column), 2018). As a result, more and more solutions are being sought to densify within the urban limits and, as a result, existing buildings are being preserved and equipped with extra floors to contribute to the growing demand for housing. Furthermore, entire blocks and neighboorhouds are being redeveloped to densify the area, but keep the rich (green) collective outdoor space (We moeten de stad op een aantrekkelijke manier zien te verdichten, 2022). Developments such as these ensure that the green environment outside cities can be preserved more and that cities are more efficient in their use of space.
But even these construction processes are often still part of a linear building process that does not, or poorly, use renewable materials, or materials with high carbon and nitrogen emissions. This makes development socially and urbanely sustainable, but from an environmental point of view, there is still a big way to go.
What if the front end of the construction industry with non-, or poorly, renewable building materials changes? Using bio-based materials can go a long way in reducing emissions from the construction sector and contribute to a sector that deviates from traditional linear construction processes. These bio-based materials can help the construction sector transform itself into a circular sector, thus making a positive contribution to the climate goals set (Chayaamor-Heil et al., 2023b).

Incorporating bio-based materials into heritage preservation and architectural restoration emerges as a sustainable and forward-looking strategy. These materials, sourced from rene-

wable origins, seamlessly blend historical authenticity with ecological responsibility (Melià et al., 2014). By seamlessly integrating bio-based elements like natural wood, lime, or earth-based plasters into heritage structures, we not only pay homage to their original construction techniques but also champion their enduring protection. These materials often possess innate qualities that rejuvenate aging edifices, bolstering their resilience against environmental pressures while ensuring the timeless cultural significance perseveres for future generations (Ben-Alon et al., 2019). In this endeavour, bio-based materials align the cause of heritage preservation with contemporary sustainability objectives, elegantly harmonizing tradition and innovation in the realm of architectural conservation.

| State-of-the-art:

Already existing research concerning bio-based materials goes in three different main directions.
The bulk of research is in the direction of materials that change our daily lives by making waste biodegradable. This so that pollution can be reduced (Al-Tayyar et al., 2020). It is also used for countering oil pollution and the materials used for it (Doshi et al., 2018).
Further, research was conducted to evaluate various bio-based materials to see how well they perform in terms of thermal and sound insulation, etc. This was done in comparison to conventional building materials (Zhu, 2014).
Another source was found that goes into a LCA (life cycle assessment) between 3 buildings that are conventional, CLT and 'increased bio' (Peñaloza et al., 2016).
This shows that bio-based materials are being researched from multiple angles and that their applications are broader than just the building sector. Namely, these studies already show that the LCA of an 'increased bio' building is much better than that of a conventional building (Peñaloza et al., 2016). Bio-based materials have also been found to serve as a good substitute for the materials currently used to clean up oil pollution. In fact, these clean-up materials were found to be polluting themselves (Doshi et al., 2018).

What is still missing in research field is a linkage of these different topics to each other. Various materials are checked, but not brought together in a whole overview. In addition, it would also add value if there were insight into which bio-based materials could serve as substitutes for certain conventional building materials.
Finally, an extension of assessments of already existing bio-based buildings is of added value to gain more insight into the various building-technical and architectural possibilities with these bio-based materials.

| Aims & Objectives:

The aim of this research is to create a list of different bio-based materials and their material properties, which are selected by using a certain set of criteria that are elaborated up on later in this research. In addition, these bio-based materials are going to be linked to various conventional materials so that the research can also serve as an auxiliary tool in substitute materials selection. This is to show the potential bio-based replacement for the conventional building material.
Furthermore, case studies are used to show the selected bio-based materials in buildings. From this, one can learn what the different application possibilities are and secondly, this serves as inspiration for designers to implement these materials in future projects.

| Research Question:

In order to reach the aims & objectives stated above, the following main question and sub-questions have been drawn up to provide a complete picture:

Main question:
"How can bio-based materials enhance sustainability and circularity in architectural renovation while prioritizing the conservation & preservation of architectural heritage?"

Sub-questions:
- What criteria should there be stated in order to select bio-based materials suited for location specific architectural heritage renovation?
- What are the distinct categories and characteristics of bio-based materials available for architectural renovation and how can their performance be assessed and compared?
- What are the cultural and historical considerations when selecting bio-based materials for heritage preservation in architectural renovation?
- What are the implications for architectural heritage renovation when transitioning from traditional building materials to bio-based materials in terms of construction techniques and practices?
- How can already existing architecture (through the use of case-studies) show the possibilities of applying bio-based materials?

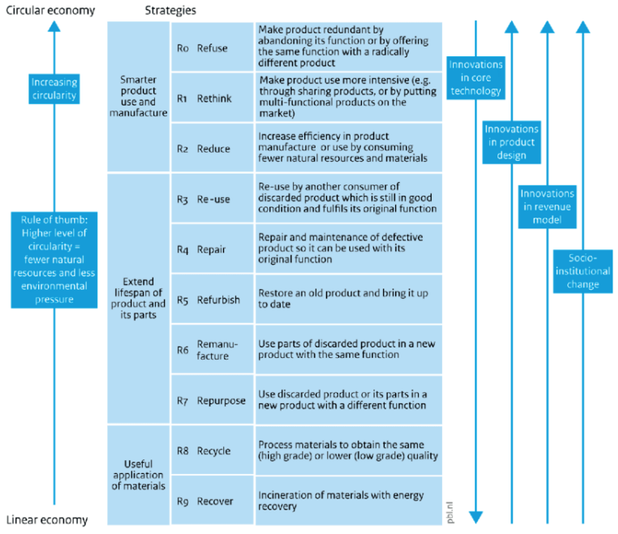
The first idea for the influence of this research on the design later on is to work with a building where all new building materials are bio-based and the design can draw inspiration from nature in order to cut down on emissions, waste materials and linear processes but still maintain the heritage value and image of that building and adding a new layer of heritage to this existing structure.
To see the approach for answering each of these research questions, see appendix 1: research table at the end of this document.
Furthermore, the envisioned design case on which the results of the research will be tested first can be found in the provided document: Design Location Determination.

The building is to form an example for future architecture on how we can work with bio-based materials.

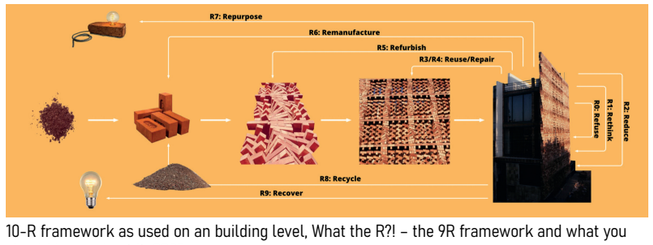
Methodology

| Theoretical Framework:

To connect the research to existing theories that are already published in the field, the 10-R method on circularity has been selected in order to place the material selection tool onto that specific ladder. With that, the tool becomes an auxiliary to the ladder in order to reach that potential.
The graph below shows the 10-R's of circularity (Potting et al., 2017). Below that is another image that shows what each of the R's could mean for a building (What the R?! – the 9R framework and what you should know about it, 2023).
This 10R system also works in preserving heritage values in a building. Potting et al (2017) states that R0, R1 and R2 are the most preferred stages to reach, because waste is minimalised and the existing building is optimally used. To add on that, What the R?! (2023) shows in their image that these cycles prove to be the shortest and best for preserving the building. This research also focusses on integrating heritage in order to make restauration and preservation more sustainable and circulair, so using the 10R system as a theoretical framework to further build the research on is a good starting point for both development of the envisioned results as well as additional information on the 10R value system.



Circularity strategies within the production chair, in order of priority, Potting et al., 2017

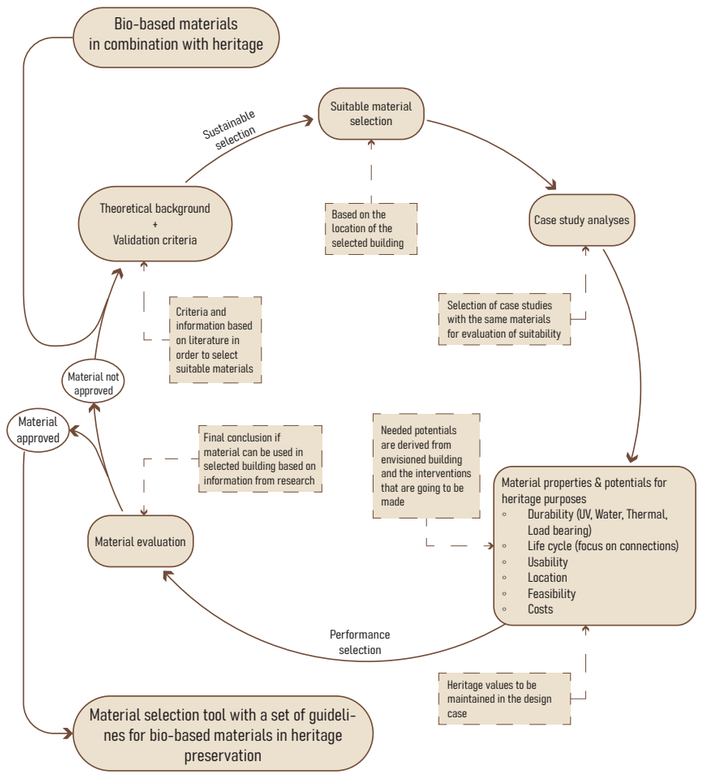


10-R framework as used on an building level, What the R?! – the 9R framework and what you should know about it, 2023

Furthermore, the criteria systems of the BREEAM and LEED are used in this research in order to help develop the criteria for evaluating materials. These are used as sources of information to base further statements on and therefore are not used as a framework, but rather as a substantiation to the formed criteria in this research.

| Methods:

For this research, the idea is to use sources that provide insights into the different kinds of bio-based materials available. That would give the first part of the research insight into the overall possibilities. Then, further investigation into the use of those materials can provide the needed information on the possible needed changes to the existing techniques used in construction. Therefore giving a total overview of usable materials, but also in depth assessment of the extent to which these materials are suitable for use in preserving heritage and making the construction sector more sustainable.
With that in mind, it is envisaged that 2 methods will be used to provide the necessary information for the study.
As the first method, a framework will be created by using literary sources and stated criteria. This framework provides insight into different bio-based materials, and whether they are of value for further application. This value assessment is done by using a number of predefined criteria (further information on the criteria can be found later in this research) that a bio-based material must meet. As a result, the most relevant bio-based materials are selected for this study. In addition, this also provides a boundary condition that keeps the research focused on the relevant information applicable for further implementation in the design.
This literature framework is completed with a selection of the materials and the link to conventional materials in order to find the best preforming material for the design.
The second method will consist of finding case studies that already apply these materials to gain more insight into the use of these materials in already existing projects. The case studies



Methodological framework, B. Turkstra, 2023

are additionally used to learn from reality and whether these materials can actually be applied. Another benefit is the insight into processing the materials. The case studies could provide information on the attachment of the materials and their final appearance.
In the diagram below, the steps of the research are shown. This process is viewed to be circular and will go on as long as required untill the 'tool' approves the material for use.
Overall, this makes the research both theoretical and practical. This is because the dual framework provides an auxiliary direction for applying bio-based materials in different situations.
In addition, it is practical because it also immediately shows how it can be used in practice by examining the various case studies.

| Sources:

Firstly, the data needed consists of information and properties about the materials to make an informed consideration about their usability. In addition, sources are needed to help determine the application and which conventional building material it can replace. Finally, case studies should be selected that show how the materials are already applied and what can be learned from them for further design assignments. This gives a total of 3 different types of data to be collected. The first two mentioned are sought by consulting literary sources and books. The latter will come from comparing different projects to find suitable ones for this research.

| Hypothesis:

A hypothesis was also drawn up for this study, to have clarity on what the expected outcome of this study could possibly be. This hypothesis serves as an aid for reflection later on this research.
The earlier shown methodological framework gives as result a tool for material selection and evaluation. The expectation is that this tool is able to combine information from literature and relevant case studies together in order to provide the answer of which materials are suited for application in the specific design case.
This would mean that the effectiveness of the tool will influence the outcome of the research.

| Case Study:

Six different case studies were chosen for this research. These are projects located in western Europe, or an area with the same climate, each using one or more bio-based materials in the building in its own way. The buildings differ in function and size so that different applications can be compared to provide a full conclusion. The chosen climate area for the case studies comes from the location of the chosen design case, being Amsterdam West (see the added Design location Determination booklet). These case studies will later be evaluated on subjects like end of life, logistics, CO2 footprint, performance, properties, etc. The results per case study will provide additional information that can be used in the evaluation tool in order to select the best materials needed for the design case in question.
As a final result of these case study analyses, a matrix will summarise the results per case and with that the overall score of each case study.

The buildings are listed from the next page onward, along with some factual data and a picture of the building in question.

Case study 01:

Name: Hemp House
Location: Ashville, North Carolina, United States of America
Architect: Anthony Brenner & David Mosrie
Date: 2010
Materials: Hempcrete and wood
About: The concept of the home revolves around creating a breathable home that helps with the emission of poor air quality, improving it for the home's inhabitants. And being able to regulate the air quality during it's lifetime.
Picture:

Hemp House (Sullivan, 2010)

Case study 02:

Name: Laherrère center
Location: Pau, France
Architect: CoBe Architecture & Paysage, WEEK
Date: 2023
Materials: Low carbon raw concrete and wood
About: The building is part of a global sustainable development approach combining bioclimatic design, bio-based materials, and energy performance.
Picture:

Laherrère center (Ott, 2023)

Case study 03:

Name: Rehabilitation & Extension of the Belfry cultural center
Location: Dives-sur-mer, France
Architect: ACAU Architects
Date: 2023
Materials: Wood, bricks, concrete (restauration)
About: A restoration of a listed building with a rich history and the realisation of a new part to match. Use of old styles and subordination to the monumental main building ensure that the building can last for generations again.
Picture:

Belfry cultural center (Silva, 2023)

Case study 04:

Name: Feldballe school
Location: Feldballe, Denmark
Architect: Henning Larsen
Date: 2023
Materials: Wood and straw
About: Designed for the climate crisis generation, the Danish school extension built of wood and straw is a scalable solution for carbon sequestering, giving the world a lesson in eco-innovation.
Picture:

Feldballe school (Pintos, 2023)

Case study 05:

Name: Earth House
Location: Boadilla de Rioseco, Spain
Architect: Lara Fuster Prieto
Date: 2022
Materials: Adobe bricks, wood, baked tiles
About: The traditional popular architecture of the region is based on adobe or raw earth bricks, as earth and straw are practically the only local raw materials. These are supplemented by baked mud (tiles, bricks, tiles, etc.) and wood.
Picture:

Earth House (Luco, 2023)

Case study 06:

Name: Wadden sea centre
Location: Ribe, Denmark
Architect: Dorte Mandrup A/S
Date: 2017
Materials: Straw, wood
About: The building is an interpretation of the local building tradition and the rural farmhouse typology in the area. The centre is erected with thatched roofs and facades and materials of the region.
Picture:

Wadden sea centre (The Wadden Sea Centre, Denmark | Dorte Mandrup, z.d.)

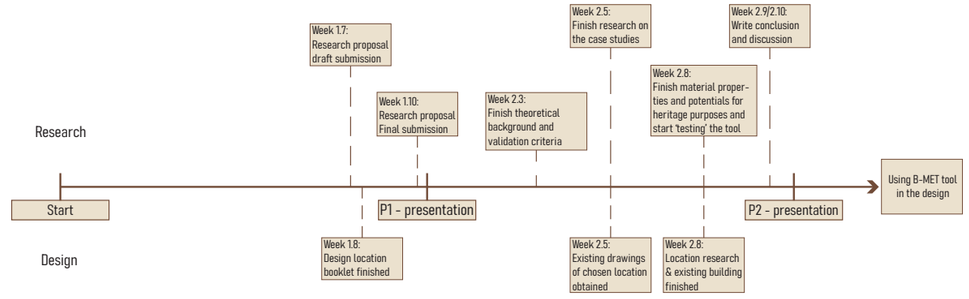
| Scope:

This research will be done in the 20-week time frame from September 2023 to January 2024. The research provides a tool that is not bound to any location or scale. It is to be implemented into a design location. Here it can provide materials specific to the building. The outcome of materials is unique for every locationthe tool is used for. For now, a number of case studies and a framework with up to 10 materials will be examined, allowing a qualitative look at these materials for a proper assessment of them.

Furthermore, no surveys are conducted that could be time-consuming for the study, which helps with containing the time required. On the other hand, as many sources as possible are consulted to make the information as objective as possible on the subject and ensure that the knowledge gained can be applied. This is sought to be done within the stipulated time period.

| Process & Timeline:

For the process and timeline of this study, the timeline below has been created to provide a guide through the study. This seeks to give clarity and structure to the research. The goal, is that it allows information to be gathered from every point of view without major quantity differences, so that the conclusion that follows from the research is as objective as possible.



Timeline, B. Turkstra, 2023

| Risks & Mitigation:

In terms of lockdown and limitations to working off-site on this research, it has few bottlenecks to consider. This is because much of the research comes from looking up sources. In addition, the relevant architectural firms can be contacted for further information on various case studies. If it is necessary to consult libraries, this should be done in a timely manner, also for the benefit of the research. The design of the research, in case it is necessary, also provides the space to integrate more materials as well as case studies that may strengthen or weaken the possible outcomes.

Selection criteria

What criteria should there be stated in order to select bio-based materials suited for location specific architectural heritage renovation?

Selecting bio-based materials for location-specific architectural heritage renovation necessitates the establishment of clear criteria for evaluation and selection. To this end, the analysis of key papers, “Sustainability and Green Building Rating Systems: LEED, BREEAM, GSAS, and Estidama Critical Analysis” by Awadh (2017) and “Critical Review of the Material Criteria of Building Sustainability Assessment Tools” by Park, Yoon, and Kim (2017), yields six essential criteria: Resources, Location and Transportation, Water Consumption, Embedded Energy, Living Environment, and Ecology and Pollution.

- **Resources:**

Sustainable sourcing of bio-based materials is of paramount importance, with a focus on preserving natural resources and minimizing ecological disruption. Evaluation of resource sustainability, as guided by methodologies such as BREEAM, encompasses factors like resource renewal rates, responsible extraction practices, and impacts on biodiversity. Notably, the sustainable management of forests ensures that timber and wood-based materials originate from well-managed sources.

- **Location and Transportation:**

Minimizing the environmental footprint associated with the transportation of materials from their source to the renovation site is a critical consideration. Assessing transportation-related environmental impacts through methods like BREEAM is fundamental. Opting for locally sourced materials or employing low-emission transportation practices reduces carbon emissions, aligning with heritage preservation and environmental sustainability.

- **Water Consumption:**

Given the prevalence of water scarcity issues in certain areas, it is imperative to evaluate the water footprint of bio-based materials. Assessment tools, including BREEAM, facilitate an analysis of water consumption throughout the materials’ lifecycle, encompassing production processes. The selection of materials with reduced water footprints contributes significantly to water conservation and sustains renovation efforts.

- **Embedded Energy:**

A crucial aspect in the assessment of bio-based materials is the energy embedded in their production. In line with BREEAM and LEED standards, comprehensive evaluation of materials should consider life cycle energy usage. Opting for materials with lower energy requirements during production is instrumental in minimizing carbon emissions and upholding environmental responsibility.

- **Living Environment:**

Architectural heritage renovation projects aim to establish comfortable and health-conscious living environments. The choice of bio-based materials should take into account their influence on indoor air quality, thermal performance, and overall occupant well-being. Rating systems, such as BREEAM, assess indoor environmental quality and thermal comfort. Materials that positively impact these aspects, such as natural insulation materials and air-quality enhancing finishes, should be prioritized.

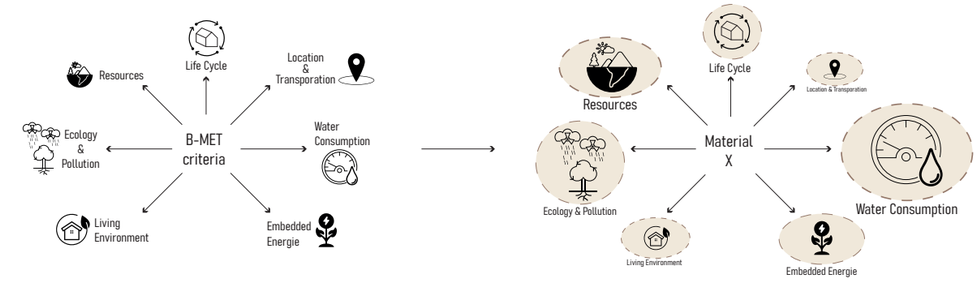
- **Ecology and Pollution:**

Bio-based materials should not pose threats to local ecosystems or contribute to pollution throughout their lifecycle. Robust environmental assessment, as provided by BREEAM, scrutinizes materials for their ecological impact and pollution potential. The selection of bio-based materials should prioritize options that minimize ecological disruption and prevent harmful pollutants from entering the environment.

- **Life Cycle:**

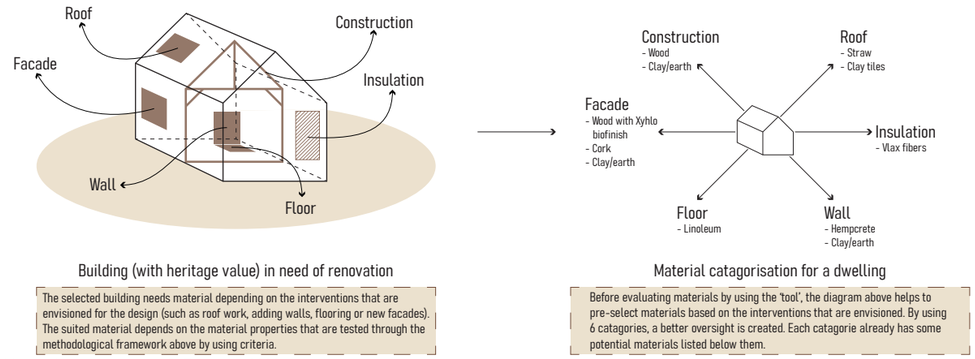
Understanding the life cycle of a bio-based material is vital. This criterion delves into how the material ages over time, its durability, and maintenance needs. Some bio-based materials may require frequent replacement or significant maintenance, while others may age gracefully with minimal intervention. Assessing the life cycle of materials ensures that they not only serve the immediate renovation needs but also stand the test of time, reducing the long-term environmental impact and costs associated with maintenance and replacement. This is of use when looking at the estimated life span of a building and the need for a long- or shortterm solution.

In the image below, these six criteria are shown in a diagram. Forming the first look at the envisioned 'tool' B-MET (Bio-based Material Evaluation Tool). Also visible in the image is that each specific resource can have a mixed amount of influence on whether the material is suited for application.



Material evaluation with B-MET, B. Turkstra, 2023

Prior to evaluating a material by using the tool, a selection in the materials is needed in order to start with materials that are suitable for the envisioned intervention. Because the needed interventions can differ from each design case, it is helpfull to already organise materials beforehand to know what material can be applied. This pre-selection helps to narrow down the amount of testing needed with the tool in order to find a suitable material for the intervention. These pre-selections have been visualized in the image above. It shows a dwelling and the six main topic on which an intervention can be based. These topics are: Roof, Facade, Construction, Insulation, Wall and Floor.
The next image shows these topics again with a list of a few bio-based materials that could be thought of when searching for suitable materials.
In conclusion, the selection of bio-based materials for location-specific architectural heritage renovation requires a structured approach based on six key criteria: Resources, Location and Transportation, Water Consumption, Embedded Energy, Living Environment, and Ecology and Pollution. These criteria, as highlighted in the analysis of research papers by Awadh (2017) and



Material catagorisation, B. Turkstra, 2023

Park, Yoon, and Kim (2017), form the foundation for making informed decisions in sustainable heritage restoration.

These criteria, when employed in a structured manner, ensure that the materials chosen for architectural heritage renovation not only preserve the historical significance of the structures but also adhere to sustainable practices and principles. They help strike a balance between heritage conservation and environmental responsibility.

Additionally, the concept of the "B-MET" (Bio-based Material Evaluation Tool) demonstrates the practical application of these criteria. This tool provides a systematic approach to assess the suitability of bio-based materials for specific renovation projects. The pre-selection of materials based on the type of intervention required further streamlines the decision-making process, minimizing the need for extensive testing and research.

In the quest for sustainable architectural heritage preservation, these criteria and tools serve as valuable guides, paving the way for informed decisions and responsible choices.

Resources & Appendix

| Resources:

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| Appendix

Research question	Requirements	Ways of collecting	Ways of analysing	Expected results
What criteria should there be stated in order to select bio-based materials suited for location specific architecetural heritage renovation?	◦ Quantitative data on different ways and subjects to use criteria to evaluate materials	◦ Official documents provided by governments ◦ Reports on projects done according criteria	◦ Literature review of found information on relevance	◦ A list of criteria that help to evaluate materials on their sustainability
What are the distinct categories and characteristics of bio-based materials available for architectural renovation and how can their performance be assessed and compared?	◦ Material properties and potentials ◦ Ways of comparing materials ◦ List of potential bio-based materials	◦ Use of Granta software for material properties ◦ Producers of certain materials	◦ Use software/producers to find material properties to be able to compare and assess each materials value	◦ List of properties that materials can score on to show their potential ◦ Easily applied on multiple materials with the same properties
What are the cultural and historical considerations when selecting bio-based materials for heritage preservation in architectural renovation?	◦ Value assessments of heritage considerations	◦ Munincipality guidelines on heritage	◦ Literature study and comparisons on relevance of found values	◦ Set of restrictions/limitations that munincipality's give in order to maintain heritage value of the building
What are the implications for architectural heritage renovation when transitioning from traditional building materials to bio-based materials in terms of construction techniques and practices?	◦ Application of conventional building techniques ◦ Application of bio-based material building techniques	◦ Manufacturers of products/materials ◦ Standard details of applying	◦ Using details to learn how to incorporate ◦ Contact manufacturers	◦ Have potentially different ways of application visible ◦ Know how to integrate each material in a existing building
How can already existing architecture (through the use of case-studies) show the possibilities of applying bio-based materials?	◦ Relevant case studies for the envisioned design case	◦ Books and website that shows multiple projects	◦ Filter on desired material and comparing projects	◦ Information from reality on how materials are used and if they have proven their worth

Appendix 1:

Research table, Turkstra (2023)
In this, one can see the approach, requirements and results envisioned for each of the formulated research questions in this research.